European Partnership "Agriculture of Data"

- Unlocking the potential of data for sustainable agriculture -

Strategic Research and Innovation Agenda

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Acknowledgment

A lot of time, energy and thought have been put into the development and compilation of the SRIA for the Horizon Europe candidate partnership Agriculture of Data. The partnership is anchored around the core group, which consist of representatives from Member States and associated countries, additional experts and is supported by two ERA-Nets.

The core group, and particularly the smaller SRIA working group, have developed a strong collaboration with representatives from the European Commission. External experts have also kindly helped to progress the SRIA of the partnership and the SRIA strongly benefitted from the input and feedback gathered through the public consultation. The development of the SRIA of Agriculture of Data would not have been possible without their collective contribution.

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Executive Summary

The primary goal of this Strategic Research and Innovation Agenda (SRIA) for the Horizon Europe candidate partnership Agriculture of Data is to address the scientific research, development and innovation needs within the overall scope of the partnership adequately and comprehensively.

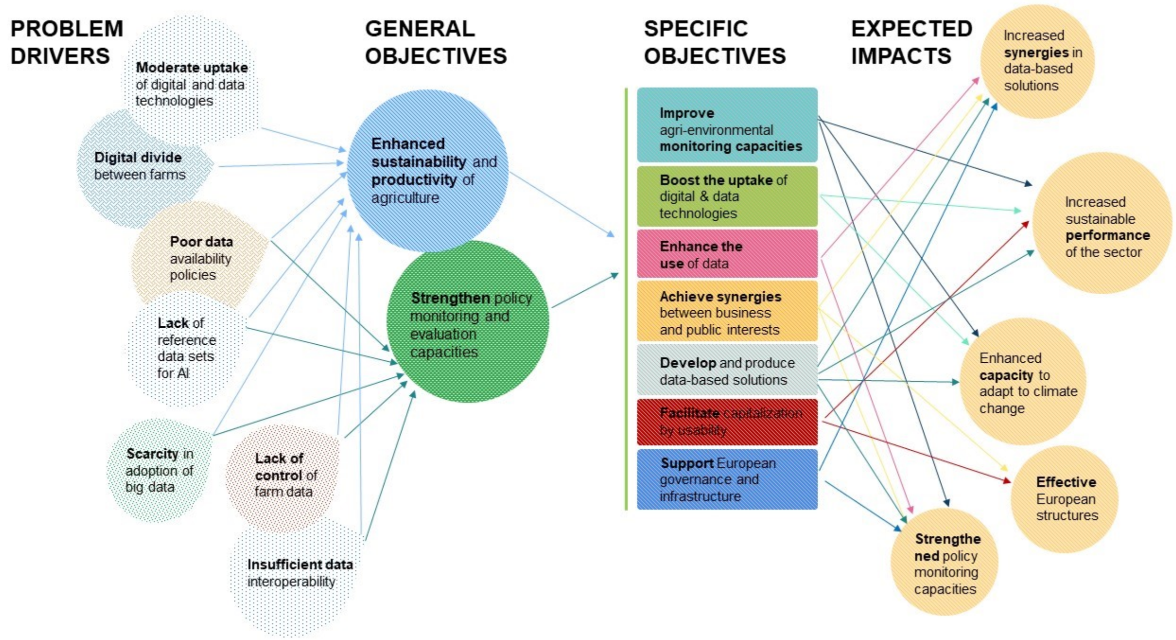
The SRIA follows up on the partnership document published in March 2022, building on its participatory approach and co-creation process, which included a number of outreach activities and public consultation. The partnership document discusses the overall scope and approach of the partnership, its intervention logic and the envisaged governance structures.

This partnership aims to enhance sustainable agricultural production and to strengthen policy monitoring and evaluation capacities through exploiting the potential of Earth Observation (EO), environmental, agricultural and other data, in combination with state of the art data technologies.

Data-based solutions are key assets to boost the resiliency of the sector and to strengthen its competitiveness in the short- medium- and long-term on local and global scales. They are also key enablers for implementing and assessing the performance of European and national policies smartly and efficiently. The further development of sustainable and competitive agricultural will require the sector simultaneously reduce its environmental footprint, respond to the decline in biodiversity, while ensuring food security and adapting to climate change. The partnership Agriculture of Data will enable the sector to meet those challenges and cope with trade-offs, in particular through providing a foundation for decision-making support, for e.g. producers and policy-makers.

The intervention logic of the partnership (Figure 1) demonstrates the links between “Problem Drivers”, “General Objectives”, Specific Objectives” and “Expected Impacts”. It identifies the critical barriers for unlocking the potential of data technologies to enhance the performance of the agriculture sector and to aid in policy monitoring and evaluation, defines specific objectives to achieve the partnerships general objectives and addresses its expected impacts.

Figure 1: Intervention logic of the Partnership



The partnership will contribute to a number of the European Commission's priorities, in particular to the European Green Deal, A Europe for the Digital Age, An economy that works for people, and A new push for European democracy. It will support the accomplishment of the objectives of the Common Agricultural Policy post 2022 and the EU's Space policies as well as to the Sustainable Development Goals, with particular focus on agricultural production, environment and climate.

The partnership will build the capacities to effectively and efficiently deploy data technologies, such as Artificial Intelligence (AI); develop innovative data-based solutions that could serve as, for instance, inputs to Decision Support Systems (DSS) and farm management systems; and generate indicator data to assess policy performance. It will exploit the opportunities novel satellite and sensor data offer. It will generate reference and training data sets from various sources for AI applications. The focus lies on Europe-wide data sets and services. Encouragement of Business-to-business (B2B), Business-to-Government (B2G), and Government-to-Business (G2B) data sharing and the reduction of administrative burdens as well as legal framing conditions will play a key role in the work of the partnership.

The partnership aims to create an "umbrella effect" through taking stock, linking and, assessing Research and Innovation (R&I) initiatives and use cases in the field of agricultural data while accounting for data interoperability. This important added value will also contribute to the defragmentation of the data landscape. The partnership will forge ahead with the ambitions of upscaling and delivering end-user tailored innovative data-based solutions. It will benefit from strategic framing actions to be carried out by partnering Member States and Associated Countries, which will form an essential corner stone of the work. They may include the generation, provision and formatting of reference data sets as well.

The scope of "data" in the Agriculture of Data Partnership (AgData) refers to all kinds of data that are relevant to achieve the objectives of the partnership. This includes geospatial observations like the environmental and Earth Observation data; public and private agricultural data including farm data and farm management data from the Integrated Administrative and Control System (IACS) and paying agencies; and socio-economic as well as modelled data.

The stakeholders targeted by this partnership are people and organizations who are interested or involved in promoting sustainable agriculture in Europe and enhancing policy monitoring and evaluation capabilities by utilizing the potential of data technologies especially through the capitalisation of data and the provision of data-based solutions. The targeted "end users" comprise of among others, farmers, cooperatives, farm advisors and governmental organisations, innovators like research institutes and start-ups, and intermediaries and businesses, such as data providers and the machinery sector, and citizens at large. The SRIA propounds an approach that is simultaneously multi-actor and end-user-centric. In the scientific domain, it embraces a range of disciplines, including data, social and legal sciences as well as agronomy and environmental sciences.

There will be internal and external (R&I) activities and there will be opportunities for the wider innovation ecosystem to participate in the work of the partnership, in particular through external calls.

R&I activities are supplemented by Horizontal Activities, which are relevant for ensuring their effectiveness and are aligned with the intervention logic of the partnership. These include R&I, as well as capacity building, and outreach activities. These concern:

- achieving synergies between interests and efforts of the public and private domain,
- developing enabling solutions – including organizational and legal solutions – for data governance, standards and security, and

- ensuring (end-)user uptake and innovation management.

Achieving complementarity with other EU activities and their synergetic capitalisation is an inherent ambition of the AgData partnership. Therefore, the partnership will not dedicate special attention to the development of standards, but rather aim for synergies with corresponding EU level initiatives. Alongside relevant R&I activities under Horizon Europe, activities in the field of agriculture and environment supported by the Digital Europe Programme, and innovation- and knowledge related activities carried out under the Common Agricultural Policy (CAP), the EU Space Programme and those undertaken by bodies operating at EU/European level will be considered. The partnership will also work towards achieving coherence and synergies with national policies, programmes and activities.

The SRIA is structured into four main parts. It starts with a snapshot of the overall scope of the partnership (Chapter 1) followed by a run-through of the ambitions of the partnership, its development and mode of operation, including Key Performance Indicators (KPIs) for assessing the performance of the Agriculture of Data Partnership and monitoring progress in the course of its implementation (Chapter 2). The SRIA goes on to present the Core Research & Innovation Activities (Chapter 3) which are organized along three main themes, reflecting the main objectives of the partnership:

- data technologies and data management,
- data-based solutions for sustainable agriculture, and
- data-based solutions for policy-making and policy monitoring.

The SRIA concludes with a description of the horizontal and cross-cutting activities, which frame the roll-out of all R&I activities. It also establishes the foundation, for data governance, for instance, and introduces key principles of the partnership, such as achieving synergies between private and public interests and efforts (Chapter 4).

While the SRIA sets out the strategic approach towards the R&I activities carried out by the partnership, operational details, such as work packages, budgetary consideration, and timeline are elaborated within the partnership proposal.

The SRIA is expected to be adopted with the launch of the partnership. The SRIA can be regarded as a "living document", which will be revisited and adjusted over the lifetime of the partnership in accordance with changing socio-economic, environmental, political and legal framing conditions. The SRIA will guide the development of work plans of the partnership.

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List of acronyms

AI	Artificial Intelligence
AKIS	Agricultural Knowledge and Innovation Systems
AMS	Area Monitoring System
API	Application Programming Interface
B2B	Business-to- Business
B2G	Business-to-Government
CAP	Common Agricultural Policy
CEF	Connecting Europe Facility
CHIME	Copernicus Hyperspectral Imaging Mission for the Environment
CSA	Coordination and Support Action
DEP	Digital Europe Programme
DESI	Digital Economy and Society Index
DG AGRI	European Commission - Directorate-General for Agriculture and Rural Development
DG RTD	European Commission - Directorate-General for Research and Innovation
DGA	Data Governance Act
DIHs	Digital Innovation Hubs
DSS	Decision Support Systems
EEA	European Environment Agency
EIP-AGRI	European Innovation Partnership for Agricultural productivity and Sustainability
EO	Earth Observation
ERDF	European Regional Development Fund
ESA	European Space Agency
EU	European Union
EuroGEO	European Group of the intergovernmental global Group on Earth Observations
EUMETSAT	European operational satellite agency for monitoring weather, climate and the environment from space
EUSPA	European Union Agency for the Space Programme
FADN	Farm Accountancy Data Network
FAIR	Findable, Accessible, Interoperable, Reusable
FaST	Farm Sustainability Tool for Nutrient Management
FMIS	Farm Management Information System
FSDN	Farm Sustainability Data Network
G2B	Government-to-Business
GAN	Generative Adversarial Network
GDPR	General Data Protection Regulation
GEO	Group on Earth Observations
GHG	Greenhouse Gases
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GraphQL	Open-source graph query language
GREXE	Member State Expert Group for Evaluation
HLEG	High-Level Expert Group
HLWG	High Level Working Group
IACS	Integrated Administration and Control System
ICT	Information and Communication Technology
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
KPIs	Key Performance Indicators
LPIS	Land Parcel Identification Systems

LSTM	Land Surface Temperature Monitoring
MARS	Monitoring Agricultural ResourceS
MCDA	Multi-Criteria Decision Analysis
ML	Machine Learning
MPC	Multi-Party Computation
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
OSPC	On-the-Spot-Controls
R&I	Research & Innovation
RI	Research Infrastructures
ROI	Region of Interest
ROSE-L	Copernicus L-band Synthetic Aperture Radar
RRF	Recovery and Resilience Facility
RTK	Real Time Kinematic
SAR	Synthetic-Aperture Radar
SCAR	Standing Committee of Agricultural Research
SDG	Sustainable and Development Goal
SME	Small & Medium Enterprises
SRIA	Strategic Research and Innovation Agenda
TEF	Testing and Experimentation Facilities
TRL	Technology readiness levels
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
VHR	Very High Resolution

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1 Introduction

1.1 Background and Motivation

In line with the European Green Deal and the EU's Farm to Fork Strategies, **agricultural production** in Europe needs to become **more sustainable**. This requires the environmental and climate performance of agriculture to increase; profitability, efficiency and competitiveness of the farming sector to be maintained; and operational risks (e.g., due to climate change) to be managed effectively. At the same time, EU policies, including the Common Agricultural Policy (CAP), are becoming more performance-oriented, requiring **efficient and effective policy monitoring.** This includes subsequent evaluation of the impact achieved and generating new knowledge for policy formation.

Data and digital technologies offer the potential to achieve both these ambitious goals (sustainable agricultural production and more evidence-based and tailored policy) and to make the "twin" green and digital transition a reality. An increasing amount of high-quality data is required to achieve this as reflected in the European Strategy for Data[1]. Applying data technologies to Earth observation (EO), environmental, agricultural and other **data**[2] offers a wide range of opportunities for new and innovative data-based solutions and subsequent actions, such as input to farm management systems, which can increase the sector's performance and strengthen policy-making, implementation and monitoring capacities. Capitalising on this potential requires that the solutions account for the needs and conditions on the ground and are accepted and deemed useful by farmers, advisors, the politico-administrative system and other key stakeholders.

The **Horizon Europe Partnership "Agriculture of Data" (AgData)** aims to support the transition to a sustainable agriculture in Europe as well as to strengthen policy monitoring and evaluation capacities by harnessing the potential that data technologies, in combination with EO, environmental, agricultural and other data, offer. The partnership will contribute to, among others, the objectives of the European Green Deal and the Headline ambition of "A Europe fit for the Digital Age", the Farm-to Fork Strategy[3], the Europe Strategy for Data and the Coordinated Plan for Artificial Intelligence (AI)[4] in particular, as well as to the objectives of the CAP, the United Nations' Sustainable Development Goals (SDGs)[5] and to the ambitions for better policy-making (see Section 2).

Data and data technologies are not only a key determinant for the effectiveness of precision and/or high-tech farming, but are an enabler for all types of agricultural production, including conventional, organic and agro-ecological approaches. They can serve small and large farms, and the partnership will dedicate attention to the needs of technologically less advanced farms. Satellite data provides important geospatial information for agricultural production. Copernicus, the EO and monitoring part of the EU Space programme, is one important reference in the context of data for the AgData partnership. EO data forms a key input to many Farm Management Information Systems (FMIS) and

[1] Strategy for Data | Shaping Europe's digital future (europa.eu)
[2] The scope of "data" in this partnership refers to all kinds of data that are relevant to achieve the objectives of the Partnership Agriculture of Data. This includes geospatial observations (e.g. environmental and Earth observation) and agricultural data (public and private data including farm data, IACS data held by paying agencies, socio-economic data and modelled data).
[3] Farm to Fork Strategy (europa.eu)
[4] Plan on AI | Shaping Europe's digital future (europa.eu)
[5] Sustainable Development Goals | United Nations Development Programme (undp.org)

thus forms an important basis for the farmers' production decisions. Through the delivery of important land-monitoring parameters, Copernicus facilitates the implementation of the Common Agricultural Policy (CAP). To capitalise data through data technologies, **reference data sets** are key assets. For instance, for capitalising Earth observation (EO)[6] data through AI e.g. i*n-situ* data or data from the Integrated Administration and Control Systems (IACS) are valuable trainings data sets to enable automated interpretation of EO data. . The vast amount of **agricultural sensor data** generated on farms, as well as **other agricultural data sets** are of great value for the improved interpretation and upscaling of Earth and environmental observation data. For example, the implementation of precision farming data as reference or baseline data, has high potential to capitalise satellite data through the application of data technologies. Therefore, the cooperation with farming and machinery sectors within this partnership is essential to further capitalise EO and farm data and to ensure the development and uptake of the data-based solutions developed by the partnership.

Finally, the creation of **Europe-wide data-based solutions** will add another important asset to both **policy monitoring and evaluation** and might be the 'game-changer' in **increasing the sector's performance** in the successful implementation of **climate change adaptation** and mitigation strategies; these data-based solutions will also form a key input to the wider innovation ecosystem for further capitalisation.

1.2 Challenges

Unlocking the potential of data technologies to increase the performance of the agriculture sector and to support policy monitoring and evaluation is extremely challenging. The most important bottlenecks have been identified:

- Moderate end-user uptake of digital and data technologies due to unclear cost and benefits, poor resolution of (imagery)data and lack of technical skills for data interpretation;
- Digital divide between farms due to different business models and different investment capacities in digital technology and data;
- Poor data availability for efficient policy monitoring & evaluation;
- Lack of (homogenous) reference data sets to capitalise Earth and environmental observation data through the use of data technologies (at European level);
- Scarcity of "big data" solutions for agricultural applications;
- Difficulties for farmers to take control of their data;
- Insufficient data interoperability and missing state-of-the-art cybersecurity protection mechanisms and privacy enforcement technologies.

1.3 Vision

This partnership envisages a European agricultural sector that is environmentally, socially, and economically sustainable and competitive, with improved capacity for policy monitoring and evaluation. Fundamental to realising this vision will be the combined use of EO, environmental and

[6] EO is the gathering of information about planet Earth's physical, chemical, and biological systems via remote sensing technologies, usually involving satellites carrying imaging devices.

other relevant data, such as agricultural production and sensor data through data and digital technologies. This will be achieved by co-designing common approaches and systems as well as sustainable structures to capitalise the combination of various data for both the private and public domain. The partnership will target, farmers/agricultural producers and their advisors as well as policy-makers and public administrations.

1.4 Objectives/Scope

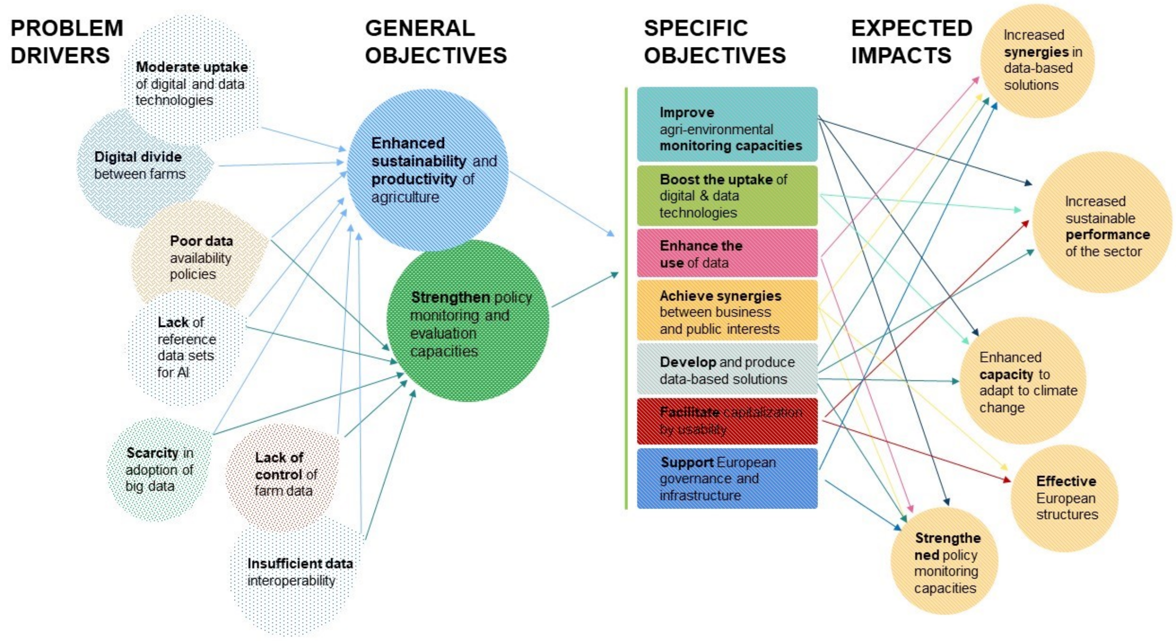
This partnership aims to enhance sustainable agricultural production (at environmental, social, and economic levels in combination with climate resilience) and competitiveness of agriculture by strengthening policy monitoring and evaluation capacities, and exploiting the potential of EO, environmental, agricultural and other data, in combination with data technologies.

To achieve this general objective the following specific objectives are defined (see also the intervention logic figure, figure 1, below):

1. **Improve agri-environmental monitoring solutions and strengthen capacities** to assess the status of agri-environmental and climate conditions, chiefly by enhancing the integration of data sets provided by various public and private sources, platforms/networks and capitalising them through the application of data technologies.
2. **Boost the uptake of digital & data technologies in agriculture**, by providing co-designed, tailored, easily accessible end-user-oriented data-based solutions building on EO, environmental and other data. The Partnership will actively support the implementation and dissemination of solutions at a European level.
3. **Enhance the use of EO, environmental and other data** for developing data-based solutions, methodologies, and indicators to improve climate adaptation and resilience of agriculture as well as to minimise the undesired impact of agriculture on the climate, environmental quality, ecosystem services, and biodiversity, whilst ensuring food security, safety, quality, as well as sustainable productivity.
4. **Achieve synergies** in the development and utilisation of data-based solutions for **both the agriculture sector and policy-making**, in particular monitoring and evaluation.
5. **Facilitate the usability of EO, environmental and other data to create and deploy services** including the data-based solutions developed by the partnership, so that it can be **easily re-used and capitalised by public and private organisations** including research bodies, government agencies, businesses, particularly start-ups and Small & Medium Enterprise (SME), and any other organisations, to achieve a wide and rapid outreach.
6. Develop and produce **Europe wide** data-based solutions including the upscaling of targeted use case results.
7. **Support the development of a harmonised European governance structure** and its related infrastructures that will enable the outcomes of the partnership in terms of data, solutions, tools, and services to be shared, taking into account existing and evolving infrastructures.

The intervention logic and the links between “Problem drivers”, “General Objectives”, Specific Objectives” and “Expected Impacts” has been developed Though “Problem drivers” and “General Objectives” were used as starting points, the key focus however, has been on the “Specific Objectives” and "Expected Impacts", since these two aspects will be the overall drivers for the Partnership. The links are discussed in greater detail in the Partnership document.

Figure 2: Intervention logic of the Partnership



1.5 Expected Impacts

The partnership seeks to achieve the following **expected impacts** under three complementary impact categories: 1. Scientific, 2. Societal (incl. environmental) and 3. Economic & technological[7].

Scientific

a) Increased synergies and better integration between different actors (e.g. scientists, technicians, policy-makers, businesses, farmers, practitioners and technicians) achieved in the digital, environmental, EO and agricultural communities within Europe, transforming both the R&I and economic ecosystem to deliver a greater quantity and variety of validated data-based solutions to the end-users.

Societal (incl. environmental)

b) Increased environmental, social and economic sustainability performance of the agriculture sector.[8]

c) Enabling the sector to adapt to climate change considering environmental, technical, economic and social risks.

[7] The three impact categories align with those set out in Annex V of the Horizon Europe Regulation.

[8] The Partnership's interpretation of sustainability for the expected impact is in the broadest sense of the term. Profitability for the farmer, and thereby food security for Europe, but also sustainable for the climate, environment, bio-diversity including protecting the environment, halting and, if possible, reversing biodiversity loss in Europe and globally, as well as to the reduction of the emission of greenhouse gasses from agriculture.

Economic & Technological

d) Enabling European structures (incl. governance and infrastructure, standards) that ensure the sustainability of the Partnership output, and that underpin data-based solutions for both policy-making and the enhanced performance of the agriculture sector.

e) Strengthened capacities for policy-making, especially in the fields of monitoring and evaluation, which consider agricultural, environmental- and market- aspects.

1.6 Approach

The partnership document details the overall approach to implementing the Agriculture of Data partnership. This includes a thorough description of the objectives and the intervention logic (see above) as well as the interplay between research and innovation actions and the governance structures designed to achieve the Partnerships' objectives.

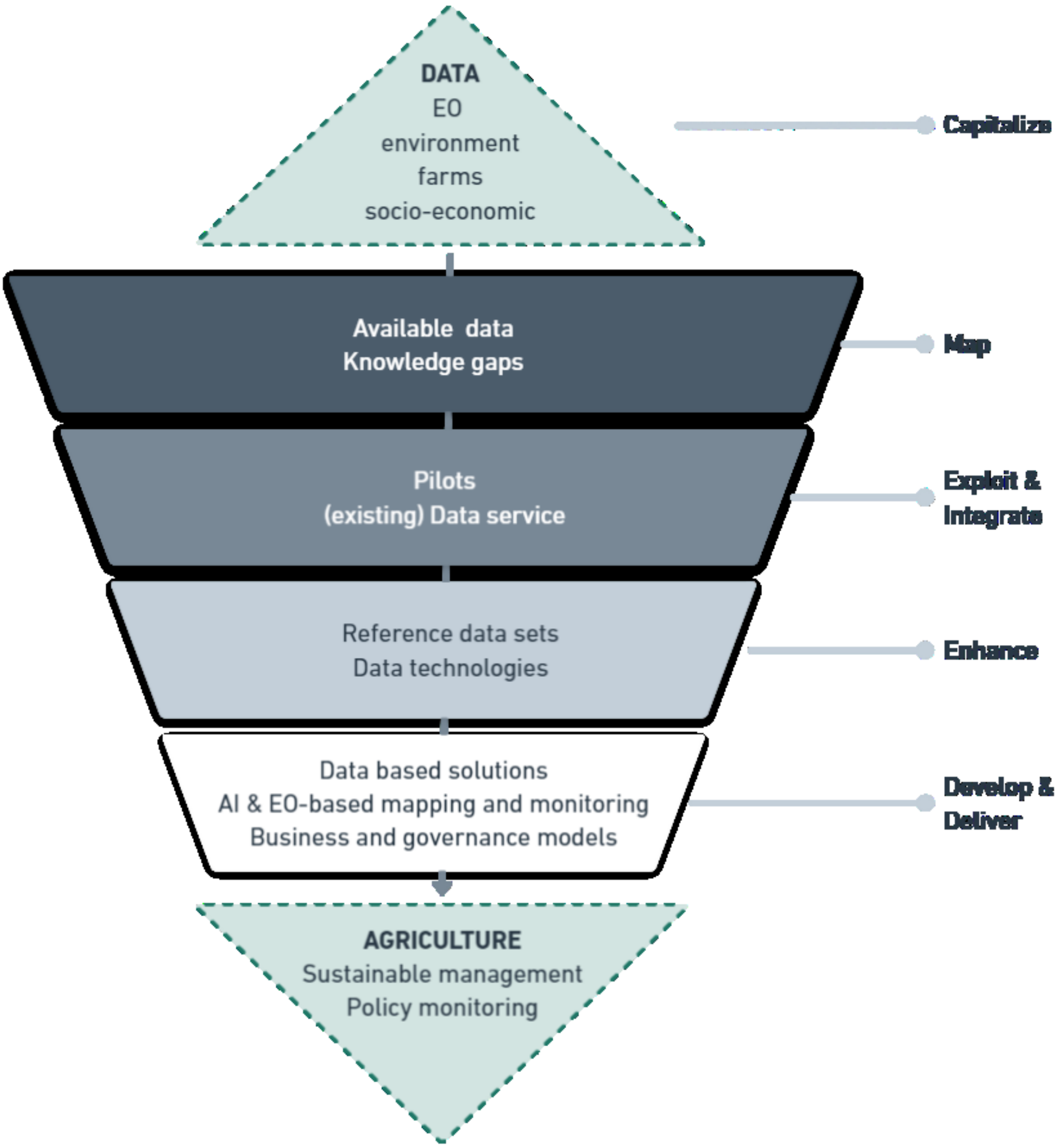
The main types of core actions identified in the **Strategic Research and Innovation Agenda (SRIA)** can be summarised as follows (see also in Figure 2):

- **Mapping of available data sets** at different geographical and temporal levels
- **Mapping of data and knowledge gaps,** in e.g. impact assessment, reducing administrative burdens, climate adaptation data for production
- **Identifying priority actions in generating data sets and data-based solutions** aimed at achieving synergies between different interest groups
- **Enhancing the availability of reference data sets for the application of AI at European level** through achieving interoperable data sets across countries
- **Development of innovative data-based solutions** for farmers and for policy monitoring and evaluation, following a co-creation approach[9]
- **Development and use of novel techniques** in applying AI and EO-based mapping and monitoring
- **Capitalisation of (sensor) data generated on farms** for the benefit of the wider farmer community and other actors[10]
- **Development of innovative business and governance models** for the sustainable management of data flows, taking into consideration the changing legal environment

[9] The development of innovative data-based solutions will be done following a multi-actor approach building on an extensive and systematic stocktaking of existing data-based solutions, so that where possible and meaningful, it can be built upon existing achievements.

[10] Sensor data generated on technologically advanced farms can serve as reference and training data for the (AI-based) interpretation of satellite data, allowing generation of more information from satellite data, from which also technologically less advanced farmers can benefit. While a main motivation driving the capitalising of farm (sensor) data is the provision of data-based solution to farmers and preventing digital divides between farms, the data may also well serve other R&D&I and public good purposes, provided that the value of data is fairly acknowledged.

Figure 3: Approach towards the capitalisation of data in the Partnership Agriculture of Data



The partnership will follow an open, participatory, interdisciplinary approach, involving not only data- and computing sciences, but also biosciences (incl. ecology, and agronomy), economics, social sciences, policy and management science as well as legal experts. The partnership will follow a multi-actor- and user-centric approach. Therefore, representatives of the targeted end-user groups and intermediaries, including farmers, advisors, and the administration as well as machinery providers, will not only be considered in the overall governance structures of the partnerships, in national mirror groups and outreach activities, but also in the implementation of the R&I activities themselves. As outlined in the partnership document, it is envisaged to also involve representatives of umbrella organisations active in the fields of data and data technologies and start-up development at European level, such as the European Start-up Network.

While the partnership will include research and innovation in several fields, it will particularly foster end-user readiness and thus higher Technology Readiness Levels (TRLs) through a systemic approach. For some technologies, it will achieve innovation by leveraging novel technologies in sector-specific contexts, e.g., building on results of projects funded by Horizon Europe Cluster 4. Moreover, the partnership will generate data-sets and data-based solutions, which can be further capitalised by "innovators", e.g. start-ups. It will thus not only close market gaps, but also indirectly further strengthen and diversify the market of data-based solutions in the agriculture and innovation ecosystem.

Primary R&I actions are supported by actions aimed at sustaining the partnership on the medium- and long-term which are:

- **Upscaling of promising pilots (including building on earlier results)** within the partnership, including for instance, geographically (from use case level to European level) or from innovation to deployment
- **Providing data and data services** (for e.g. farmers, administration, start-ups, R&I institutes)
- **Building capacities to ensure (end) user uptake and further capitalisation of results**
    - by making data sets and data-based solutions easily available;
    - by strengthening data literacy of "multipliers", such as farm advisors and influential end-users, who apply and transfer their knowledge in a targeted manner;
    - by considering legal requirements in the design of data-based solutions, and
    - by linking up to other initiatives, such as the Common European Agriculture Data Space

As the partnership aims to be sustainable after the funded lifetime, an important element will be to ensure and test the functionality of up-scaled solutions and data service provisions, as well as the development of innovative, self-sustaining business models serving public and private interests.

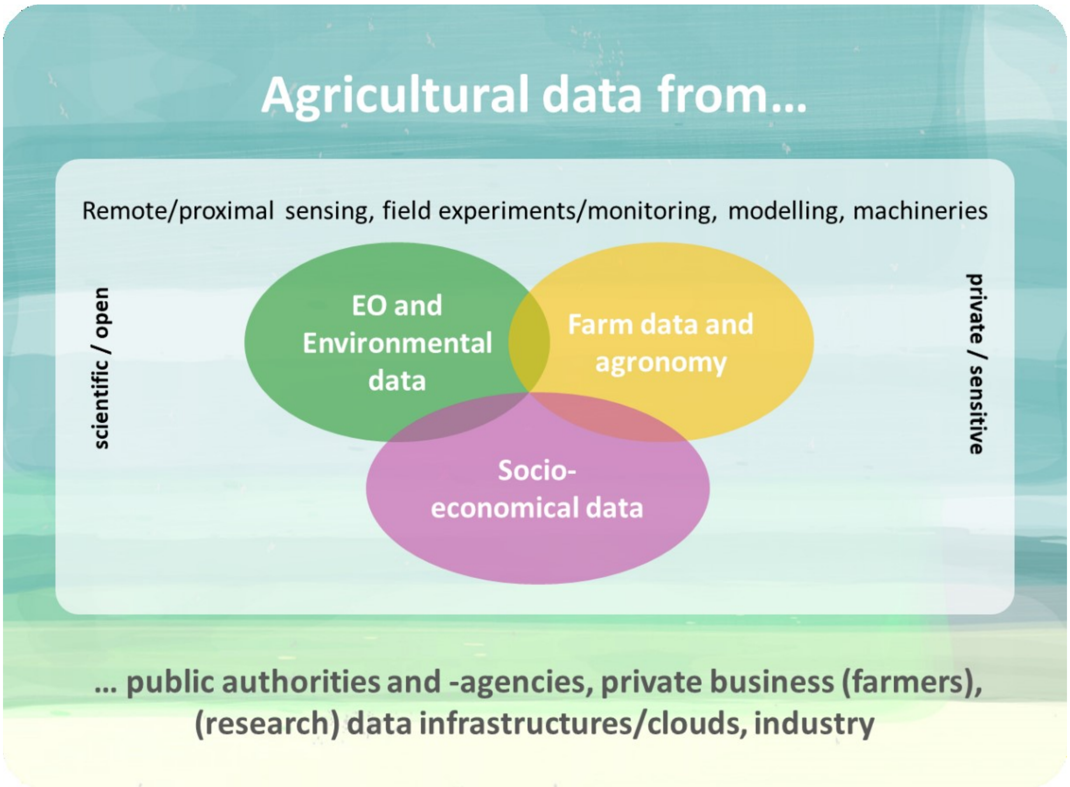
The partnership instrument allows us to go beyond the implementation of a set of coordinated calls in the portfolio of activities. This opportunity is important for the Agriculture of Data Partnership, whereby the set-up of Strategic framing actions[11] is essential to achieve its objectives. For this partnership, they are supplementary to R&I activities and may concern, e.g. governmental decisions supporting the roll-out of the partnership and the uptake of its results in the fields of data access and the use of data-based solutions. Strategic framing actions can for instance, also serve as a bridge between research and innovation on the one side, and users on the other side, by creating infrastructure that makes research project outputs and results available to end-users, such as policy-makers. The direct involvement of governmental organisations is not only important, to ensure the uptake of the results in policies, most noteworthy in monitoring and evaluation schemes, but also to provide public data from national assets that can be tailored and fed into R&I activities and to ensure their upscaling, implementation, and maintenance after the funded lifetime of the partnership.

[11] Strategic framing actions may include the identification and communication of policy monitoring and evaluation data needs and taking an active role (feedback mechanisms) in the R&I based development of related data-based solutions to ensure suitability for policy uptake; - Data provision to partnership actions (e.g. provision of reference data sets (in a certain format) for the use of AI); - Ensuring consistency in the approaches across Europe within the domains covered by the partnership; "Umbrella function" to link and review several types of past and ongoing projects falling within the scope of the partnership and bringing multiple initiatives on different levels (national/European) together; Linking up to existing capacity building initiatives for end-users, such as AKIS, digital innovation hubs or training supported under the Common Agriculture Policy; Working towards ensuring sustainability of the partnership.

1.7 The data

The scope of “data” in the Agriculture of Data Partnership refers to all kinds of data that are relevant to achieve the objectives of the partnership. This includes geospatial observations like the environmental and Earth observation and public and private agricultural data including farm data, IACS data held by paying agencies, socio-economic as well as modelled data. While data can be grouped into different domains, there is overlap and the domains are fluid (see Figure 3).

Figure 4: Data scope of Agriculture of Data



Data sources in this partnership essentially include Earth observation (EO) and other satellite data[12]. Europe, through programmes such as Copernicus, has well-established spaceborne infrastructure and expertise. Data from these programmes and others like Landsat are widely and routinely used across the agriculture sector for weather forecasting, monitoring of extreme weather events, crop growth, pests and diseases, and irrigation needs, as well as by the Global Navigation Satellite System (GNSS) and the Galileo and Global Positioning System (GPS). The Copernicus programme, led by the European Commission and in partnership with the European Space Agency (ESA), provides petabytes of open data at global and European level. The Sentinel missions[13] of the Copernicus programme are the backbone of the European EO community. Its flagship, the multi-spectral Sentinel-2 mission delivers global data coverage of the land surface at medium spatial resolution and can be used for a variety of agricultural and farm management applications. Sentinel-1 operates a synthetic-aperture radar (SAR) system that delivers frequent and weather independent information about the status and condition of

[12] EO is the gathering of information about planet Earth’s physical, chemical, and biological systems via remote sensing technologies, usually involving satellites carrying imaging devices.

[13] https://sentinels.copernicus.eu/web/sentinel/missions

the agricultural landscape. Sentinel-1 derived products are important data sources for regions that experience high cloud cover where optical imagers, like Sentinel-2, cannot penetrate. The Copernicus Sentinel Expansion Missions[14] provide further opportunity to exploit EO for agricultural applications; these missions will include the generation of hyperspectral (CHIME), thermal (LSTM) and L-Band SAR (Rose-L) observations capable of monitoring and deriving properties like soil moisture, land-surface temperatures and evapotranspiration. With the Copernicus Land Monitoring Service the EU already provides a portfolio of readily available data products at EU level.[15] The valorisation of these products for agricultural applications is still in its early stages. At present ESA/EU and national EO missions do not include high-resolution imaging systems for frequent and regular land monitoring. This is partly compensated by the promotion of data from third-party missions (TPM[16]). ESA enables access to TPM for scientific research and application development but only within a limited quota.

In order to increase the uptake and application of EO data, particularly with regard to the development and rollout of accountable and sustainable policies in agriculture, and also for the development of services for farmers, fast, reliable ground-truthing of data is needed. Ground-truthing includes the in-situ measurement of biophysical and biochemical variables, or agricultural variables such as cropping practices, production intensity, stress symptoms (e.g. due to infestations, diseases, drought), yield, and yield quality. Information is needed from across Europe representing different biogeographic, climate and production conditions. Once this is in place, it will be possible to use EO data in agriculture at local, national, and global levels.

Environmental data is provided by meteorological agencies, agri-research institutes, environmental agencies (e.g., European Environment Agency (EEA)), and observational networks (e.g., Eionet). In addition, a large amount of environmental data, relevant to agriculture, is collected in-situ e.g., by field sensors or machineries, by scientific and/or public sampling and mapping campaigns, and in short- and long-term experiments or in living labs. In the context of the partnership, environmental data provides the basis for the development of decision support tools for farmers, for improved pest- and nutrient management and irrigation systems or other tools in support of a more sustainable agricultural production system. Environmental data, and the knowledge drawn from it, is crucial for dealing with the great challenges in agriculture such as ensuring food security, biodiversity conservation, soil health, water protection, landscape diversity, air quality and climate change adaptation and mitigation. Innovative sensors offer new opportunities to generate information. Yet, often data are difficult to find, not freely accessible, poorly described and/or not stored in standardised or open formats. These difficulties are increasingly recognised as challenges to the effective use of public environmental data.

Farm data has a special role in this partnership. Modern agriculture is data intensive as farms collect data as part of their everyday operations. Farm machines and robots generate and directly analyse information from the field data. Digitally or manually generated annual crop and soil samples as well as harvester yield maps enable feedback loops on production pattern, crop and agri-environmental conditions. There is an increase in the use of drones to provide a variety of imagery. External companies offer data-based apps and services for farms and host their data, mostly charging fees and/ or for acquiring data use rights. All these data help farms to keep food production competitive and sustainable and improve farm management and operations. In the EU, farms are subject to EU

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[14]) The first Copernicus Sentinel Expansion Mission to be launched is CO2M (scheduled for 2026), which will provide an important first step towards monitoring the GHG emissions from the agriculture domain (see Section 3.2.4). https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions

[15] This EO information can be freely accessed via different data access hubs, including from the Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu) and other hubs, such as e.g. SCI Hub, CSCDA, CODA, depending on the data product of interest.

[16] https://earth.esa.int/eogateway/missions/third-party-missions

agricultural policies, which adds another layer for farm data. The Integrated Administration and Control Systems (IACS) is an important part of the governing infrastructure for the EU's Common Agricultural Policy (CAP). IACS and the Land Parcel Identification Systems (LPIS) managed by the Paying Agencies contain critical spatial data for agricultural subsidy payments.

With lots of valuable farm data available, AI and machine learning methods can yield a wide range of improvements and innovations (e.g., improved remote sensing products or agricultural models, better supply chain management, smarter policy monitoring, as well as in neighbouring sectors, such as tourism, health, finance or insurance). The value of data is increasingly recognized in the agricultural sector. At EU level, there is interest to increase farmers' data sovereignty and opportunities for them to monetise their data. At the same time, the legislative requirements towards farmers to provide data for control and statistics are increasing. Questions such as "How to make the data available" and "How to make sure it is being used in a fair way" are dealt with in current EU initiatives and the respective legal and technological developments[17].

By incorporating **Socio-economic data** this Partnership can make a significant impact. People as actors and decision-makers are an important key to understanding the dynamics of the agricultural sector and to set goals for assessable agricultural policies. Socio-economic data differs fundamentally from environmental or physical data. It is often semi- or unstructured, collected and stored using different formats and standards than environmental data, and may consist of qualitative elements such as opinions, stakeholders' inputs, or advice. Living labs represent important socio-economic data sources. Socio-economic data are an important component of policy monitoring and evaluation as well as of policy formation and their use allows the development of services relevant to European farmers. In turn, data (e.g. market data on input and output prices) influences farmers' decisions. Geographic dimensions are a common key to link socio-economic data to other data sources if databases are properly organized. European wide data collection, including for monitoring purposes, [18] provides up to date statistical information in the scope of this Partnership.

(Data relevant to this Partnership together with considerations on data governance, privacy and security issues are further elaborated in the Annex.)

[17] Data Act, Open Data Directive, Fair data economy, Common European Agricultural Data Space
[18] Data collection efforts relevant for policy monitoring include e.g. European Statistic System and Eurostat, Farm accountancy data network (FADN), Farm Sustainability Data Network (FSDN), Digital Economy and Society Index (DESI)

2 The AgData partnership: Ambition and operation

The aim of this chapter is to give the reader background information about the foundation of the partnership before describing the R&I activities in detail in chapters 3 and 4.

This chapter holds a diverse spread of information due to the complexity of the partnership scope; the existing data, how the partnership will contribute to policy objectives and ambitions, how the partnership provides added value, how the SRIA has been developed, the links and synergies to other initiatives and finally, the next steps of the partnership.

2.1 Contribution to policy objectives and ambitions

The two central elements of the partnership are a) to support the "twin green and digital transitions" through excellence in R&I and the generation of data-based solutions and knowledge; and b) to strengthen policy capacities, including a contribution to the formation of policy priorities based on identified gaps (Ehlers et al., 2022).

The partnership will contribute to a number of the European Commission's priorities, in particular to the *European Green Deal*, *A Europe for the Digital Age*, *An economy that works for people*, and *A new push for European democracy.* It will contribute to the objectives of the **Common Agricultural Policy (CAP)** post 2022 and the EU's Space policies as well as to the Sustainable Development Goals, in particular the fields of agricultural production, environment and climate.

In addition to supporting the **twin digital and green transitions** of the agriculture sector, the partnership will support the (re-) use and capitalisation of data for the economy and society by fostering innovation, which is a key ambition of the European Strategy for Data. The partnership is an inherent part of the **Coordinated plan for AI**. It will also probe new instruments introduced through the **Data Governance Act**, e.g. in the field of data altruism, and strengthen the capacities of private and public actors to adjust to changing regulatory framing conditions in the field of data and AI (e.g. the forthcoming Data Act, and Act on AI, see Table 1).[19]

The partnership fosters objectives stipulated in the **Digital Compass** – a Pathway towards 2030 and the Digital Decade Policy Programme, in particular by increasing businesses' capacities to use AI- and cloud based technologies.[20]

The partnership is in line with evolving **space policies** as reflected, for example, in the recent "Council's conclusions on Copernicus by 2035'' issued in June 2022. Here Council expressed the need to follow new trends in order to maximise the benefits of the Copernicus programme (technologies, science and digital such as AI, big data analytics etc.).[21] Furthermore, it highlighted the need to ensure the

[19] Table 1 is discussed in greater detail in the partnership document. The (draft) legal acts are discussed in Chapter 4.

[20] Europe's Digital Decade: digital targets for 2030 (europa.eu)

[21] In the Council Conclusions it is also mentioned that services, data and information must be user-friendly, relevant to societal, economic and environmental needs and useful first for public authorities, but also for scientific, economic actors and citizens, which are also clear objectives of the partnership (improve policies monitoring and evaluation, and on the other hand develop data based solutions, methodologies, and indicators to improve climate adaptation, and resilience of agriculture and minimise undesired impact of agriculture on the climate, environmental quality, ecosystem services, and biodiversity, whilst ensuring food security, safety and quality as well as sustainable productivity etc.). In the conclusions of the Council it is also mentioned that the Commission must assess how far the Sentinel missions, as the backbone of the Copernicus infrastructure, could be complemented with additional European public and/or commercial capacities, paying particular attention to New Space solutions, and also the need to ensure the calibration and validation of satellite data and information products, using reliable high quality in situ data, with documented quality, access to analysis ready data, the

calibration and validation of satellite data and information products using reliable high quality in-situ data, with documented quality, access to analysis-ready data, the integration of data from different sources at different resolutions.

The partnership will contribute to achieving the objectives of the CAP post 2022 with regards to increasing the sustainability and competitiveness of the agriculture sector through multi-criteria decision-making support. It will contribute to building capacities for achieving the cross-cutting objective of the CAP; *Modernising the sector by fostering and sharing of knowledge, innovation and digitalisation in agriculture and rural areas, and encouraging their uptake*. The partnership will play a decisive role in increasing the effectiveness of digital technologies used by farmers through the provision of data-based solutions. Next to minimising digital divides between businesses, e.g. digitally advanced and less advanced farms; and farms which can or cannot invest into data acquisition[22], the partnership will also strengthen the position of SMEs and start-ups, through the provision of data-services and big data sets, which can be further capitalised.

The partnership will contribute to achieving the objectives of the **Farm-to-Fork Strategy, the Biodiversity Strategy, the Zero Pollution Action Plan, the European Climate Pact/Adaption strategy** and **the 8th Environmental Action Plan**. A key factor here will be the partnership's contribution to reducing emissions and strengthening capacities for climate adaptation through the provision of independently generated data-based solutions as input to (precision) farming applications and FMIS across production approaches, e.g. organics, conventional, agro-ecological approaches.

With its approach towards supporting sustainable agricultural production while also strengthening the agriculture sector's competitiveness, the partnership will contribute to a number of **Sustainable Development Goals** (SDGs), in particular to targets in the areas of Zero Hunger, Sustainable Land Management, Sustainable Economy and Climate Action.

Through several pathways, the partnership will contribute to the ambition of better policy-making along the policy cycle. It will thus contribute to the headline ambition of "**A new push for European democracy**". First and foremost, it will strengthen monitoring and evaluation capacities and thus the capabilities to generate input to policy formation processes and to assess policy performance. In the medium-term, the partnership has the potential to simplify processes by generating monitoring and evaluation data without creating additional reporting obligations. Next to the medium- and long-term monitoring needed for performance assessment across policy fields (agriculture, climate, environment), in the context of the CAP, the partnership can also facilitate compliance monitoring and the implementation of interventions through the provision of dedicated data-based solutions.

Finally, the partnership will promote European values in the handling of data; it also contributes to the headline ambition of "**Promoting a European way of life**". It may serve as a prototype of a novel approach towards the capitalisation of data under the consideration of the evolving legislation in the fields of data, data technologies and digital technologies.

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fusion of data from all sources and different resolutions, as well as the rapid availability of high-quality data in order to maximize their use, as the partnership include in its objections and activities.

[22] Data is an asset for strategic decisions in agricultural production; for instance, sensor data - in comparison to freely available satellite data - allow for a higher level of precision and thus performance in smart farming, and buying in market data on inputs and outputs facilitates to plan and manage production approaches in a more tailored way.

Table 1: Overview of selected (forthcoming) legislation relevant for the implementation of the Partnership Agriculture of Data

	Agricultural sector (public and private domain)	R & I in AgData
Data Governance Act	Very relevant	Relevant
Data Act	Very relevant	Partly relevant
Digital Markets Act	Partly relevant	No direct relevance
Digital Services Act	Partly relevant	Partly relevant
Implementing Act on High Value Data Sets	Relevant	Very relevant
Horizontal Act on AI	Directly relevant for agricultural administration and for agriculture sector also through machinery directive/regulation	(Very) relevant

Note: The content of this table and the assessment approach is further discussed in the Partnership Document. The (draft) legal acts are also discussed in Chapter 4.

2.2 Added value of the partnership

The AgData Partnership will be an essential instrument to address multiple common challenges and strategic opportunities in the agricultural field existing at European level. Requiring concerted actions, these include the increased demand for better environmental and economic performance of the sector, the need to adapt to climate change, elimination of digital divides, addressing the societal expectations for tailored and successful policies and a clear communication of their impact, as well as the capitalisation of data in a fair manner. The partnership, with its SRIA, governance structures and capacities (see Partnership Document), is expected to create significant EU added value. The following aspects are to be highlighted in particular:

- "**Umbrella effect**": The partnership is expected to consolidate and link the efforts of existing and ongoing use cases and pilot projects in the field of the development of data-based solutions for the agriculture sector and policy monitoring and evaluation. Governance structures proposed for the partnership (see Partnership document) will help to capitalise the consolidated results and works of projects across Europe and to foster excellence. In addition, dedicated review mechanisms to assess in particular (R&I) initiatives and their results will be set up (see Chapter 4).
- "**Defragmentation":** The partnership will contribute to defragmentation of the "landscapes" of initiatives and approaches in the field of EO, environmental and agricultural data, which at present are being carried out in parallel. Mechanisms for tailored interaction will be set up to achieve scale-effects through common approaches, to enhance and where possible secure interoperability (including across countries as well as in B2B, B2G and G" settings), the generation of homogenous (Europe-wide) data sets, and to prevent the duplication of efforts.
- **"Systemic effects":** This partnership is expected to achieve systemic effects in the provision of data-based solutions through, among others, the upscaling of piloted approaches in terms of geographical outreach and maturity level, end-user readiness, and the creation of sustainable governance and service structures.

- **Effectiveness and efficiency in data processing:** Due to its geographical outreach and its general ambition of enhancing data availability, this partnership will achieve the "critical mass" of high quality (geospatial) reference datasets needed for the effective application of big data for Europe-wide data-based solutions.
- **Addressing "digital divides"** between farms, e.g. between technologically advanced and less advanced farms, through the capitalisation of sensor data from individual farms for a wider farming community.
- **Closing market gaps** in the provision of independently generated data-based solutions for sustainable agricultural production, (also enabled through achieving the critical mass of high quality input data).
- **Coverage for climate adaptation**: This partnership will span over several biogeographic and climatic zones. Gathering adequate data in relation to agricultural production and environmental conditions across these zones will be critical for the development of climate adaptation approaches. Lessons learnt from regions that have previously experienced shifts in production conditions, such as lengthened growing seasons and more frequent extreme weather events will be tailored for application in regions where such shifts have been forecast in the near future.
- **Uptake and integration of monitoring approaches**: The direct involvement of all / the majority of Member States in the partnership will facilitate the uptake and integration of associated results into monitoring and evaluation processes of common policies[23].
- **Synergies between public and private domains**: Through the design of the SRIA and of the governance structures (see Partnership Document), the partnership will achieve synergies between public and private interests and efforts concerning the use, re-use, sharing and capitalisation of data. In order to achieve many of the above listed EU added values, it is essential that **all / most of the countries in Europe join the partnership**. A key ambition of this partnership is to cover all of Europe and to create innovative data-based solutions while avoiding uncovered spots and regions in the provision of independent data services to the agriculture sector, policy-makers and public administration as well as to other stakeholders.

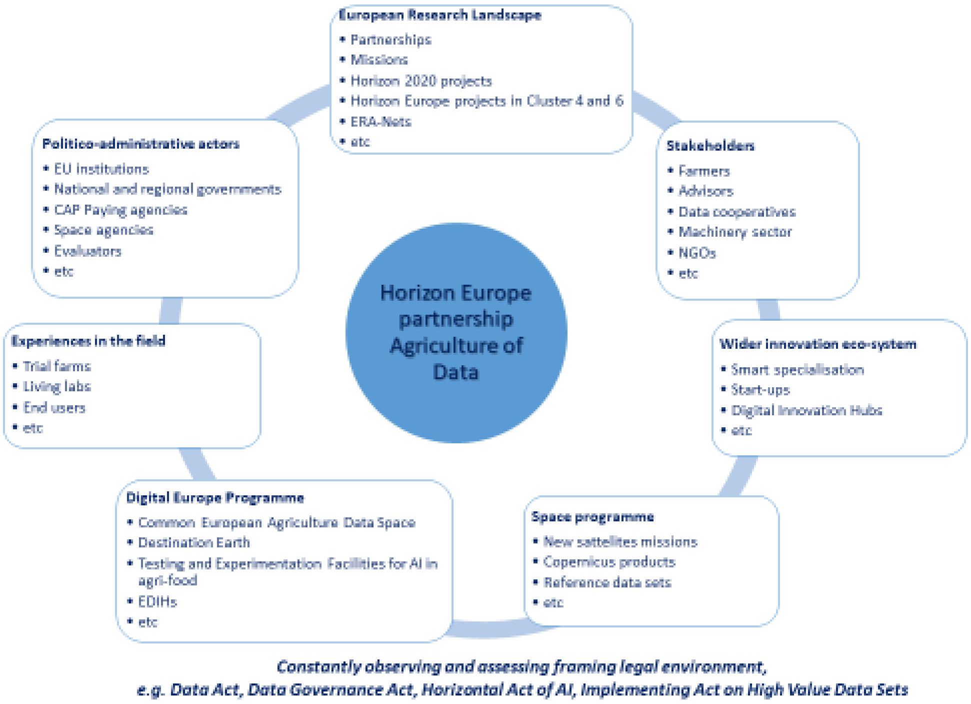
Further benefits emanating from the partnership are the **reduction of administrative burdens** for public administration and farmers, through the optimisation of reporting mechanisms, the replacement of statistical data collection by innovative data solutions, the provision of a higher level of flexibility and transparency in the use of FMIS, and the empowerment of start-ups and innovative SMEs through the provision of data-based solutions, which can be further capitalised. Moreover, in the partnership, forces will be joined in adjusting practices and processes in the sector and in R&I to the changing legal framing conditions in the field of data, data technologies and digitalisation. The partnership will also develop inputs to policy implementation and formation processes.

Overall, the AgData partnership will follow a comprehensive approach (Figure 4) going beyond the above-mentioned umbrella effect. It will develop innovative data-based solutions and scale them up, among others, through building on a comprehensive stocktaking and leveraging of past, ongoing and evolving (R&I) initiatives across Europe. Governance structures and capacities of the partnership will allow to capitalise R&I efforts undertaken in the domains of data & data technologies, EO, agriculture and policy monitoring by linking results, and to co-create, test and validate solutions with the targeted end-users and key stakeholders. The partnership will closely coordinate and collaborate and achieve

[23] "Common policies" refer to EU policies affecting all EU Member States.

synergies with other initiatives, especially with other Horizon Europe partnerships and missions and initiatives under the DEP (see Section 2.3.5). It will consider the evolving EU legislative framework, including the Data Act and the Data Governance Act (see Table 1), tailor the developed data-based solutions accordingly, and support capacity building for its implementation and further development (Chapter 4).

Figure 5: Comprehensive approach of the partnership – achieving an "umbrella effect", synergies, and EU added value



2.3 Complementarity and synergies with other programs and initiatives

A key ambition for the AgData partnership is to achieve complementarity with other EU and national activities and to harness synergies wherever possible. The AgData partnership is an R&I initiative with the ambition to establish sustainable structures well embedded into the overall data ecosystem. It can also be seen as a cornerstone in building capacity for the digital transformation of the agricultural sector, as well as an enabler for start-ups and SMEs, which may not have the capacity to generate Europe-wide reference layers themselves but who can further capitalise data-based solutions developed in the partnership.Within the context of building synergies with other EU and national level initiatives, it will be important to consider and engage with relevant R&I activities within

a) Horizon Europe – particularly activities and pilot projects in the field of agriculture and environment supported under the Digital Europe Programme

b) Innovation and knowledge related activities carried out under the Common Agricultural Policy (CAP)

c) Programmes carried out by the European space agency (ESA), European Union Agency for the Space Programme (EUSPA), and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)) and the European Environment Agency (EEA).

The ambition to achieve these optimal synergies with other initiatives is also reflected in the proposed governance structures of the partnership (see partnership document, Figure 4). Table 2 summarises the main expected synergies and complementarities between the AgData partnership and other policy instruments.

2.3.1 Horizon 2020/Horizon Europe

As outlined in section 2.2, this partnership aims to achieve an umbrella effect and to link and build upon the results/outcomes of relevant Horizon 2020 and Horizon Europe projects.[24] For the first Work Programme of Horizon Europe Cluster 6, the call, *HORIZON-CL6-2022-GOVERNANCE-01-11: Upscaling (real-time) sensor data for EU-wide monitoring of production and agri-environmental conditions* directly linked to the partnership was put forth. Funded projects were required to collaborate with the AgData partnership and to address a research question crucial for the partnership's work:

Several other projects funded by Horizon Europe Cluster 6 work programmes 2021/22 and 2023/24, will produce results relevant for the partnership.

A number of topics under Horizon Cluster 4, aimed at developing data technologies and approaches to safer data sharing and data security using a cross-sectoral approach (potentially including space borne data) will be monitored by the Partnership.

In November 2022, a workshop "R&I in Agricultural data – Achieving synergies, mapping achievements, knowledge gaps and potentials" was organised for projects operating in the field of R&I agricultural data funded by Horizon 2020, Horizon Europe and the Digital Europe Programme to achieve synergies and capitalise results (see Section 2.4).

The partnership will continue to map possible synergies with other Horizon Europe partnerships and missions, in particular with the three forthcoming partnerships under Horizon Cluster 6 on Sustainable Food Systems; Agro-ecology Living Labs and Research Infrastructures; and Animal Health and Welfare. Because of the horizontal focus of the AgData Partnership from a thematic viewpoint, it will only be possible to identify and define concrete links after the topic priorities are defined in the SRIAs. The interim results of the other three partnerships are expected to inform the process of priority setting in the generation of Europe-wide data-based solutions outlined in Section 4.1. The potential of living labs set up under other partnerships and missions to serve as extended testbeds for data-based solutions developed within the AgData partnership is promising.[25] Other Horizon Europe Cluster 6 partnerships may also benefit from the stocktaking and solutions developed in the fields of Farm Management Systems (FMIS) and Decision Making Support Systems (DSS). In addition, this SRIA already takes into consideration that a Horizon Europe partnership on Forestry is evolving. It therefore concentrates on agricultural production. The possibility of synergies of the work of the two partnerships might be explored at later stage.

The potential for synergies with the European Partnership on Artificial Intelligence, Data and Robotics is to be closely monitored especially under Horizon Europe Cluster 4.

Due to its unique approach from a methodological point of view - where the main ambition is the generation of data-based solutions at European level through the use of data technologies - there is little risk of direct overlaps with the work of other Horizon Europe partnerships.

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[24] For the results of a mapping of relevant Horizon 2020 and other projects, see Annex II in the partnership document.

[25] Similarly, such testing could be done in cooperation with Digital Innovation Hubs or the Testing and Experimentation Facilities to be funded by the Digital Europe Programme or within the remit of activities funded by Smart specialization (see below).

2.3.2 Digital Europe Programme

It is crucial to align the implementation of the AgData partnership with the roll-out of the Common European Agriculture Data Space, announced under the European Strategy for Data, and supported by the first and second work programme (2021/22 and 2023/24) of the Digital Europe Programme (DEP). The data space aims to support trustworthy data sharing in the sector and the development of commonly agreed business and governance models. Within the Coordination and Support Action (CSA) a specific approach towards data sharing in the sector will be developed; one that considers the changing framing conditions created by the forthcoming Data Act and Data Governance Act and the experiences gained with the Code of Conduct of agricultural data sharing by contractual agreement[26]. The partnership may supplement the work of the CSA and may also elaborate innovative data-based solutions highlighting ways in which data shared through the data space could be used. Moreover, the AgData partnership can provide input to the data space by providing Europe-wide data layers supplementing high-value datasets, which will be made available for all Common European Data Spaces. Depending on the final set-up of the data space, the AgData partnership may gather reference data, e.g. for training AI applications, through this space.

Data interoperability is a key to unlock the potential of data and remains a key challenge. Joint efforts are needed and coordination will be required with respect to data interoperability and standards to achieve synergies and avoid overlaps with the work of the Common European Data Spaces and any actions which may result from the Data Governance Act and the Data Act.[27] [28] Furthermore, cooperation and monitoring of other data spaces developing in parallel with the partnership, such as DestinationEarth (DestinE) which will develop digital twins of the Earth for climate change readiness, will be essential to align our respective work programmes. Synergies with other activities are to be achieved as well, for instance with the Testing and Experimentation Facilities for AI in agri-food, on which data-based solutions might be tested. Furthermore, Digital Innovation Hubs can support the AgData partnership serving as testbeds and demonstrators to end-users. On the other hand, Digital Innovation Hubs may also harness data sets generated by the partnership.

2.3.3 Common Agricultural Policy (CAP)

With the CAP, synergies are to be achieved particularly in two fields, 1) strengthening monitoring and evaluation capacities and 2) capacity building for the digital transformation of the sector in support of sustainable agricultural production.

Efficient and effective responses to monitoring needs and ascertainment of the uptake of partnership results, will be achieved via a close engagement with the European Evaluation Helpdesk, the Member State Expert Group for Evaluation (GREXE) and Member States' paying agencies. In addition, a continuous mapping of relevant Technical Assistance projects will be important to achieve the best synergies. While the partnership will support the simplification of monitoring and evaluation

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[26] https://cema-agri.org/images/publications/brochures/EU_Code_of_conduct_on_agricultural_data_sharing_by_contractual_agreement_2020_ENGLISH.pdf

[27] For all Common European Data Spaces, common building blocks will be defined. For the Common European Agriculture Data Space, minimum interoperability standards might be defined. The European Innovation Board, which will be introduced through the Data Governance Act, will work on questions related to cross-sectoral data interoperability. To avoid overlaps with those EU level initiatives, the partnership will coordinate with the other initiatives in the event that its work closely relates to those fields. This does not imply, that the partnership may not work on data interoperability at all, e.g. in cases where an EU-wide reference data layer is needed and data formats vary across countries. It may also communicate proposals for interoperability solutions to the other bodies.

[28] To align the work of the AgData partnership with that on the data space, the CSA on the data space was also invited to the above-mentioned workshop in November 2022.

approaches, it will also inform the development of future monitoring schemes. Moreover, the AgData partnership will be able to assist CAP implementation by developing innovative solutions that facilitate the "ongoing monitoring approach", and methods to reduce administrative burden for public administrations and farmers. The partnership is expected to capitalise IACS data in its work on data-based solutions. EO-based solutions offering greater insights into e.g. crop development, yield forecasts and pest and disease incidence, will facilitate the tailoring of market and risk management measures towards policy objectives.

The CAP provides key instruments to support the digital transformation of the sector at the level of the end-user, including advisory services, training, investment support, demonstration projects, and support for cooperation, innovation and knowledge transfer. The exact use of these instruments to support the transformation process has been decided by Member States within their digitalisation strategies as part of their CAP Strategic Plan. The partnership will supplement these CAP instruments. While the instruments supported under the CAP primarily focus on capacity building and deployment support at the level of the end-user, the partnership will provide input to actions under the CAP through R&I at systemic level taking end-user needs into account and linking up mechanisms that reach out to farmers. Two concrete examples of possible synergies include 1) the provision of additional input data layers to the Farm Sustainability Tool for Nutrient Management (FaST) which is available to all farmers and 2) the AgData partnership can feed practitioner-oriented knowledge into the Agricultural Knowledge and Innovation Systems (AKIS) and into farm advisory services.

2.3.4 EU Space Programme

The EU Space Programme, specifically the Earth observation and monitoring part, Copernicus, provides a large range of data, based on satellite remote sensing and in-situ or other ground-based observations, as well as related services. In addition, the EU Space Programme focusses on the technological development of satellites for different purposes as well as on the development of infrastructures, services and applications. The partnership will benefit from data, information and services delivered under the EU Space Programme/Copernicus, the existing and planned Sentinel missions, and contribute to and support the delivery of accurate and reliable Earth observation data, information and services in the domain of agriculture. Of particular interest for the partnership are also the Copernicus Sentinel Expansion missions[29], like CHIME, which will provide routine hyperspectral observations to support new and enhanced services for sustainable agriculture and biodiversity management. Relevant for the Partnership are also future ESA Earth Explorer missions such as the ESA FLuorescence EXplorer (FLEX) mission will provide global maps of vegetation fluorescence that can reflect photosynthetic activity and therefore be an indicator for plant health and stress. The EU Space Programme also includes agriculture-related R&D activities.

2.3.5 Other initiatives

There are several other initiatives at EU and national levels with which synergies are to be achieved. Close collaboration with the European and national agencies in the space and environmental domains as well as with CAP paying agencies will be essential. Smart specialisation projects in the field of digital agriculture funded by the European Regional Development Fund (EFRD) can be expected to develop innovative solutions of interest for the partnership; they may also be interested in testing data-based solutions developed by the partnership.

[29] https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions

Table 2: Complementarity between the work of the AgData Partnership and selected EU level policy instruments

Policy instrument/ Programme	Scope	Examples	Comments
Horizon Europe/Horizon 2020	**Research & Innovation**	(Dedicated) Calls/projects identified through mapping Partnerships under Clusters 6 and 4 Soil mission	Umbrella effect and uptake of results Informing the selection of data-based solutions fostered on Possibilities for using Living Labs
Digital Europe Programme	**Innovation & Deployment** **Capacity building**	Common European Agriculture Data Space Data portal Digital Innovation Hubs (DIHs) Testing and Experimentation Facilities for AI in agri-food (TEF) Advanced digital skills	AgData partnership may Issi2001## develop innovative solutions to further exploit the potential of the data space and provide input layers AgData may supplement High Value Data sets and data portals with additional layers Developed data-based solutions might be tested by DIHs and TEF Network of Digital Innovation Hubs in agri-food expected to proactively link up to other relevant EU initiatives DIHs may further capitalise results of the partnership through the development of data-based solutions AgData partnership may inform the development of classes in advanced digital skills
Common Agricultural Policy	**Application &** **Capacity building** **Innovation**	FaST Advisory services Training Investment support AKIS EIP AGRI	AgData may develop additional layers and data-based solutions for FaST Advisors may take up results of the partnership and provide feedback Link to Horizon Europe through EIP-AGRI Through AKIS, EIP and advise, capacities for the uptake of results of the partnership are developed Programming primarily at national level through CAP Strategic Plans to be achieved through national partnership mirror groups Strengthening of monitoring, implementation and evaluation capacities through the partnership as well as generating input to policy formation for the CAP post 2027
EU Space Programme	**Technological development, services and applications**	Copernicus for Earth observation and monitoring Gallileo/EGNOS for satellite navigation	Copernicus (including data and service products) important for this partnership Exploiting the potential of imagery of new satellites for the agricultural sector through the partnership
European Fund for Regional Development	**R&I, Technological development, services and applications**	Smart specialisation activities in the field of agri-food	Developed data-based solutions might be tested in smart specialisation regions Smart specialisation actors may further capitalise results of the partnership through the development of data-based solutions

* Please, note that in this table only select EU policy instruments are listed; other potentially relevant instruments include e.g. the Connecting Europe Facility (CEF), the Recovery and Resilience Facility (RRF), the Agricultural Knowledge and Innovation System (AKIS) and the European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI)

Synergies with other initiatives will be fostered through the implementation of outreach and capacity building activities, e.g. through linking up to existing platforms, such as CLIMATE Adapt[30].

Synergies could also be sought with relevant activities of the European Environment Agency (EEA) and its Environmental Information and Observation Network (Eionet). The work carried out by the EEA in the context of indicator and knowledge development for policy support and strengthened monitoring regarding agro-ecosystems, agriculture and food systems and relevant policies is also particularly relevant. Synergies could also be achieved with the EEA's Copernicus User Uptake activities aimed at strengthening communication, dissemination and capacity building on Copernicus products as well as with relevant activities planned by the EEA in the context of its contribution to the European part of the intergovernmental global Group on Earth Observations (EuroGEO) on improving access to *in-situ* data regarding rural landscapes, agro-ecosystems, agriculture and food systems.

The partnership is an inherent part of the Coordinated Plan on AI, and the activities of the partnership should be well-aligned with other activities in the Coordinated Plan on AI. The fact that Member States committed to consider the Coordinated Plan on AI in the planning of national AI-related activities, should facilitate synergies between the partnership and countries' activities.

The development of INSPIRE activities and the revision of related legislation is to be observed by the partnership so as to continuously make best use of existing INSPIRE-compliant data sets.

Another initiative to be monitored by the AgData partnership is the establishment of a Farm Sustainability Data Network (FSDN), which will evolve from its predecessor, the Farm Accountancy Data Network (FADN) and will include farm-level statistical information, especially in the field of farm economics and agri-environmental and biodiversity statistics.

Similar to the envisaged collaboration with Digital Innovation Hubs described above, the partnership may link up with regions that are active in relevant fields and supported under the Smart Specialisation window of the European Regional Development Funds. In fact, some regions have already proactively contributed to the AgData partnership development process.

The mapping and monitoring of evolving and upcoming initiatives at EU level has to be similarly carried out at national level to achieve best synergies. Such mapping has already been carried out in the development of the partnership. Consideration of evolving and upcoming initiatives in the implementation phase of the partnership will be facilitated through dedicated governance structures, with so-called mirror groups in participating partnership countries (see Partnership Document).

2.4 Inputs to, and development of, the SRIA

The development of the AgData partnership from early 2019 to March 2022 is well documented in the partnership document. This section will outline key aspects of this process, particularly relevant for the development of the SRIA, as well as the process from April to December 2022. Like the overall development of the partnership, the elaboration of the draft SRIA followed a participatory approach. The partnership process is led by a Core group of country representatives from Member States and Associated Countries and accompanied by the European Commission General Directorates DG AGRI and DG RTD. The Core group is led by three co-chairs from Denmark, Italy and Spain. For the elaboration of the SRIA, a SRIA sub group, composed of Core group members and additional experts, has been set up.

[30] Home — Climate-ADAPT (europa.eu)

The vision, objectives, expected impacts and the intervention logic (see Figure 1) of the Partnership have acted as a reference point for the development of the SRIA, including Key Performance Indicators (KPIs), with adjustments being made over time, following an iterative process with multiple feedback loops.

Following a co-creation process, the R&I needs of the Member States'/Associated Countries and stakeholders were identified through a participatory process, while in parallel, a comprehensive stocktaking of relevant initiatives and assessment thereof was carried out, among others, through a series of webinars and online surveys (see ANNEX IV and Figure 3 of the Partnership document). The results of these were considered and complemented with further stocktaking of relevant R&I activities (see also ANNEX II of the Partnership document), including close collaboration with the existing ERA-Nets (ERA-PLANET[31] and ICT-AGRI-FOOD[32]) and initiatives such as INSPIRE, Destination Earth, EuroGEO/GEOGLAM and the Common European Data Spaces.

In addition to country representatives, stakeholders involved in this process include the R&I community; concerned umbrella organisations at EU level in the fields of agriculture, machinery data, data technologies, environment and earth observation data technologies; start-ups; private companies; smart specialisation initiatives; CAP paying agencies; the European Evaluation Helpdesk, working groups of the Standing Committee of Agricultural Research (SCAR); other Commission services and EU bodies (including relevant agencies) and Commission Expert groups, such as the Member State Expert Group for Evaluation (GREXE), the High-Level Expert Group for AI (HLEG for AI), Standing Committee on Agricultural Research (SCAR) and the European High Level Working Group of the Group on Earth Observations (GEO HLWG). These actions have been organised across four domains relevant to this partnership:

1. Agricultural production
2. Policy monitoring and evaluation
3. EO, environmental and agricultural data
4. Data and digital technologies

To build on the partnership document, and to gather targeted input to the SRIA from different stakeholder groups, a series of public webinars were organised throughout the summer of 2022. Key elements of the draft SRIA were further elaborated and fine-tuned using this input. In November 2022 a draft of AgData Partnership R&I activities was discussed at an in-person workshop with various R&I projects operating in the field of agricultural data[33]. In parallel, the partnership and the development of the SRIA has been presented and discussed, on several occasions, including conferences, working groups and hearings.

Inputs gathered in the participatory processes go far beyond the gathering of R&I needs expressed by targeted end-users, and the mapping of existing and forthcoming initiatives. Therefore, in the above-mentioned series of webinars in summer 2022, next to webinars with the R&I community and stakeholders, one webinar was dedicated to the potential provision of data by actors to the work of the partnership. Some aspects such as the following were repeatedly raised in this discussion:

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[31] http://www.era-planet.eu/
[32] https://www.ictagrifood.eu/
[33] Both, established R&I projects, as well as starting projects funded by Horizon 2020, Horizon Europe and the Digital Europe Programme working in the field of agricultural data, participated in the workshop organised by the European Commission, to take stock of R&I achievements, challenges, and to map planned R&I activities. Results of the workshop will also allow to organise best synergies between the work of the projects and the forthcoming partnership and will facilitate to achieve the "umbrella effect" of R&I activities.

- Much data, relevant for the agricultural sector is available; a systemic approach is needed to exploit its full potential;
- Many use cases exist to make better use of data for sustainable agriculture;
- Many Farm Management Information Systems (FMIS) exist;
- The rapidly changing legal framing conditions affecting data sharing and use in the sector and also data use for R&I, present a challenge;
- The data ecosystem in Europe is evolving quite quickly; good coordination with other initiatives will be essential;
- Involving targeted end-users and (potential) data providers in the development and implementation of the partnership will be an asset.
- If the partnership is to reach its fullest potential, a strong focus should be put on the uptake of the partnership outputs.
- Due to the vast data landscape of agriculture in Europe, the starting point for the partnership should be a mapping of the existing available solutions.
- Following an interdisciplinary approach, including data scientists, agronomists, EO experts and policy scientists among others, within the core team of the partnership has been and will be an asset to achieve and capture excellence in R&I, foster systemic effects, and to tailor data-based solutions to end-user needs.

The further development of the SRIA is outlined in Section 2.5.1.

2.5 Steps towards annual work plans and monitoring framework

2.5.1 Next steps

The SRIA in this document and subsequent versions will present high-level scientific and innovation frameworks. The SRIA is to be regarded as a "living document" and will be reviewed regularly to check whether updates are required, e.g. to adjust to changing legal, economic or environmental framing conditions. Moreover, in order to achieve the "umbrella effect" envisaged by the partnership, it will be important to continuously take stock of and assess R&I achievements, as has been done in the preparation of the first version of the SRIA (see Section 2.4), and to adjust the SRIA accordingly.

While the SRIA works at strategic level, to achieve the ambitions outlined in the SRIA, further operationalisation will be elaborated[34]. Building on the work undertaken over the last two years, development of the AgData partnership will be implemented via the partnership proposal, and the development of relevant work packages, and will rely upon the set-up of a sound governance structure. The partnership will have a high level of flexibility to involve various types of actors in the innovation and data ecosystems in the R&I activities, including in "agenda setting", data exchanges, data service, provision of advice to farmers, co-creation and feedback loops. The partnerships under Horizon Europe are expected to elaborate Annual Work Plans, to specify the activities that the partnership will carry out in a given year. The Annual Work Plans will be based on the SRIA and inputs from the partnership

[34] The R&I activities listed in the following sections should therefore also not be regarded as lists of forthcoming calls for proposals to be launched by the partnership.

members and the advisory boards. They need to be agreed with the European Commission. A collaborative approach will be adopted for developing Annual Work Plans; collaboration between bodies of the partnerships, including EU bodies and stakeholders, and national mirror groups in partner countries. These Annual Work Plans will consider the evolving R&I landscape, the legal framing conditions, and sectoral and policy needs.

During the creation of the SRIA it became evident, that a mapping of existing data and data-based solutions is needed at European, EU and national levels, and will give the partnership the best starting point to achieve the most successful outputs. This mapping needs to be carried out with stakeholders, thereby ensuring prioritisation of the needs identified in the SRIA; not just in terms of importance, but also in terms of the sequence of activities.

In tandem with monitoring the broader R&I community, the AgData partnership will closely coordinate with Cluster 6 and Cluster 4 partnerships and the Common European Agriculture Data Space and other initiatives, to ensure the best possible cooperation and exploitation of synergies.

2.5.2 Potential KPIs of the partnership

In the table 3 below, potential Key Performance Indicators (KPIs) for assessing the performance of the Partnership Agriculture of Data and monitoring progress in the course of its implementation are described. The set of KPIs is expected to be further developed in line with updates of the SRIA and the partnership proposal.

Table 3: Proposed KPIs

Specific objectives	Examples of quantitative indicators
1. Improve agri-environmental monitoring solutions and strengthen capacities to assess the status of agri-environmental and climatic conditions particularly by enhancing the integration of data sets provided by various public and private sources, platforms/networks and capitalise them through application of data technologies.	• Number and value of transnational projects funded that target integration of data sets; • Number of data harmonisation activities with stakeholders, relevant actors of the agricultural sector, data collectors and technology providers including activities with other initiatives • Number of relevant datasets which are considered to be integrated as a result of activities of the Partnership. • Number of training/capacity building courses aimed at reinforcing capacities (to assess the status quo of agri-env. & climatic conditions)
2. Boost the uptake of digital & data technologies in agriculture, by providing co-designed, tailored, easily accessible end-user-oriented data-based solutions building on EO and other environmental data. The Partnership will support the implementation and dissemination of solutions on a European level.	• Number and value of transnational projects funded that target provision of data-based solutions • Number of dissemination activities per stakeholder group • Number of and exploitation activities per stakeholder group • Number of Member States and Associated Countries targeted in dissemination activities • Number of partners from “widening” countries[1] • Number of data-based solutions (with Europe-wide outreach) developed • Number of unique users per data-based solution or how frequently the data-based solutions are used and further capitalised through another innovator, such as start-ups which use the databased solutions developed by the partnership and build on it further.
3. Enhance the use of EO, environmental and other data for developing data-based solutions, methodologies, and indicators to improve climate adaptation, and resilience of agriculture and to minimise the undesired impact of agriculture on the climate, environmental quality, ecosystem services, and biodiversity, whilst ensuring food security, safety and quality as well as sustainable productivity.	• Number and value of transnational projects funded that target sustainability of agriculture • Number of data-based solutions for quantitative assessment of environmental performances of agricultural systems • Number of data-based solutions in support of environmentally and/or climate friendly measures (mitigation) • Number of data-based solutions in support of climate adaptation of farms.
4. Achieve synergies in the development and utilisation of data-based solutions for both the agriculture sector and policy making, in particular monitoring and evaluation.	• Number of workshops that bring together primary producers and government ministries/EC. • Number of funded transnational projects that include primary producers and/or monitoring agencies. • Increase in % of data provided to monitoring agencies which can be reused by primary producers • Increase in % of data provided to monitoring agencies which can be easily sourced from existing data collected by primary producers for their own needs. • Number (or increase in %) of national / regional bodies and authorities using data-base solutions for policy monitoring/evaluation • Increase in % of synergic funding from other EU/national/regional programmes & initiatives that is devoted to development and use of data-based solutions
5. Facilitate the usability of EO, environmental and other data to create and deploy services including the data-based solutions developed by the partnership so that it can be easily re-used and harnessed by public and private organisations including research bodies, businesses, particularly start-ups and SME’s, and any other organisations, to achieve wide and rapid outreach.	• Amount of data available / published / accessible in open access (of EU-/ Europe-wide outreach/ coverage) • Number and value of transnational projects funded that focus on sharing of agricultural data between farmers • Number and value of (cascading) projects involving start-ups and SMEs to test or capitalise data-based solutions developed in the partnership
6. Develop and produce European wide data-based solutions including through the out- and upscaling of the results of use cases.	• Number of innovative solutions brought to market with involvement of the Partnership • Number of promotional activities that bridge research to deployment across Partnership activities • Number of lighthouses for demo and training
7. Support the development of a harmonised European governance structure and its related infrastructures that will enable the outcomes of the partnership in terms of data, solutions, tools, and services to be shared, taking into account existing and evolving infrastructures	• Number of communication and dissemination activities • Number of annual visits to website • Number of infrastructures/major initiatives that are involved in sharing the outcome of the partnership • Number of joint activities between the partnership and other initiatives/infrastructures.

[1] https://rea.ec.europa.eu/news/eu-committed-research-and-innovation-through-horizon-europe-widening-programme-2022-08-29_en#:~:text=According%20to%20the%20Horizon%20Europe,R%26I%20performance%20and%20the%20Outermost

3 Core research and innovation activities

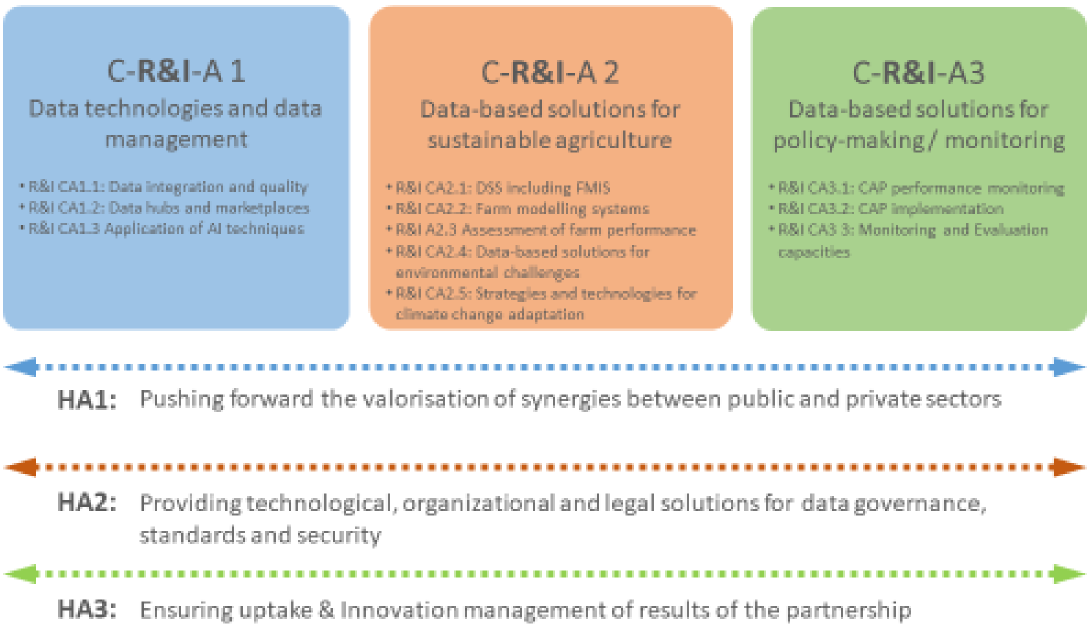
In this chapter, the Core Research & Innovation Activities (C-R&I-A) envisaged by the partnership are described. They are organized along three main themes, reflecting main objectives of the partnership:

- Data technologies and data management
- Data-based solutions for sustainable agriculture
- Data-based solutions for policy-making.

As illustrated in Figure 5, the Core R&I Activities are supplemented by **Horizontal Activities** (HA), which are relevant for ensuring the effectiveness of the Core R&I activities and aligned with the intervention logic of the partnership. These Horizontal activities include R&I as well as **capacity building and outreach activities**. These concern

- **achieving synergies** between interests and efforts of the public and private domain,
- developing **enabling solutions** – including organizational and legal solutions – for data governance, standards and security, as well as
- **ensuring (end-)user uptake and innovation management**.

Figure 6: Interplay between Core R&I activities and Horizontal activities in the SRIA



3.1 Data technologies and data management

3.1.1 Research and Data Infrastructures

Research infrastructures (RIs) in the field of cloud and data technologies are essential instruments to fulfil AgData partnership objectives, particularly in the fields of data exploitation, data engineering and data management. RIs are one cornerstone for excellence in R&I activities supporting sustainable agricultural production and policy monitoring by improving data integration, data computing capacities, data technologies and model performance. Examples of existing European RIs with a link to Agriculture and Natural Resource fields are AnaEE ERIC, LifeWatch-ERIC. They provide multistakeholder and interdisciplinary communication networks enhancing knowledge transfer and upscaling of R&I results. Moreover, a number of smaller R&I infrastructure assets in the field of agricultural data are used across Europe, frequently of temporary nature, including in the public administration to develop data-based solutions in-house.

In the context of this partnership, not only R&I infrastructures in the field of data are relevant, but also several other types of data and cloud and computing infrastructures and data technologies, applications in the public and private domains, including infrastructures at farm level in the public administration, like the IACS systems, and (semi-) open systems, such as data under the INSPIRE and Data and Information Access Services under Copernicus.[35]

Smart farming is achieved through the information from multiple data sources, from which data is processed and analysed through the use of advanced technologies like Internet of Things (IoT), sensors and actuators, GNSS, location-based systems, big data, unmanned aerial vehicles, robotics, etc. as part of an integrated and interoperable system.

Data technologies can be classified as being part of a system of record, insight, or engagement. The "system of record" allows data storage and management, it is the system used to maintain datasets. The basic agricultural plot management system is one such system. The "system of insight" provides analytical tools used to make better decisions, such as monitoring crops for growth, pests and diseases with imagery analysis to improve production. It can be differentiated between analyses carried out in the cloud and those carried out on edge devices. While in cloud computing large amounts of data can be considered in the analyses, in edge computing within a distributed information technology architecture, analyses are carried out with a limited amount of data directly at the source of data and/or the device where analytical result should induce action avoiding the transfer of huge amounts of data. The "system of engagement" allows data and information to be shared with other stakeholders and is used to gather field data with mobile devices or to share nationwide statistics at national level.

Furthermore, especially in agriculture, most data have a spatial component (location is a key feature), so Geographic Information Systems (GIS) are widely used.

Challenges

- Data relevant for the development of data-based solutions in agriculture are held in several public and private data-bases, hampering its joint processing and computing.
- There is a lack of R&I infrastructure as well as of cloud and computing capacities allowing for the systematic storage and processing of data and the development and provision of Europe-wide data-based solutions to end-users on a longer-term.[36]
- Data storage and processing is resource-and energy intensive; a duplication of databases is ideally to be avoided.
- Data search and the pre-processing required so that data technologies such as AI, can be applied in the field of agriculture, is time intensive, mainly due to the lack of common standards and approaches (see also Section 3.1.2 and Chapter 4).

[35] Data and Information Access Services | Copernicus

[36] Systemic storage of data at larger scale may also be hampered by a lack of awareness about the existing R&I and cloud infrastructure.

3.1.2 Data integration and data quality

High-quality, trustworthy, integrated, FAIR (Findable, Accessible, Interoperable, Reusable) agricultural data has the potential to provide solutions for agricultural stakeholders on one hand and an information basis for policy-makers on the other hand. Such data can be processed, used, as reference data e.g. to validate EO data, analysed, and capitalised, e.g. through the application of data technologies. The provision of data, derived value-added information, knowledge and applications will help to achieve more efficient, sustainable and competitive agricultural production through facilitating data-driven decision making. It will also support development, implementation, monitoring and evaluation of policies.

Challenges

For the different types of agricultural data, a number of activities and procedures were defined to increase the data accessibility and fitness for use. These procedures include data normalization and homogenization, a rich description by standardized metadata, quality checks and the integration into accessible, and preferably unified, data representations.

One of the major challenges to unlocking the potential of agricultural data is their enormous diversity in terms of format and content, fragmentation, metadata description, standards and semantics. Different services and technologies in a smart farming ecosystem have limited capability to work together due to the lack of standardized practices for data and system integration (Amiri-Zarandi et al., 2022). The interoperability problem exists both at the technical and semantic level. Solutions for improving semantic interoperability in smart farming are standardization, rich metadata collection, and connecting each data variable to a common language, in the form of taxonomies and ontologies (Jiang et al. 2022).

Yet, there is no universal approach to agricultural data integration and data quality assurance in Europe. A complete data integration solution needs to deliver quality data from various trusted sources (both public and private), support existing and ready data pipelines for large- and small-scale data operations, and act as a means for clients to access data from a master server.

R&I activities

In order to address existing challenges, it is necessary to develop advanced frameworks, procedures, services and tools for data integration, data analysis and results presentation, and data quality procedures. For the AgData partnership, the ambition is to apply and further develop innovative data technologies and data management approaches in the domain of agriculture taking using learnt in other sectors/ domains as a foundation for the development of innovative data-based solutions as described in Sections 3.2 and 3.3.[37] The main R&I activities to be accomplished, which might be supplemented by the development of toolkits for users and will be supplemented by "horizontal activities" in the field of data governance (Chapter 4), are:

1. Develop a data acquisition and re-use framework supported by a semantic integration. This should have the capacity to receive and manage data and information from multiple data

[37] Other than partnerships under Horizon Europe Cluster 4, the AgData partnership does not aim for developing innovative data technologies themselves. Also as it regards possible side effects of digital and data technologies and their use in general, the AgData partnership will build on the results of other R&D&I initiatives to avoid or mitigate negative impacts, especially to lower the environmental footprint through, the consumption of energy and other resources.

sources and on different scales, e.g European, EU, national data sets and approaches, as well as to provide mechanisms to allow efficient selection and reception of data by the entities and/or tools that will make use of them.

2. Define innovative approaches to link existing (and new) databases and computing capacities to carry out data technological analyses and the development of data-based solutions in an efficient way, in terms of both energy and time and where necessary use (if available, an existing) data storage system that supports the storage and classification of data and allows fast and efficient exploration of the data.

3. Elaborate schemes to enhance data interoperability (e.g. across countries as well as in B2B, B2G and G2B settings) especially to achieve/generate Europe-wide reference and training data sets[38], taking due account of, and ensuring complementarity with, ongoing and planned initiatives such as the Common European Data Spaces or actions which may result from the Data Governance Act and the Data Act (see Chapter 4).

4. Develop and provide reference data sets of high quality and "non-discriminatory" datasets for different scales[39] to enable agricultural data capitalization and to adopt non-discriminatory algorithms and techniques especially as basis for the elaboration of reliable AI-based solutions in the long-term that permit autonomous decisions at different temporal and spatial scales (see following sub-sections).

5. Develop and use a standardized metadata scheme, and ontologies and meta-language for data querying taking into consideration existing and evolving systems as well as tool(s) for (semi-)automated quality checks, e.g. statistics, gap analyses, outliers, plausibility checks.

6. Boost data re-usability by agricultural stakeholders through the development and establishment of domain-specific measures of data quality control, the creation of customized data "fitness for use" and "fitness for purpose" concepts, addressing different data quality dimensions, such as integrity, completeness, consistency and accuracy, and defining requirements for different levels of "data fitness for use".

7. Develop a multi-layer geospatial data tool compatible with geo network-based systems and providing a powerful Application Programming Interface (API) for data users compatible with commonly used open-source graph query language, such REST, GraphQL and SparqQL systems.

8. Develop innovative approaches towards context-based data curation standards and empower curated small data. Standard curation of small data sets by experts will improve data accuracy and usability for the agricultural and farming models and digital innovations. The application of small data methodologies will permit the elaboration of data-based systems that do not require extensive data to train but can nevertheless offer valuable insight to stakeholders.

[38] The scope of the activities of the partnership in the field of data interoperability will be extended in accordance of the evolutions of other initiatives as outlined in Chapter 4, and may also serve other purposes to enhance the sharing and use of public and private data in the agricultural domain.

[39] While the general ambition of the partnership is to generate European-wide data sets, activities at regional and national level levels might be carried out for testing approach before deciding on upscaling to a wider geographical outreach.

9. Improve data granularity and precision by the combination of existing agricultural and farming systems with innovative smart systems and devices, including newer sensor and sensor networks and edge computing to tackle operational decisions in near real-time.
10. Develop error processing and quantifying methods incorporated into predictions, projections and in-situ computations (edge analytics) to minimize the cascading error transference across systems and computations and to avoid unintended large impacts on the end decisions.
11. Develop innovative models or transfer functions to increase data granularity (e.g., from field to sub-field levels, or higher temporal resolutions) to increase the data fitness-for-use (see Sections 3.2 and 3.3).
12. Develop data-based solutions serving private/commercial and public interests using data of high quality and high information value in the field of operation of this partnership (see below).
13. Develop innovative procedures to aggregate sensitive data (e.g. farming data) with minimal loss of quality while withholding sensitive information as much as possible.
14. Establish a system to monitor the functionality and the product evolution of the implemented and described tools and systems.

3.1.3 Data marketplaces and cooperatives in agriculture

The huge amount of data is generated by new agricultural machinery that is increasingly equipped with smarter sensors (e.g. for meteorology, field conditions, machine location, crop development analysers). The next stage in innovation in agriculture requires state of the art tools and systems for data sharing and data integration to support advanced real-time analyses, decision support systems development, and more sustainable production. In the European context, an EU Code of conduct on agricultural data sharing by contractual agreement,[40] was introduced by EU stakeholders in 2018 (see also Section 1.7). Data generated through precision farming is collected and analysed by machinery companies or related third parties. Data marketplaces and data cooperatives offer alternative data handling and exchange options.

Data marketplaces are data exchange platforms that allow a safe, compliant data circulation thanks to a trusted and secure environment. They enable stakeholders and partners to source, distribute and exchange data. In agriculture, marketplace platforms can contribute to fostering innovation and maximizing the reuse and value of data and enhance farm performance. Marketplaces are based on a central service, which serves as a point of mediation and facilitate data sharing.

Data cooperatives in agriculture are structures created by producers to store and pool produced data as well as to serve some or all of the following purposes: minimizing the cost of digital services development and provision, increasing negotiation power of data access, getting data they produced analysed by experts of their choice, who are not the machinery producers as well as joint performance

40 https://cema-agri.org/images/publications/brochures/EU_Code_of_conduct_on_agricultural_data_sharing_by_contractual_agreement_2020_ENGLISH.pdf

benchmarking. Data cooperatives may manage the data themselves or may use central services or data warehouses to archiving structured data and high quality data sets.

A number of private and public-private partnership initiatives on the sharing of agricultural data have been established in the agricultural sector, the most relevant being API-AGRO[41] in France, DjustConnect[42] in Belgium, Join Data[43] in the Netherlands, DKE agrirouter[44] in Germany, Agri Marketplace[45] in Portugal and Gaia E. in Greece[46]. In addition, the European Agriculture Machinery industry released its strategy for achieving full data sharing,[47] and this put a focus on technology as a carrier for their delivery.

Both marketplaces and data cooperatives can be relevant for the partnership in three ways:

a) as data providers or donors to gather reference and training data for AI applications (see Section 3.1.4);

b) in testing of data-based solutions; and

c) as users of data-based solutions developed by the partnership.

In cooperation with the AgData partnership, data marketplaces and cooperatives have the potential to be a real game changer in the development and adoption of data-based solutions by the agricultural sector. By developing data-based solutions based on the inputs from marketplaces and cooperatives across Europe, a new quality of products and services at European level can be provided. Moreover, in this way, the partnership will facilitate and mobilise data and data technologies between practitioners, technicians, SME's, researchers, public administrations and policy-makers.

Challenges

The roll-out of the concept of data marketplaces and data cooperatives in agriculture, and linking them to R&I initiatives is ongoing with some shortcomings and challenges.

A key issue includes the access to, and sharing of, data that are generated by farmers; i.e. farmers have to be enabled to access the data from the machines and need to have the rights to save it in a data marketplace or within a data cooperative and then to share it for R&I and other purposes. Such issues are part of a complex intersection with intellectual property rights, personal data protection and privacy, contract and competition law, and overall data governance, among others (see Chapter 4). Moreover, gaps include data fragmentation, due to for example incompatible formats of data generated through precision farming equipment from different providers; non-disclosure; and misappropriated ownership by banks, insurance companies, agribusinesses, hardware suppliers, etc.

Some of the challenges are further elaborated in Chapter 4 and will not all be addressed primarily under this partnership itself but by related EU-level initiatives. This concerns initiatives launched under the European Strategy for Data (see Section 4.2 4), and actions ensuring end-user uptake of data-based solutions (Section 4.3).

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[41] https://api-agro.eu/en/
[42] https://djustconnect.be
[43] https://www.join-data.nl/?lang=en
[44] https://my-agrirouter.com/en/
[45] https://www.eitfood.eu
[46] BoD & Partners - GAIA ΕΠΙΧΕΙΡΕΙΝ (c-gaia.gr)
[47] https://www.cema-agri.org/images/publications/press_releases/2020-02-05CEMA_Press_Release_Strategy_Agricultural_Machinery_Data-Sharing.pdf

In the development of the partnership, attention is dedicated to challenges related to data marketplaces and cooperatives in the data acquisition strategy (see Section 3.1.1) and the testing of data-based solutions. Three main issues will be addressed: the readiness of farmers to share data for R&I purposes (following a common approach); the appropriate acknowledgement and reward for data supply; and the gathering of comparable reference/training data across Europe.

R&I activities

To approach existing shortcomings and challenges it is necessary to carry out the following R&I actions following a multi-actor approach:

1. Design and deploy a Service Cloud to develop and test basic, standardized services. This includes steps toward the development of a "network of data-hubs" initially serving R&I purposes of the partnership, especially the gathering of training data for AI applications (see Section 3.1.4). The Service Cloud may be further developed for sharing data and services to provide a new data exploitation service ecosystem where integrated data is enriched by re-usable, modular services. The definition of semantics for data and for functions is done under consideration of the evolution of the Common European Agriculture Data Space (Section 4.2).
2. Develop an innovative "pay as you go" system, where services or data published in addition to free data-based solutions of the partnership can be offered as free or paid versions[48], enabling third parties to capitalize on partnership products.
3. Develop and probe reward mechanisms for data sharing to encourage an increase in data sharing. It includes the development of approaches to assess the value of data and the consideration of the "common good" principle considering the variety of business and governance models relevant in the context of agricultural data such as cooperatives, contractors, investments needed for the generation and storage of data as well as their use potential and returns in form of advice.
4. Develop innovative solutions to increase the discoverability and composability of services in order to be easily found and used by end-users or third-party companies;
5. Develop innovative approaches to data payment services adapted to the users' needs, so that the end-user only pays for what they are really using.

3.1.4 Applications of AI techniques

Agri-food production faces challenges in terms of productivity, environmental impact, food safety and sustainability. To address these challenges with smart solutions, it is essential to evolve the current agriculture and agribusiness towards a process of incorporating intelligence based on data analysis that is interconnected with all its actors. The evolution towards this smart agriculture involves exponentially increasing the level of knowledge and understanding of the complex, multivariate and unpredictable agricultural and rural ecosystem. This will allow the generation, analysis and implementation of new scenarios quickly, efficiently and robustly keeping economic and environmental costs to a minimum.[49] This implies the incorporation of sensing at different spatial and temporal scales, big data analysis, model development, digital twins as an advanced generation of

[48] The concept "pay as you go" can also be applied to data services provided/received for free, in such cases, e.g. only Terms of References need to be confirmed or payment occurs indirectly, e.g. through the acceptance of data re-use.

[49] Agricultural Big Data have no real value without Big Data analysis (Sun et al., 2013): such data, coming from different sources, must be integrated. In this process, data quality problems are likely to arise due to errors and duplications, which may require a number of steps to ensure quality. Big data processing depends on data and metadata mediated by traditional processes for the context and consistency needed for full and meaningful use. The results of Big Data processing must be traced back to traditional business processes to enable business change and evolution (Devlin, 2012).

interactive models and decision support, and implementation of advanced supercomputing techniques. The conventional data processing techniques are incapable of meeting the constantly growing demands in the new era of smart farming. Instead, AI, especially Machine Learning (ML) techniques are particularly suitable for processing the large amount of data collected by heterogeneous sources such as sensor, robots, drones, autonomous tractors and harvesters by taking advantage of the exponential increase in computational power of the last decades. Data fusion from different sources will be important for more robust dynamic crop modelling applications and forecasting exercises (see Section 3.2.2).

Image annotation is a critical activity in the generation of datasets that allow AI models to operate in a real-world setting. Preparing accurate training data is crucial since it directly impacts the performance quality of the AI algorithms when developing scalable, collaborative, and AI-assisted applications. In order to build high-performing, robust AI models, large scale annotated datasets that capture sufficient variations, under a wide range of imaging conditions, are needed. However, generating and annotating such datasets with ground truthing is time consuming, resource-intensive, and monetarily expensive. In the agricultural domain, analysis and modelling of images face important challenges resulting from significant biological variability (no two leaves are the same) and unstructured environments (e.g., object occlusion, variable lighting conditions, cluttered scenes). This is especially true for specific applications (e.g., plant disease detection, weed recognition, fruit defect detection) that place constraints on biological materials and imaging conditions and for precise annotations at pixel level.

Currently, satellite imagery is already interpreted using AI technologies, e.g. data technologies are used for the development of certain Copernicus products based on Very High Resolution (VHR) and other imagery[50] or using other training data, such as geo-tagged photos.

The partnership has a particular focus on geo-spatial datasets. It will not develop robotics, but data-based solutions developed by the partnership may form an input to robotic operations, e.g. in the context of automated harvesting or weeding robots.

The Partnership Agriculture of Data is an inherent part of the Coordinated Plan on Artificial Intelligence, which provides the natural context for the exploitation of AI techniques, including in the agricultural domain at the European level.

Considering ethics in AI is important also in the field of agriculture, in particular to achieve and maintain trust in AI-based solutions. The partnership will follow a human-centric approach towards AI, as it will be discussed in Chapter 4.

Challenges

In agriculture, AI is intrinsically present in the development of new solutions for the sector, since, due to the complexity of agricultural production and the multiple framing conditions, it would be impossible to address problem solving without the incorporation of AI. On the other hand, to deploy AI without incorporating the in-depth knowledge of producers on production conditions (agri-environmental conditions, in particular) and success factors which supplements data analytics, would be inefficient. Building systems, linking the two dimensions – AI results and their interpretations and producers' know-how, and operate them effectively, requires several issues to be addressed.

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[50] Local — Copernicus Land Monitoring Service

Two main categories of challenges for the inclusion of AI-based solutions in agriculture can be identified:

1) **Technical challenges**: to leverage AI techniques, tailoring them to the agricultural applications and
2) **Governance challenges**: to make the use of AI in agriculture part of a sustainable and reliable process involving all the relevant stakeholders, in particular farmers and their advisors.

Technical challenges:

- The application of all the knowledge of the agricultural sector in the generation of solutions through AI is still at an early stage compared to other productive sectors such as the energy or industrial sectors. Although there is already a large body of work incorporating AI into agriculture in a variety of fields – including obstacle detection, fruit counts for harvest, prediction of crop yield, soil water content, farmer behaviour, irrigation community management, agro-climatic conditions, quality control - most of the works are a mere refinement of existing models, which have not been conceived or designed to develop specific tasks in agriculture, being far from the frontier of knowledge in this field;
- Agriculture generates big data (volume challenge) and that data is complex (variety challenge); The complex nature of the interaction between the various factors makes it difficult to describe relationships between an input (e.g. time interval between fertilizer applications) and an output (e.g. harvest yield);
- AI model approaches mostly do not combine the analyses of agri-environmental conditions and the knowledge of producers and advisors at the same time;
- Traditional local and cloud-based AI infrastructures struggle to manage agriculture data because of the high bandwidth and latency requirements when implementing real world applications for agriculture;
- There is a lack of homogenous (Europe-wide) reference/training data (in sufficient resolution) to capitalise/interpret satellite data achieving a high level of information power. Frequently, training data primarily includes test-positive, but not test-negative cases;[51]
- Currently, there are very few image datasets that consist of hundreds of images per category and are publicly available. The scarcity of annotated, large-scale image datasets relevant to agricultural processes creates a bottleneck reducing the power of advanced AI algorithms in the agriculture domain. Although there are currently several commercial solutions that provide easy-to-use manual annotation tools, data annotation is time consuming, costly, laborious and needs domain expertise.[52]

Governance challenges (for non-AI-specific governance challenges, see also Section 4.2):

- most farmers are non-experts in AI and cannot fully comprehend the underlying patterns obtained by AI algorithms, this requires to consider the possibly "weaker" role of the farmer in the development of governance structures for a data-service ecosystem;

[51] One reason, explaining the need for Europe-wide training/ references data is the fact that biogeographic conditions vary across Europe.

[52] The main challenge is the implementation of (semi)automatic annotation tools based on AI techniques to simultaneously achieve high standards in efficiency and accuracy in labelling training data. For example, data augmentation could play a relevant role in boosting model performance while reducing manual efforts for data preparation, by algorithmically expanding training datasets. Beyond traditional data augmentation techniques, generative adversarial network (GAN) can provide a suite of novel approaches that can learn good data representations and generate highly realistic samples.

- the incorporation of AI in the agricultural system has a social and ethical impact.

All this highlights the need to guide short-, medium and long-term strategies for the development and consolidation of new data analysis technologies in the agricultural sector that can add to the currently available applications like, crop maturity, pest and disease detection, intelligent spraying and fertilization, etc. It also suggests the need to open paths to new and emerging applications, developed following a co-creation approach, involving farmers and advisors. The way in which topical priorities are identified and set in the work of the partnership, are described in Section 4.1.

R&I activities

There is a necessity to carry out specific research and innovation activities following a multi-actor approach addressing the identified challenges and gaps. To elucidate a few:

1) Identify key (reference/ training) data sets to strengthen AI capabilities in agriculture, including data from existing and planned satellites, VHR imagery as well as sensor data generated in the context of precision farming. This should be done in alignment with relevant European and other initiatives on data sharing including Copernicus, national assets, Horizon Europe, EuroGEO, and the Common European Data Spaces.
2) Capitalize historical satellite data to extract useful features such as vegetation- and water-related indices, e.g. the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), to train AI models e.g. for yield prediction, disease and stress identification in farms.
3) Develop innovative solutions to overcome challenges inherent to privacy laws by using satellite imagery data.
4) Develop innovative AI-based approaches handling heterogeneous data, fuzzy and ambiguous information e.g. in the context of sensors, search algorithms, as well as in the generation of relevant indicators.
5) Develop data governance procedures, tools, and instruments for clarifying and guaranteeing data ownership and privacy in sharing farming data (see also Chapter 4).
6) Develop or contribute to the development of digital twins of farms and of relevant natural environments for agricultural applications. These can be used for short- and medium-term simulations and predictions building on various types of data in synergy with other EU level initiatives.
7) Develop innovative approaches to strengthen the use and uptake of AI applications in agriculture considering an assessment of the practical barriers that hamper the transformation of this sector compared to other sectors, e.g. trust in AI. In this context, the use of careful application and evaluation loops will be an asset (see also Section 4.3).

3.2 Data-based solutions for sustainable agriculture

The support of sustainable agricultural production through data-based solutions and strengthening the capacities of the sector to adapt to climate change are key ambitions followed by the partnership. Building on the activities outlined in Section 3.1, R&I activities to achieve these goals focus in particular on enhancing the functionality and generating input for decision support and FMIS, farm modelling systems, farm performance assessment as well as on the development of data-based solutions in support of sustainable production (including climate mitigation) and climate adaptation. R&I activities described in this section will be supplemented by capacity building and other horizontal activities outlined in Chapter 4.

3.2.1 Enhancing functionality of and generating input for decision support systems including FMIS

Digital technologies can provide a unique opportunity for implementing sustainable production practices in agriculture by enabling the conversion of theories, data and information into daily farming practice (Pierce et al., 2013) and simultaneously increase competitiveness of farms and the quality of life of farmers, e.g. through better time management.

The use of data, data technologies, and digital technologies in agriculture will result in a more environmentally, socially and economically sustainable and climate resilient agriculture system combined with a strong policy monitoring capacity and subsequently, better informed policy-making (see Section 3.3). The challenge will be extracting the right information from the vast quantity of data that technologies will supply. Decision support systems (DSSs) are used in agriculture to collect and analyse data from a variety of sources with the goal of providing end-users with insight into their critical decision-making processes. In the agricultural domain, these systems help farmers to solve complex issues related to increasing efficiency, lowering emissions, lowering production costs, adapt production to weather predictions, and increasing competitiveness. The work on DSSs should consider that DSS information will be in data lakes, which offers the opportunity of generating added value through selecting the right dataset and its subsequent analysis. Information and Communication Technology (ICT) systems such as Farm Management Information Systems (FMIS) and Decision Support Systems (DSS) can support and supplement all types of agricultural extension services, even in remote rural areas and can generate new learning spaces in the Agricultural Knowledge Innovation System (AKIS) (Hanks et al., 2008, Susi et al., 2015; Fieldsend et al., 2021; Bragança et al., 2022).

DSS will, gradually over time develop into an ecosystem of hardware, software, datasets, and data scientists. These profiles will be needed in greater quantity to achieve a structured approach to building big data, interoperability, and data science expertise.

One key input to DSS, are satellite-based technologies, which might be useful for monitoring plant communities or changes to the structure of an agricultural habitat. However, their implementation in precision agriculture for early detection of stress factors is restricted by their relatively coarse spatial resolution.

Unmanned aerial vehicles or drones make it possible to overcome some limitations of satellite-based methods by providing high spatial resolution imagery and 3D data as well as cost-effective tools for early identification and quick control of weed and plant diseases. The input data providing information on crop and agri-environmental conditions to DSS can be of various types and come from a variety of sources.[53]

[53] The seamless incorporation of new functionality and assisting features into an existing FMIS is of paramount importance (Raja et al., 2019). Precision Agriculture not only allows timely field operations, respecting the multifaceted variability of agroecosystems, but it is also configured as a strategic management that uses information technologies to collect data from multiple sources, with a view to their subsequent use in the decision-making process (Bacco et al., 2019). Such explicit information use can effectively contribute to improve economic returns and to mitigate the environmental impact (Sørensen et al., 2010; Coppola et al., 2020).

The digital market for data and decision support systems (DSS) with public and private suppliers and users in the agriculture sector has grown steadily over the past decade as a number of digital technologies have been developed and implemented. Borrero and Mariscal (2022) distinguish between embedded digital physical devices such as agricultural machines or sensors which belong to the so-called precision agriculture; and non-embedded software tools such as agricultural advisory applications and online platforms, which contain the same data as the embedded technologies but in an aggregated form or at lower temporal or spatial resolutions.

New digital technologies have created new DSS and digital algorithms and new forms of cooperation with strong and weak structural relationships between farmers, private companies, authorities and consumers of agricultural products (see Section 3.1.3). The societal interest in the use of natural resources or the impact of farming on climate and the environment has also promoted renewed interest in DSS.A strategic research and innovation goal for the AgData partnership is to develop data that creates value and solutions for the next generation of digital agriculture technologies with a particular focus on limiting Greenhouse Gases (GHG) emissions, leaching of nutrients and pesticides; and increasing the functional biodiversity in agriculture systems.

The AgData partnership offers the opportunity act as a bridge between new DSS communities and the established communities for business process management, decision modelling and knowledge management, including the emerging field of declarative business process management and executable law.

Only a few DSSs are being used significantly in farming practice, because of several factors such as conceptual design flaws, lack of added value and insufficient validation under different conditions. Moreover, the availability of DSS proposed by private companies, usually from the agrochemical industries, and the need to monetize the development of these DSS are also creating disturbances and a lack of trust by farmers and farm advisors. The AgData partnership can approach this challenge as DSS are a key part of improving farm sustainability. A set of relevant core models on which DSS (e.g. water use and irrigation, pest and disease management, fertilizer/nutrient management) are based will be (re)developed within a common framework and made publicly and transparently available for the farming community and application developers. These will be supplemented by modular data-based solutions.

The emerging paradigm of Digital Twins (DT) (Section 3.1.4) can boost the capacities of the DSS. DTs assimilate data from sensors, Earth observation, etc. into the soil-crop models that power decision making. A new generation of DSS is enabled by the combination of real time monitoring plus the capabilities for forecasting, knowledge discovery, real life experimentation and “in silico” experimentation. Examples of fields, where DSS and FMIS have been or could be developed, include: crop management, soil management (e.g. on nitrogen balance), irrigation, pest prediction and control, different types of farming models (e.g. conventional, organic, agro-ecological, agroforestry, circular etc.), ecosystem management/regional management, biodiversity, machine/operations optimisation.

Little is known about the overall uptake of DSS and FMIS by farmers in Europe, the types of FMIS used by farmers, and the performance of FMIS.[54] DSS and FMIS have to differ between sub-sectors, crop- and livestock types, to provide tailored support to producers.

As DSSs scale into data-extensive, real-time monitoring systems, the goals of these systems become more challenging (e.g. in terms of information overload, system design, data collection). Furthermore, DSS designers are also interested in making these systems easier to access and user-friendly.

Some of the detected challenges are summarized: (i) simplification of graphical user interfaces to improve accessibility and usability; (ii) adaptation to uncertainty and dynamic factors to provide accurate decision supports; (ii) adopting knowledge from experienced experts to adjust inappropriate recommendations; (iv) performing analysis on historical information to enhance the quality of decision supports; and (v) enabling prediction and forecast to prepare farmers for future decision-making activities.

AI applications, such as Machine Learning (ML), that digitally drive a series of agricultural operational services can be tested in pilot projects before being employed under real world conditions. Different levels of human operator engagement in smart data-driven decision-making will be considered. From feeding inputs to fully automated decisions of systems/robots operated on the field, such as with irrigation systems[55], to mere decision support systems for the human operator to implement the recommendations, including input to semi-automated decisions of robots in the field, requiring authorization by the human operator to enact. These activities will be carries out under consideration of the evolving legislation on AI.

The information from different data sources, Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs), IoT sensing systems placed in the field, climate observation and weather forecast data from public stations, and satellite images, is automatically collected and integrated in an FMIS, providing warnings of climatic conditions, or risk of pest and disease infestations.

This would be the single access point for the farmer to all the information of interest in the field. Additionally, it would integrate direct connection mechanisms with automated systems, such as AI algorithms or robotics solutions, allowing activation of irrigation, use of robots to inspect risk areas or apply preventive treatments, and creating added value by generating thematic maps, for example.

The general trend in sustainable agricultural systems is towards more complex and technology-based crop management, with increasing regulation and supervision on the use of fertilizers, pesticides and other chemicals (Rossi et al., 2014). An AgriDSS needs to be developed by integrating multiple scientific expertise, approaches and disciplines, including SSH (Hanks et al., 2008; Lundström and Lindblom, 2018; Rogers, 2012)

In the EU, the adoption of AgriDSS's so far was constrained by several factors including the lack of motivation, skills and knowledge, infrastructural issues, resistance to the use of business intelligent devices and fear of losing power over information (Ain et al., 2019). This leads a to a consequent "implementation problem".

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[54] Figures are available for the subscriptions to larger providers of FMIS frequently directly or indirectly linked to machinery or agro-chemical companies. Subscription figures, however, do not reveal, in how far FMIS are used and how they perform. Figures for the uptake of digital and data technologies in agriculture are generally rare and information has frequently been gathered at case study level (see e.g. https://h2020-demeter.eu/tag/barriers/).

[55] Note, that the partnership will generate input to DSS and DSS linked to robots, but it will not develop robots as such.

Over the past 30 years, scientific and technological research have produced a large number of agricultural Decision Support Systems (AgriDSS), but most of them have not met the expectations of the developers in being adopted by farmers and advisors, and are therefore under-exploited (Aubert et al., 2012, Eastwood et al., 2012; Korte et al., 2013; Rossi et al., 2014; Van Meensel et al., 2012). The needs of the end-users need to be central in the development of a DSS (Lindblom et al., 2017).

There are currently many DSS on the market using satellite data, sensors in the field and agronomic models, but the main problem is that many European farmers, (especially small and medium-sized farmers), express concern about the use of these tools. In fact, even after a map has been produced as a spatial representation of all the relevant factors, the operational passage in the field is not trivial, as it is necessary to have interoperable systems and machines capable of implementing the prescriptions emerging from these maps into effective actions. Another problem is that the DSS currently on the market are not often certified and validated by recognised institutions.

Although most people can see the benefits of using a more precise approach to farming, the tools provided by precision farming and other information technologies have not yet moved into mainstream agricultural management. The increased complexity of the systems inhibits easy adoption and makes cost-benefit analysis uncertain.

Practical knowledge of farmers' decision making process is an important element in the transition to sustainability. A success factor can be, for example, the level of involvement and trust in the farmers' experience (Ljung et al., 2014), because in the last two decades it has been widely accepted that participatory approaches to sustainable management can bring additional benefits (Thorburn et al., 2011; Van Meensel et al., 2012). Sustainable agriculture crucially depends on sustainable ICT systems and 'user-centered design' methodologies.

DSS and FMIS – Use beyond production decisions

The development of DSS are based on multiple factors: access to large amounts of data placed in databases that are continuously updated with new data from local and remote sensor systems, as well as their processing with mathematical-statistical techniques developed in the field of artificial intelligence studies, integrated with agronomic research. Smart farming is – as explained above - very data intensive and even if historically linked with site-specific activities and management, it is not limited to site-specific farming (Xu et al., 2018). The use of techniques and methods that constitute smart farming can provide a wealth of information and tools to handle and apply information properly for any type of farm in any region. This information-driven approach can not only be used to help improve crop management strategies, but also e.g. for the proof of compliance through documentation, and thus lead to a reduction of administrative burden through Business-to-Government (B2G) data sharing. The introduction of advanced ICT technologies into agriculture will also bring significant progress in all efforts for performance-oriented payments within agro-environmental programs and related efforts to enforce environmentally sound systems in land use within the EU (Kernecker et al., 2021).

In many cases, DSS try to provide the farmer and the advisors with a multi-dimensional description of the state of the field based on the greatest amount of information (Debauche et al., 2020; Rose et al., 2016). In the perspective of a purposeful and aware agricultural practice, aiming to contain its ecological footprint and to enhance its profitability and compliance with regulations, FMIS can provide solutions able to automate the identification and registration of all mechanized activities carried out in the company. Such an IT framework has the potential to support decisions in every management area of the farm.

For instance, from the point of view of consumers an online farm portal, should ideally describe the history of the farm, information about the expertise and experience of the producers, farm location, climatic and soil conditions and, last but not the least, adopted farming practices.

There is increasing demand for information on the production processes, both from the perspective of the value-added chains, e.g. with regard to traceability[56], (Carli et al., 2014) and from regional stakeholders in order to fulfil the multifunctional objectives of farming. An important prerequisite for farmers to comply with all these different demands is to easily find sufficient and timely information available for timely site-specific decision making or providing documentary evidence of their practice. The rapid development of ICT's, new sensors, AI facilities as well as the vast potentials for providing geo-referenced data (remote-sensing, on-line sensors, public databases etc.) potentially enables farmers to access new and high-quality specific information to support decision making or process documentation (Navarro et al., 2020, Poonia et al., 2019). With automatic data acquisition and handling in an on-farm management information system, farmers can be seen to comply with a rapidly growing demand of standards in the management of production processes. Smart farming applications today involve planning targeted interventions with machines, able to accurately transfer directly the prescriptions to the field crops (D'Antonio et al., 2020). Automatic and geo-referenced driving of tractors with satellite correction (RTK) is fundamental in this context. The automatic driving technologies make it possible to read and transmit geo-referenced maps in isobuses that refer to field crop treatments.

R&I activities

There is a necessity to carry out specific research and innovation activities following a Multi-actor approach involving at least farmers and farm advisors, following a technology-open approach, and where applicable, applying the results of R&I activities presented in Section 3.1, addressing the identified challenges and gaps, in particular:

1. Develop data layers, algorithms and data-based solutions founded on multiple sources, including private and public ones, allowing for innovative FMIS services that build on (Europe-wide) datasets to close market gaps in the provision of decision-making support.[57] [58]
2. Extrapolate farm-generated sensor data, capitalizing it for a wider farming community through combination with satellite (and other) data and the application of data technologies (see Footnote 10).
3. Explore the opportunities from new satellite imagery and new ground sensors (including substrate analysis) for data-based solutions as input to DSS and FMIS.
4. Take stock of existing FMIS and their uptake by farmers and analyse their strengths and weaknesses in supporting sustainable agricultural production and compliance and performance documentation (in B2G settings) as well as of gaps in service provision (including in low-cost

[56] As outlined in the Partnership document, the partnership Agriculture of Data does not envision to cover the whole food systems and aspects of traceability in the value chain, which will be covered under other EU-funded initiatives, including under Horizon Europe Cluster 6 and the DEP.

[57] Decision-making support tools frequently require crop- and production type specific approaches; on which crops, sub-sectors and production approaches it will be focussed will be decided in the course of implementing the partnership, in the decision, the results of the assessment of market gaps will be considered (see also Section 4.1.1).

[58] This R&I activity will be carried out under consideration of results of R&I activities on data valuation outlined in Section 3.1.

solutions) to augment the sustainability of agricultural production, enhance competitiveness and working conditions under consideration of G2B data sharing opportunities.

5. Enhance interoperability and switchability options for FMIS users.
6. Develop innovative multi-criteria simulation modules for transparent decision-making support, allowing for priority and objective setting by the end-user (e.g. farmer) under consideration of the existing FMIS landscape. Results should allow e.g. testing of different scenarios and different parameters (e.g. economic, environmental and social impacts) and include innovative approaches to overcome the complexity barrier of data platforms and enhance trust in data analytics by fostering user-friendliness.
7. Develop innovative ways (e.g. public incentives, open-data-services, research infrastructures) to increase the profit of using data technologies for DSS and FMIS applications (see also Section 4.3).
8. Develop business models which clearly demonstrate the value of services in ROI terms e.g. through apps that easily calculate savings in operating costs (e.g. water, fertilizer, pesticide) and environmental impacts on short-, medium- and long-term. The added value of farm data sharing is to be reflected.

3.2.2 Farm modelling systems

Crop growth is a temporally highly dynamic process that requires management decisions throughout a growing cycle, which are based on the assessment and analysis of current conditions, past conditions and predicted conditions. All decisions require up-to-date information on crop and/or agri-environmental conditions. Other parameters, such as market information for inputs and outputs, may be considered as well. Since measures and treatments are usually planned in accordance with the short-term weather forecast, the actual treatments take place at very short notice. Almost real-time transfer of the EO data into farm forecasting models is therefore fundamental. Farm modelling is instrumental to link the different temporal dimensions under consideration of various parameters and to provide inputs to support decision-making to farmers and advisory services. Farm modelling also facilitates the testing of policy scenarios.

While farm modelling is an established means, there is a large and untapped potential in developing (precision) agriculture with new tools, forecasting, for example

- spatial and temporal optimal irrigation;
- protein content in cereals and nutrient needs to target yield and quality goals and at the same time, to reduce loss of nutrients to the environment and to enable the farmers to fertilize more optimally;
- optimal timing of the application of pesticides.

As discussed in Sections 1.7 and 3.2.4, to improve the use of EO data for precision applications, e.g. in the fields of irrigation, fertilization and pesticide application, collection of high-quality reference data is needed. This will include gathering field-scale and sub-parcel data (e.g. generated through precision farming applications), from farming practices. The generation of long-term time series of data for certain parameters will be essential to strengthen farm modelling capacities, as well as results of monitoring the impact of certain practices, such as crop rotation, or agri-environmental conditions, such as soil quality.

Further improvement of modelling capacities and subsequently of decision algorithms or decision support systems will require the use of machine learning or combined process-based and data-driven approaches; it may also be achieved through building on digital twins (see Section 3.1.4). In addition, technologies for the digitalisation of business processes, decision rules and regulations, such as business process management and decision modelling notations, and formal notations for executable law can be considered. Furthermore, novel approaches towards modelling, such as hybrid & multi-scale modelling, which takes into account local characteristics and local/"traditional" knowledge, could be considered.

The following examples are some cases where innovative data-based solutions addressing end-user needs could be developed through the enhancement of input data and the application of advanced data technologies.

Protein prediction There is a need to further develop tools for (precision) farming e.g., development of models to predict protein content in cereals. This is essential to develop as it will enable farmers to fertilize more optimally according to the desired protein content at field level.

Yield prediction: Integration of yield prediction models into models for prediction of fertilizer needs and other aspects that influence the yield. More accurate yield predictions will improve farming strategies, e.g. fertilization, and result in a reduced loss of nutrients to the aquatic environment.

Degree day model: When implemented in a web-based management tool, it could be used to show the farmer the time period when the crop in a field will benefit from pesticide application and when it will have no effect.

Precise nitrogen application: Data-based solutions for the development and use of high-resolution nitrogen retention maps to be used in field and fertilization planning can reduce the load of nitrogen to the aquatic environment.

In addition, farm modelling can provide assistance to policy-makers, for instance, when developing the design of agri-environmental measures.

The further improvement of this model type, will require use of imagery of higher resolution, machine learning or combined process-based and data-driven approaches. Moreover, integration and use of all satellite images and satellite bands from sowing until the prediction date in the models will be important. The following activities should also be developed/considered:

R&I activities

There is a necessity to carry out specific research and innovation activities following a Multi-actor approach to address above outlined challenges and generate input to other work stands of the partnership.

1. Take stock of existing modelling approaches and assess their strengths and weaknesses and suitability for the work of the partnership
2. Enhance existing and develop novel forecasting and prediction approaches/methodologies (e.g. on extreme weather events, pest, yield) suitable for cross-border usages under consideration of strengthened data capacities.
3. Enhance existing and develop novel modelling approaches to estimate the environmental impacts of agricultural production following "whole farm" and "landscape" approaches to account e.g. for the effects of agro-ecological approaches and farm structures.

4. Develop novel farm modelling approaches extending, where possible, existing ones (e.g. phenology, pest, yield, protein content, water, nutritional status) for the farmer to use for an optimal farming practice based on real-life testing and trial farms, eventually in cooperation with existing and evolving living labs.
5. Based on the novel data-based solutions available, enhance capacities to use farm modelling in support of designing agri-environmental measures, responding to current and predicted policy needs.

3.2.3 Assessment of farm performance

Benchmarking can help farmers to improve their productivity and sustainability along various indicators and compare their farm's performance with that of others, to learn from others and to identify actions to take.

Benchmarking is based on data availability, technical exchange and data sharing. In about 80% of EU Member States, benchmarks are regularly discussed individually between a farmer and his or her advisor or in a peer group of farmers[59]

Improving the technical capacity to collect, exchange and share data at farm level in a transparent way with the help of systems (see Sections 3.1 and 4.2) will encourage greater participation in benchmarking, increase the data set availability and thus improve the accuracy and usefulness of the benchmarking.

To carry out benchmarking it is necessary to define parameters, and to set those parameters against a target. Deciding on targets for a resilient farm system and establishing baselines accounting for the diversity of farms in Europe will therefore be a key activity to be able to create calculable parameters. Moreover, the discussion around targets is influenced by personal and political priorities, which have to be transparently reflected in any benchmarking system. A benchmarking system is ideally responsive, in the sense that it allows the development of targets for different ambitions and the discussion of trade-offs.

To develop KPI's or parameters for benchmarking there is a need to identify what to monitor, based on which, it be possible to define what parameters need to be measured. Models and tools can then be developed for aggregating and expressing compiled data, and - very importantly - look for gaps in data collection. Therefore, there is a need to clarify which identified targets can be transferred into parameters and how the data sources can be translated into datasets and where gaps exist.

Finally, since the landscape of assessment of farm performances is ever-changing and under debate, with many different opinions, there is a need to focus on a long-term funding and maintenance strategy (see Section 4.1).

R&I activities

There is a necessity to carry out specific research and innovation activities following a Multi-actor approach addressing the identified challenges and gaps. In particular:

1. Identify thematic areas where farm metrics are needed and which can be well addressed through novel data-based solutions in the scope of the partnership on both farm/production

[59] https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-factsheet-benchmarking.

level, considering the environmental and socio-economic parameters for monitoring transformation towards increased resilience.

2. Develop ambitious farm performance targets, taking into account economic, environmental and social aspects, including creating a baseline and selecting parameters to assess and monitor. An example could be the assessment of farm performance in terms of sustainability, including carbon emissions and storage, accounting for the diversity of farm types across Europe and for different policy objectives.
3. Develop approaches for displaying farm performance and discussing trade-offs, following a Multi-Criteria Decision analysis (MCDA)-based approach and presenting the underlying data in a transparent way in order to foster the use of data-technology based farm-level KPI's.
4. Identify technical and social obstacles in data collection and data exchange on-farms and issues that hamper benchmarking between farms (see also Section 3.1.3).
5. Identify and possibly develop a long-term funding and maintenance strategy for the indicators to ensure sustainability (see Section 4.1).

3.2.4 Data-based solutions for addressing environmental challenges, incl. climate change mitigation, biodiversity, water, and soil

Strategic research goals for tools for environmental protection and climate mitigation in agriculture, include the integration of digital monitoring technologies and capacities to measure, document and mitigate GHG from different agricultural production systems, varying environmental and climatic conditions and available agronomic tools like biochar, nitrifications inhibitors, reduced tillage etc. A particular goal is to enhance the integration of data from embedded and non-embedded agricultural technologies to effectively address the sustainable management of the water, carbon and nitrogen cycling in agro-ecosystems. The goals will boost climate mitigation solutions for farmers, private and public organisations, providing tailored, easily accessible end-user-oriented platforms offering data-based solutions.

Climate is mainly affected by the agricultural sector through GHG emissions. In order to reduce the contribution to climate change by the agricultural sector, the sector needs to reduce its total GHG emissions. This can be done both by reducing the GHG emissions from livestock and by increasing the GHG uptake through e.g. carbon sequestration in the fields.

Remote sensing, via satellites, drones and in-situ measurements can be used to estimate total GHG emissions, including both emission and uptake (Perugini et al., 2021)

The national and international carbon budget is presently calculated by the use of inventory data. However, in 2006 and 2019 the Intergovernmental Panel on Climate Change (IPCC) recommended the national states to use independent information such as satellite observations and inverse modelling to validate their emissions (IPCC, 2006; IPCC, 2019). So far no national states have fully incorporated this recommendation.

Another way by which the agricultural sector affects climate is through changes to the Earth's albedo (fraction of light that is reflected by the Earth). Using EO it is possible to measure the albedo of different land cover types and thus aid albedo management.

The concentration of intensive farming activities in the most favourable areas and the abandonment of marginal and mountain areas increase environmental risks (e.g. groundwater depletion and diffused freshwater pollution, wildfires, landslides, avalanches etc). These diverging trends together contribute to a definite risk of biodiversity loss, increased land degradation and deterioration of water resources.

Groundwater depletion, salinization, increased crop water requirements and glacier melting due to global warming, coupled with diffuse freshwater pollution of agricultural origin are all issues generated by a similar combination of economic and climate drivers contributing to the emission of GHGs from agriculture. In many areas of Europe, agricultural water use represents over 2/3 of the total freshwater consumption.

Challenges

In this context, data technologies in agriculture can provide an invaluable contribution to address the following key challenges:

- Decouple the need for increased productivity from net GHG agricultural emissions in agriculture (including soil C sequestration), by providing end-users new data-based solutions;
- Identify tailored win-win options on short-, medium- and long-term for a wide range of European crop and livestock faming systems able to couple climate mitigation with soil, water and biodiversity conservation;
- Increase environmental and climate mitigation performance of agriculture through the provision of data-based solutions, not only through fostering efficiency gains through precision applications, but also through adjustments to production structures and patterns (e.g. in the field of crop rotation).

R&I activities

There is a necessity to carry out specific research and innovation activities following a Multi-actor approach addressing the identified challenges and gaps. In particular:

1. Based on the mapping of existing decision-making support portfolio available to farmers and the extent to which environmental concerns are taken into consideration (see Section 3.2.1), assess the particular needs in the provision of data-based solutions for decision-making support to increase farms' environmental performance.
2. Develop innovative data-based solutions to support the design (e.g. through prescription maps) and the management (e.g. irrigation, fertilization) of precision cropping systems (including grassland) by taking into consideration short- and long-term production approaches and effects, leaching and GHG emission forecast maps and field variability in terms of productivity and product quality, by integrating high-resolution remotely sensed data, proximal smart sensors and crop models, as well as market data for inputs, such as energy and fertilisers, and outputs.
3. Develop innovative, data-based solutions and software to support precision farming techniques to bridge crop and pasture site-specific yield gaps (e.g. based on e.g. high-resolution satellite data, novel satellite and sensor data); this could be achieved e.g. through precision integrated weed, pest and disease management or grazing management contributing to stabilize crop and pasture yields across years.
4. Develop innovative, integrated (e.g. satellite + IoT) data-based solutions to support the identification of agricultural areas (at farm and field scale) most suitable to biodiversity conservation and/or pollinators' feeding with respect to productive areas.
5. Develop novel data-based solutions and software to couple sensors for the continuous monitoring of soil, soil moisture, and soil water parameters (e.g. nitrate concentration, salinity) to support

water, fertilization and pest and disease management at sub-parcel level under consideration of overall farm-structures, using the potential of such solutions to also serve reporting and control purposes in B2G settings.

6. Develop data-based services based on data from robot, autonomous vehicles and IoT technologies equipped with sensors and AI-based applications to support the geo-referenced 24/7 early detection of plant pests and diseases or weeds to minimize the use of agro-chemicals, while increasing their effectiveness either for crops and the open fields.
7. Enhance research infrastructures based on long-term observations and long-term agronomic experiments for the assessment of the impact of cropping systems on soil health and soil carbon dynamics and the improvement of soil C model forecast capacity, including the design and recording of carbon farming schemes.

3.2.5 Strategies and technologies for climate change adaptation in the agricultural sector

While agricultural sector is one of the major contributors to climate change, it is also one that is most susceptible. Climate change adaptation is a crucial and urgent requirement for agriculture to meet the growing food demands in spite of the changing climatic conditions which have a direct impact on crop growth, pest and disease infestation and hence agricultural productivity.

Approaches for adapting to climate change

The impact of climate pressures is highly variable and depends on the interaction of site-specific biophysical conditions and the typology of farming systems.

While some specific types of farming systems could even benefit from climate change locally, most scenarios indicate that overall, the future climate will generate negative impacts at country and regional scale across Europe, particularly in relation to the increased frequency of extreme events (drought, floods, heatwaves, wildfires etc.) combined with a rapid diffusion of new pests and diseases (EEA, 2016). Increasing climate pressures challenge some key EU agricultural systems that could result into a loss of food sovereignty and security in the EU. The polarization of the production of commodities in few large districts worldwide (e.g. more than 75% of the total soybean production is generated by three countries), generated by global market drivers and aggressive agricultural and trade policies at national level, raises additional concern about EU food security, as many European agri-food chains are totally dependent on external sources for raw materials (e.g. plant protein for milk production). Exposure of these regions to frequent climate extremes could result in a world food crisis. The changing climate also affects agriculture yields and therefore the agriculture sector needs to adapt to these changes in the future. To ensure food security in the future, a more efficient management system is thus needed that can ensure that crops are changed in accordance with the changing climate as new crops become more suitable.

Differently from climate change mitigation, which is related to the reduction of GHG emissions, climate adaptation in agriculture can be understood in different ways and through different actions, depending on the specific socio-ecological contexts (Dono et al., 2016; Nguyen et al., 2016). A framework for developing effective climate adaptation capacities includes the ability of stakeholders to learn to perceive ongoing and future changes, rather than only being trained to implement adaptation approaches (Nguyen et al., 2014), and to design effective actions enabling them to keep their business within the boundaries of an adaptive pathway (Wise et al., 2014). The forecast and the assessment of the expected impact chains through the quantification of local vulnerabilities, risks, uncertainties and risk mitigation actions is a necessary pre-condition for developing resilient farming systems.

The European Union and some Member States have already adopted adaptation strategies to climate change, which represent a fundamental framework for designing effective actions in agricultural systems. A key challenge is to develop adaptive pathways that can contribute at the same time to boost rural development and possibly mitigate GHG emissions, thus achieving a triple-win strategy.

Digital technologies can effectively contribute to support adaptation strategies in many ways.

Warmer air temperatures have already affected the length of the growing season over large parts of Europe. Flowering and harvest for cereal crops are now happening several days earlier in the season, generating a mosaic of impacts on crop production, depending on many factors. These changes are expected to continue in many regions. In general, in northern Europe agricultural productivity is expected to increase due to a longer growing season and an extension of the frost-free period. Warmer temperatures and longer growing seasons might also allow new crops to be cultivated. However, extreme rainfall and drought events are also expected with higher frequency (EEA, 2016). In southern Europe, however, extreme heat events and longer droughts, leading to reduced water availability, are expected to impact on crop productivity. Crop yield variability is also expected to increase from year to year due to extreme weather events and other factors such as the emergence of new pests and diseases. In some areas of the Mediterranean region, due to extreme heat and water stress in the summer, some summer crops might disappear or require new varieties to be developed. In other EU areas, such as western France and south-eastern Europe, increased crop water requirements and yield reductions are expected due to warmer and dry summers. Changes in temperatures and growing seasons might also affect the proliferation and the spreading of new species of insects, invasive weeds, or diseases, all of which might in turn affect crop yields. The expected yield losses can be partially offset only by an incremental adaptation of cropping systems, such as changing crop rotations or agro-techniques (e.g. adjusting sowing dates to the new temperature and rainfall patterns, and using new crop varieties better suited to the new conditions).

The incoming CAP for 2023-27 requires Member States to develop a country-level Strategic Adaptation Plan including specific actions, allocation of funds and assessment protocols that will then be implemented by competent authorities. This approach is in line with current knowledge on ways to design and evaluate effective and efficient measures to promote the environmental and social sustainability of farming systems. Many studies conclude that it is urgent to increase funding to mitigate the negative effects of climate change on agriculture and biodiversity (Pe'er et al., 2021, Riberio et al., 2018).

R&I activities

There is a necessity to carry out specific research and innovation activities following a Multi-actor approach addressing the identified challenges and gaps. In particular:

1. Develop data-based solutions for livestock and cropping systems to adjust production to become more resilient towards climate change on the long-, medium-, and short term under consideration of the overall sustainability performance and competitiveness of farms, climate adaptation, mitigation and sustainable development.[60]

[60] In many cases, for the development of data-based solutions, i twill not be sufficient to differ only between cropping and livestock systems, but also between sub-sectors and/ or crop- and livestock types.

2. Building on lessons from effects of climate change in other biogeographic regions, taking into account the concept of zonation, long-term time series agri-environmental data (including yield data, phenology data), and climate prediction models, develop decision support tools supporting farmers to adjust production to prevent negative effects of climate change on agricultural production.
3. Enhance high-throughput phenotyping technologies and research infrastructures for climate adaptation of crop systems (e.g. drought resistance, salinity, waterlogging).
4. Develop innovative transformational strategic approaches for tailored data-based decision support systems for resilient agriculture for short-, medium-, and long-term time horizons. These should go beyond resource use efficiency, and address biodiversity conservation, soil protection and climate change adaptation, building on (novel) approaches to assess the short-, medium-, and long-term impacts of climate change.

3.3 Data-based solutions for policy-making

In recent years, the impacts of agriculture on the environment, and the importance of the sector for food security have received increasing public attention. European and national policies have become more sustainability-oriented, e.g. fostering ambitions laid under the Green Deal and the SDGs. At the same time, policies, the Common Agricultural Policy (CAP) in particular, have become more performance oriented, in the sense that the contribution of policies, programmes, and subsidies to sustainability ambitions have to be demonstrated more consistently.

A key challenge with performance assessment is the development of indicators that reflect effects of policies on the one hand, but do not entail a significant increase in administrative burdens for the administration and beneficiaries on the other.

Throughout the policy cycle, actions benefit from robust policy monitoring data, allowing for evidence-based policy formation and design, active steering of the roll-out of measures in the implementation phase as well as input to performance assessment and evaluation. In this context agri-environmental monitoring data is not only of interest for agricultural policies but also for environmental and climate policies. It is important to ensure that a high quality data foundation is available to policy makers and monitoring agencies. Biophysical data is of particular importance, yet this is seldom readily available. Improvements in data quality and availability of policy-effects, especially in the fields of CO_2, nitrogen and phosphor emissions, and biodiversity are essential to adequately designed agricultural policies resulting in cost-effective environmental and climate improvements.[61] The impact assessment for the CAP 2020[62] (post 2022) has revealed that the evidence base underpinning policy design can still be strengthened.

In policy formation, accounting for “competing objectives” and/or “contradictory objectives” (e.g. achieving sustainability gains while ensuring food security), present a challenge for policy-makers. To approach this, evidence of the effects from past interventions is an asset.

Overall, one approach to strengthen policy performance assessment capacities, is to increase the information power of data bases and analytical capabilities to assess agri-environmental conditions as

[61] The work of planned under the partnership can contribute to the design and evaluation of several types of policy measures in support of sustainable agriculture, including also e.g. risk management measures.
[62] EUR-Lex - 52018SC0301 - EN - EUR-Lex (europa.eu)

well as production patterns and their effects (see also Section 3.2.2 on farm modelling). In its special report (16/2022) "Data in the Common Agricultural Policy – Unrealised potential of big data for policy evaluations"[63], the European Court of Auditors identified barriers to making best use of collected data for policy making. One example is that a lack of standardisation results in limitations to data aggregation and reduces data availability and usability. The Court recommendations include the improved use of disaggregated data from Member States as well as the upscaling of (precision) farming data generated on farms.

Utilizing farming data at a larger scale and in a more systematic way, combining it with satellite data and data technologies to scale it up, appears to be a game changer. It can increase the information power of performance assessment approaches compared with the status quo. This is also reflected in the Horizon Europe Work Programme 2021/22.[64]

While responsibilities for monitoring and evaluation lie to a certain extent at national level, it would be ideal to develop and use common approaches across Europe to make policy efforts comparable, achieving the critical mass of data for applying data technologies and for achieving scale effects and efficiency gains in monitoring efforts.

In the context of the CAP, next to performance monitoring, compliance monitoring forms a key task in policy implementation. In other words, next to assessing the medium-and long-term impacts of policies and generating information for the policy formation process, there is a need to ensure appropriate spending of funds.[65] During the past CAP, many Member States voluntarily opted to change their approach of compliance assessment by gradually replacing sample-based "on-the-spot controls" (OTSC) by automated analyses of satellite data covering full populations (i.e., by "checks by monitoring"). Satellite-based monitoring allowed Paying agencies of the CAP to generate indicators assessing whether farmers are, or are not, complying with area-based eligibility conditions without undertaking time-consuming OTSC. Yet, the 10m spatial resolution of current Sentinel satellites is not of sufficiently fine to address detailed area-related eligibility conditions.[66]

For the new CAP post 2022, Member States have to set up an Area Monitoring System (AMS) to observe, track and assess agricultural activity on claimed parcels in order to feed indicators in the national annual performance report reliably. The AMS can only provide a conclusive result on monitorable eligibility conditions. The mandatory use of geotagged photos from 2025 onwards will substantially expand the set of covered eligibility conditions with respect to the last CAP's "checks by monitoring" approach. Non-monitorable eligibility conditions have to be controlled by other means, whereby some decisions on assessment approaches remain with the Member States. The AMS

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[63] Special report 16/2022: Data in the Common Agricultural Policy – Unrealised potential of big data for policy evaluations (europa.eu)

[64] Projects, which will be funded by the call "Upscaling (real-time) sensor data for EU-wide monitoring of production and agri-environmental condition HORIZON-CL6-2022-GOVERNANCE-01-11" are expected to directly link up to the Partnership Agriculture of Data.

[65] The CAP is distributing vast amount of funds to the farmers all over Europe, and therefore, it also needs an assurance that the payments are being done on a correct set of terms and that the farmers are not bending CAP rules.

[66] The new approach of checks by monitoring brings potential benefits for the farmer; and Member States can implement it in a way serving administrative and beneficiaries interests, and ambition, which is also fostered by the partnership: the short revisit times of the Sentinel satellites permits a continuous monitoring, thus allowing Paying Agencies to warn farmers of impending deadlines for not-yet-executed farming activities or to alert them of the need to amend their aid applications prior to the formal deadline for submission.

approach will generate datasets that are comprehensive and thus can also be used also for other purposes in other contexts.

Overall, neither the farmers nor the administration is interested in increasing the bureaucracy, but are interested in real burden reduction.

As outlined in Section 1.7, different data sources relevant to agriculture are becoming more and more readily available, yet without the ability to provide definite conclusions on the impacts and/or production effectiveness of agriculture[67]. This is exemplified by the freely available Sentinel satellite imagery, which does not provide the highest resolution of satellite imagery. In fact, even the best available satellite imagery might not deliver concrete answers, but only indications for the questions posed by policy-makers and the organisations administrating the policies. On the other hand, very detailed data on production approaches is available for some farms due to the use of digital technologies. The solution to these conundrums is the combination of different data sources, the creation of big data sets, and the increased use of data analytics allowing, for example, extrapolation of precision farming by combining it with Europe-wide reference data. Thereby, data sets, information and knowledge of sufficiently high quality and resolution could be created for policy performance and compliance (for farmers – see Section 3.2.1).

For instance, to enhance policy performance assessment capacities and reduce reporting obligations for farmers and the administration, while ensuring a common approach across countries, Europe-wide data sets could be generated through AI-based interpretation of satellite data, based on training with precision farming data.

An additional element in CAP implementation benefitting from the capitalisation of data through data technologies, is the FaST (Farm Sustainability Tool). It supports farmers' decisions in the use of nutrients (similar to FMIS introduced in Section 3.1.3) and aims to take advantage of Europe's space capabilities – Copernicus and Galileo - to help farmers sustainably manage their holdings. FaST will ensure that farmers will be supported digitally in their farm management and compliance requirements regarding nutrient management and further sustainability objectives. Member States are obliged to introduce the FaST or to provide tools that fulfil a similar function.

Development of long-term strategies for policy-interventions requires the continuous monitoring of basic agri-environmental conditions and the assessment of trends. Data-based solutions are not meant to be developed and implemented in response to just one specific funding period. There is naturally a delay between implementation and assessment of specific impacts which cannot be covered within one funding period. At the same time, next to the long-term perspective, for active policy steering and for instance (market) interventions initiated on an ad-hoc basis, and ensuring food security, yield forecasts (see Section 3.2.2) are essential.[68]

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[67] A stocktaking exercise of (interim) results of EU-funded R&I projects relevant to monitoring and evaluation of the CAP has been carried out by the European Evaluation Helpdesk, and challenges and opportunities been summed up Evaluation Knowledge Bank | The European Network for Rural Development (ENRD) (europa.eu)

[68] An overview of (EO-based) modelling and prediction tools provided by the Joint Research Centre provides the MARS bulleting (see Monitoring Agricultural ResourceS (MARS) (europa.eu))

Challenges

- Developing and applying monitoring approaches to assess the performance of policies following a common approach without generating large administrative burden for the administration and beneficiaries;
- Having timely data allowing causal links to be drawn between patterns of agricultural practices and production, and – where applicable - interventions, and environmental impacts;
- Having consistent, long-term time series of data on agri-environmental conditions of sufficient granularity and/ orresolution;
- Enhancing the reuse and reusability of datasets relevant for policy monitoring and evaluation in a systematic way across administrative levels;
- Developing and applying data-technology based approaches for "ongoing monitoring" of CAP implementation, which are compliant with the legal requirements;
- Differences in the level of uptake of digital and data technologies across countries in the administration and among beneficiaries (including farmers).

Overall, there is a clear need to strengthen policy monitoring capacities by better using the potential of data technologies to facilitate the implementation of the CAP; to generate evidence for the CAP post 2027; and to develop proposals for smart and burdenless monitoring and implementation approaches for the future CAP and other policies[69] benefitting from "big data" and the synergetic use of public and private data.

R&I activities

Against this background, activities carried out by the partnership to develop and provide innovative data-based solutions for policy monitoring and evaluation, to generate information, knowledge and services to be used along the policy cycle in agricultural and other policies following a Multi-actor approach, considering the overall ambitions related to simplification and "Better regulation" (see Section 1) will include:

1. Identify data needs for the monitoring and evaluation in the scope of this partnership as well as for the implementation and development of current and future agricultural policies, considering a wide range of (indicative) agri-environmental parameters. Where applicable, data needs of related policy fields, such as environmental and climate policies, might be considered.
2. Take stock and compare existing indicators and approaches to monitor policy implementation and impacts and of the (practical) experiences gained with their application.
3. Develop innovative data-based solutions through the application of data technologies and supply and/or develop indicators that facilitate a common approach across Member States (and candidate countries) in assessing the performance of agricultural policies. This may include the generation of homogenous EU-/Europe-wide reference data sets, e.g. IACS-based reference data-sets and data-based solutions.[70]

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[69] For instance, data-based solutions considering B2G and G2B data sharing, may also consider provisions in the field of carbon farming or requirements resulting from the forthcoming legislation in the sustainable use of pesticides (see REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the sustainable use of plant protection products and amending Regulation (EU) 2021/2115), and requirements in the field of labelling of agro-chemical products and thus data from the agro-chemical sector.

[70] For the creation, of some types of reference data sets of EU- or European-wide outreach, key stepping stones might be the harmonisation of data types and achieving interoperability.

4. Develop innovative approaches to monitor agri-environmental conditions and the implementation of policy measures (including “good agri-environmental conditions” as part of conditionality under the CAP), and production patterns following a consistent approach in the medium- and long-term.
5. Develop approaches to extend the application of the Area Monitoring System (AMS) including for the assessment of more eligibility conditions through the use of new input data sources, the use of novel satellites and sensors and data analysis techniques, while acknowledging the opportunities of privately operated sensors and B2G data sharing.
6. Develop new methodologies to monitor policy performance and compliance building on public and private data and with the ambition to reduce or minimize administrative burdens.[71]
7. Develop proposals for data-based solutions supporting design, implementation, monitoring and evaluation of the future CAP, ensuring “baseline data” availability including MCDA (Multi-Criteria Decision Analysis) based applications.
8. Develop innovative data-based solutions supplementing Member States’ efforts in the provision of FaST services to farmers (see also Section 3.2.1).
9. Explore the opportunities from new satellite imagery and other sources, such as new ground sensors, drones and substrate analysis[72], for policy monitoring and implementation.[73]
10. Generate Europe-wide data-based solutions through the upscaling of (precision) farming data generated on farms. This could be done by combining it with other sources of data, e.g. satellite data, and will allow the data to be utilized at a much larger scale in a more systemic way.

[71] This could include, for instance, the development of (new) approaches for farmers to collect data on their activities (e.g. via their machinery use, animal data loggers), which at the same time satisfies their reporting obligations to national authorities e.g. in the context of CAP support.

[72] Here, it is assumed that for instance projects funded by the call HORIZON-CL6-2021-GOVERNANCE-01-21: Potential of drones as multi-purpose vehicle – risks and added values, will generate results, on which the partnership can build upon.

[73] The partnership will focus in exploiting the capabilities that will result from the future Copernicus expansion missions. For example, CHIME (Copernicus Hyperspectral Imaging Mission for the Environment), will support new and enhanced services for sustainable agricultural and biodiversity management, as well as soil property characterisation. LSTM (Copernicus Land Surface Temperature Monitoring) will provide observations of land-surface temperature and derived evapotranspiration expecting to improve sustainable agricultural productivity at field-scale in a world of increasing water scarcity and variability. ROSE-L (Copernicus L-band Synthetic Aperture Radar) will provide data to monitor subsidence and soil moisture and to discriminate crop types for precision farming and food security etc.

4 Horizontal/crosscutting activities

Some "horizontal or cross-cutting" activities to be carried out when implementing the SRIA will be related to several or all of the R&I activities and set a framework for the roll-out of the SRIA.

Additional horizontal/cross-cutting activities will be needed to increase the effectiveness of the SRIA activities through creating an enabling environment or initiating capacity building among partners, targeted end-users or multipliers. Some "horizontal & crosscutting activities" are of a systemic nature e.g. to ensure standards and quality.

In the following, the main horizontal activities in the fields of achieving synergies between public and private interests and efforts; data governance, standards and security; and ensuring end-user uptake and innovative management of results of the partnership are outlined.

4.1 Pushing forward the valorisation of synergies between public and private sectors

The partnership aims at supporting sustainable agricultural production and strengthening policy monitoring and evaluation capacities serving both public and private interests. It also aims to combine public and private efforts and achieve synergies between them. The partnership also aims to foster an active, effective and synergetic innovation ecosystem, including public and private organisations, such as research institutes and start-ups and businesses providing data-based solutions in the field of agriculture. These ambitions go far beyond achieving an "umbrella effect" of assessing relevant past and ongoing activities, interlinking initiatives and building upon R&I and study results.

At a conceptual level, the principle of serving both public and private interests will influence the decisions on which data sets will be generated by the partnership, as data sets of dual relevance might be given priority.

At an operational level, synergies can be achieved through business to government (B2G) and government to business (G2B) data sharing as well as through publicly funded facilitation of business to business (B2B) data sharing.

The ambition to make better use of business and governmental data for private and common good purposes is well founded in the European Strategy for Data (EC, 2019). More specifically for the agricultural sector, the unused potential business data for policy monitoring has been discussed by the European Court of Auditors (ECA, 2022), highlighting the need for action.

In the field of B2G data sharing, precision farming data is essential as reference data for the application of AI to the interpretation of satellite data (see Sections 3.1.4 and 3.3). Here, the partnership will develop and probe different implementation models for the (re)use of farm data for R&I purposes and the development of data-based solutions. These implementation models may include remuneration of data provision by farmers through the provision of advice and data-based solutions for decision support, as well as data donation schemes following the principles laid down in the Data Governance Act (COM/2020/767 final). There may also be scope for the extended application of the Code of Conduct of agricultural data sharing by contractual agreement to R&I organisations, as is already being investigated in Norway (See Sections 1.7, and 3.1.3)[74]. Currently, B2G data sharing in the field of

[74] Synergies between public and private interests in the handling of agricultural data can also be achieved in the facilitation of reporting obligations through digital technologies, e.g. in the field of the use of pesticides and fertilisers, which is not a

precision farming for R&I is probed in case studies, and the European-wide reference data for the efficient and effective application of data technologies is frequently missing[75]. The partnership will also observe and consider the development of the Common European Agricultural Data Space (Section 4.2.1), and see if the data sharing mechanisms developed for that data space may also serve the ambitions of the partnership[76].

In the field of G2B data sharing, different dimensions will be relevant in the implementation of the partnership. First and foremost, the publicly funded partnership will generate data sets and data-based solutions for the agricultural sector. This could be organised e.g. through the development of supplementary modules to FaST available to all farmers[77] avoiding digital divides (see Section 3.3).

Results of the partnership will also serve as input for the generation of subsequent data-based solutions through private actors with results of the partnership thus being further capitalised. This effect can currently be observed for the freely available satellite data: on the one hand, it serves as free input for basic data-based solutions for farmers and the administration, on the other hand, freely available satellite data forms a main input to the work of many businesses offering services to farmers.

In addition, as many public data sets are not available as a Europe-wide layer for R&I purposes, data sets held by countries will be made available and operationalised to achieve European-wide layers of reference data sets for the work of the partnership. One key example here, is the reuse of IACS data through the partnership (see Section 3.3).[78]

Overall, in comparison to many other R&I initiatives, this partnership benefits from the direct involvement of governmental organisations, which will facilitate the provision – and where needed the transformation – of public data sets, taking up results in policy-making, the upscaling of data-based solutions, and sustaining the provision of data services.

4.1.1 (R&I) Activities

1) Establish governance structures for the partnership involving representatives from the public and private domains, the latter including representatives of the agricultural sector as well as of businesses providing data-based solutions to the sector (see Partnership document).
2) Map data needs in the public and private domains as a basis for the prioritisation of data-based solutions to be generated by the partnership.

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central focal point of the partnership as it regards the development of innovative solutions. Technical solutions for such reporting mechanism have been developed e.g. within the Horizon2020 project DEMETER (https://h2020-demeter.eu/). Such reporting mechanism will be implemented at a regular basis starting from 2026, whereby digitalised transfer will not be mandatory for farmers (see forthcoming revised regulation on agricultural inputs and outputs (SAIO), see https://data.consilium.europa.eu/doc/document/ST-9974-2022-INIT/x/pdf).

[75] The use of precision farming from a number of farms for the application of data technologies for the interpretation of satellite data is already common practice for larger companies in the machinery and agro-chemical domains (see Section 3.2). Through the partnership, a level playing field for smaller companies providing data-based solutions might be achieved.

[76] As outlined in Section 4.2, the partnership may also inform the development of the Common European Agriculture Data Space by pointing to the potential of certain data flows and data re-use opportunities for the provision of innovative data-based solutions.

[77] As the FaST tool is mandatorily to be provided by Member States, in this case, the partnership would also serve as Technical Assistance to Member States in CAP implementation.

[78] In the context of making IACS data better accessible, the partnership can build upon e.g. achievements of Horizon 2020 projects, as well as on the results of a process launched by DG AGRI in 2017 in collaboration with other DGs to make IACS data (spatial and non-personal) more accessible and reusable in the context of INSPIRE Directive.

3) Continuously take stock, assess and – where applicable – interlink and/or build upon relevant projects and initiatives and their R&I results at European and national scale to achieve the envisaged "umbrella effect".[79]
4) Moderate the relevant innovation ecosystem to achieve an "umbrella effect" and develop a review mechanism to capitalise key results of R&I initiatives and foster excellence, while accounting for intellectual property and open science (see Section 4.3).
5) Develop data-based solutions through the application of data technologies, which can be used by the agricultural sector as well as by R&I organisations and businesses for further capitalisation of data.
6) Develop and probe scalable solutions of B2G data sharing to gain farm data from across Europe, particularly precision farming data, for the work of the partnership. These could include building on the Code of Conduct of agricultural data sharing by contractual agreement and data donation mechanisms established under the Data Governance Act as well as remuneration schemes entailing the provision of data services (see Section 4.2).
7) Generate Europe-wide data layers from public data, including national and regional assets, as input for the work of the partnership and of other public and private actors in the innovation ecosystem.

4.2 Providing technological, organizational and legal solutions for data governance, standards and security

A sustainable and competitive European Agriculture needs to have a distinct and resilient governance and technical framework for the handling of data. As the sharing and (re-)use of data in the private and public domains are essential to exploit the innovation potential of data, the creation of a favourable and enabling environment for data sharing is an asset. Sound data governance, privacy- and trade-secret-preserving data-sharing mechanisms, data security and quality standards are key factors influencing farmers' readiness to use data-based solutions and share data (see also Jouanjean et al., 2020) as well as governments' decision to (re-)use data for policy monitoring and evaluation purposes.

4.2.1 Data governance

While the development of digital agriculture means that farms are becoming a rich source of data that is automatically collected, the data in digital format is often still stored "natively". Thus, data aggregation and data analysis to develop valuable insights and to generate value from these data streams remains challenging from a farm perspective. Indeed, several private and public initiatives exist to generate big data sets and deploy data technologies to farm data. However, what is missing are sufficient tools, models, and a regime that would allow the seamless, transparent, and secure interoperation of existing agri-data infrastructures and platforms as well as the readiness to share data between parties. The latter is not only induced by insufficient data interoperability, but also by the missing state-of-the-art cybersecurity protection mechanisms and privacy enforcement technologies. Moreover, lack of clarity relating to questions of data ownership, access rights and the sharing of the value of data sets hampers data sharing.

[79] This activity may include the set-up of a searchable catalogue of use cases.

For the partnership it is relevant to take a closer look at B2B, B2G and G2B data sharing, considering the roles of farmers, the machinery sector, agro-chemical providers, farm advisors, providers of data services to farmers and the public administration (CAP paying agencies in particular).

B2B Data sharing: Key factors for data governance structures in agriculture are, among others, increased trust in data sharing; strengthened mechanisms to increase data availability and assistance to overcome technical obstacles to the re-use of data in agriculture. A first step towards agricultural data governance has been taken for the B2B sector with the establishment of the "**EU Code of Conduct on agricultural data sharing by contractual agreement**". However, discussions are ongoing whether this EU Code of Conduct, as a private soft law on a voluntary basis, is sufficient in itself to strike a balance of interests between the market players in the agricultural sector. The central causes of the lack of a balance of interests where data are regulated on the basis of private law are the fundamental asymmetries with regard to information and negotiation between farmers and providers. But companies need efficiency and legal security in handling contractual relationships which hardly permits negotiations with individual farmers.

Another potential risk of a missing data governance is the risk of data abuse by third parties which may cause disadvantages in competition. Overall, the lack of transparency as well as of legal security and balance with regard to the shaping of agricultural data rights, harm farmers' confidence in digital farming, thus reducing their acceptance of it. Another critical issue for farmers, and machinery companies alike is the risk of disclosing trade secrets and confidential data[80]. For the farmers, a trade secret, which could be disclosed through farm data sharing, are e.g. factors for a successful production.

Thus, data sharing regimes and solutions have to be developed to overcome the various problems encountered in the application of current laws and regulations on agricultural data sharing and use[81]. (See below)

B2G and G2B data sharing: In the fields of B2G and G2B data sharing there is no regime at EU or European level, comprehensively covering several types of agricultural data. Currently, many **reporting obligations** exist, e.g. in the context of CAP implementation (see also Section 3.3). Examples of specific types of G2B data sharing include FaST and the provision of High Value Data Sets. Additional B2G and/or G2B data sharing approaches exist in individual countries.

At EU level, cross-sectoral/horizontal activities as well as sector-specific actions have been launched to create an environment conducive to the sharing and (re-)use of data. The **European Strategy for Data** published in February 2020 aims to establish a Single Market for data, enabling data flow between countries and sectors and easy access and use of data based on a common understanding as well as regulations that respect European values. Following this strategy, the European Commission has launched a number of legal initiatives to create an environment that enables the sharing and reuse of data, including the Data Governance Act; an Implementing Act on High Value Data Sets; the proposal for the Data Act; and a proposal for a Horizontal Act of AI (see Section 2 and Table 1). Moreover, the roll-out of a portfolio of Common European Data Spaces, including the fields of agriculture and environment, has been announced.

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[80] For instance, with the GDPR (*Regulation (EU) 2016/679 of the European Parliament and of the Council*) rules for personal data treatment with regard to their protection have been established. It should be mentioned that not all categories of data collected in agriculture can be qualified as personal data, this meaning that they are related to identifiable natural person.

[81] For instance, one challenge specific to the agricultural sector, when apply cross-sectoral legislation, is the classification of data as it regards private, personal and business data.

With the **Data Governance Act** (DGA), the EU established a legal foundation and framework to facilitate data sharing within the EU. It follows a cross-sectoral approach and introduces specific instruments to facilitate data sharing. Of particular interest for the work of the AgData Partnership are the introduction of mechanisms for data altruism/data donation (e.g. for R&I purposes), as well as an approach to set-up trusted intermediaries for data sharing between different parties. Through the DGA a Data Innovation Board has also been set-up, which will – among others - provide advice on questions related to cross-sectoral data interoperability (see below).

The **Data Act** and the **Horizontal Act for AI**, are still negotiated among co-legislators. They follow a cross-sectoral approach as well. Elements of these legal initiatives of particular relevance to the partnership include the proposal for provisions of access rights between parties in IoT data sharing contexts and mechanisms for B2G data sharing in specific situations with the option to re-use that data for R&I purposes. Provision under the Horizontal Act on AI may potentially concern the agricultural administration and private entities providing data-based solutions in the field of agriculture and R&I.

The **development of the portfolio of Common European Data Spaces** is supported by a Data Support Centre, which has as one key task to achieve common approaches across sectoral data spaces, e.g. as it regards the use of common building blocks and data interoperability. The **Common European Agriculture Data Space** will be rolled out following a step-wise approach: A Coordination and Support Action (CSA), which has been launched in October 2022, is expected to develop a proposal for governance structures and a business model following a participatory approach. Tasks of the CSA also include taking stock of the experiences gained from the above-mentioned Code of Conduct of agricultural data sharing by contractual agreement. The CSA will be followed by an implementation action, to set-up the data space, building on the results of the CSA.

The AgData Partnership can build upon and supplement these initiatives, draw lessons learnt, contribute to their further development, and support the building of capacities in the sector to comply with new legal regimes. It aims to make effective use of the instruments by developing innovative solutions for implementing the instruments in the domain of agriculture.

For the partnership it will be essential to closely coordinate with the actions/projects working on the roll-out of the Common European Agriculture Data Space[82]. On the one hand, results of the partnership can inform the development of the data space and they may highlight options for ways in which the data space could be used to serve innovative data-based solutions. On the other hand, the partnership may also draw on data which will be made available through the data space.

4.2.2 Data and data processing standards

Data and data processing standards are of high importance when aiming for the creation of products for decision-makers and policy-makers. In the agricultural domain there is a lack of consensus on data formats, processing standards and methods of analysis. Datasets are typically collected with a specific hypothesis or practical use in mind and data standards are rarely prioritized when developing new analytical methods or data-based solutions. Ensuring that standards are not implemented retrospectively, but are adopted before data are actually generated, remains a key challenge. Also, the definition of agreed workflows and processes for the generation of standardized products is essential

[82] Coordination between the CSA and the partnership has already been initiated right after the launch of the CSA at a Commission workshop for projects operating in the field of R&I in agricultural data in November 2022, at which also the draft SRIA of the partnership was presented.

to allow comparability and the creation of regional and pan-European datasets for policy monitoring and assessment.

Another problem encountered in existing data-based solutions is the “vendor lock-in effect”, i.e. the lack or insufficiency of data portability and data interoperability that makes farmers dependent on technology providers. This makes it difficult to combine technologies from different providers or change between them.

From the R&I perspective, the generation and propagation of quality and uncertainty information is essential, allowing a correct assessment and interpretation of data products and data-based solutions. Therefore, data quality information must be generated and documented according to well-defined practices and standards.

In the context of the implementation of the Data Governance Act, a Data Innovation Board supplemented by an expert group will be established to provide advice on questions related to cross-sectoral data interoperability and standards, in particular to facilitate the implementation of the Common European Data Spaces. It will thus closely collaborate with the Data Support Centre, which coordinates the implementation of the Common European Data Spaces.

In the roll-out of the Common European Agriculture Data Space, it remains to be seen how far standards for data interoperability and data quality will be developed. The development of the Data Act is expected to prevent vendor lock-ins in the context of IoT-related data sharing.

Horizon 2020 projects have developed technical solutions to enhance data interoperability in the field of agricultural applications (e.g. DEMETER and ATLAS), and in the field of public agricultural data. For instance, the Implementing act on High Value Data Sets will lead to the publication of data sets, which can be re-used for R&I and commercial purposes, following a common format and processing standards.

Considering the evolving activities, R&I achievements, and the objectives of AgData, the partnership will closely follow the development of activities in the field of data interoperability and standards. It will assess relevant R&I results, will proactively aim for achieving synergies between R&I projects/initiatives, as well as between projects and its work. Where relevant for achieving the objectives of the partnership, and where the partnership cannot build up on works carried out by other initiatives, the partnership may develop data interoperability mechanisms as well as data and data processing standards, e.g. for aligning national data sets to create Europe-wide reference data sets.

Standards and ethics are also important as it regards the use of AI, especially for ensuring trust in AI-based applications (see Sections 3.1.4 and 4.3). Here, the partnership will follow a human-centric approach and apply the guidelines on Ethics Guidelines for Trustworthy Artificial Intelligence prepared by the High-level Working Group on AI[83]. It will also follow the development of further guidance documents and the evolving legislation related to the application of AI, that of the Horizontal Act on AI, in particular.

4.2.3 Security and Privacy

To enable the sharing of data as a basis for the generation of data-based solutions for the sector and for policy monitoring, it will be essential to increase trust and establish secure and privacy-preserving

[83] Ethics Guidelines for Trustworthy AI | FUTURIUM | European Commission (europa.eu)

systems. Technical opportunities to address the **lack of trust** exist. With the advent of smart digital services for farmers in complex scenarios such as Internet of Things (IoT) infrastructure, inter-cloud environments, Industry 4.0, etc., it is pertinent to devise methods for developing **resilient systems out of potentially insecure components**, and to develop certification and security assurance methodologies, including *Composition (*defining security claims for composed systems and certifying the security contributions of components); and *Certification methods*. Security assurance methodologies allow harmonisation and mutual recognition based on evidence and not on trust. Yet, for effectively deploying such an approach, it is essential to understand the interplay between functional safety and security.

For enforcing **privacy**, e.g. for protecting the economic value of data, combining data sources without breaking privacy regulations, privacy-preserving technologies can be deployed. These include, for data intensive applications, operations over encrypted data, property-preserving encryption, secure multi-party computation, data exchange models and analyses.

The development of innovative solutions in the fields of technologies to increase transparency, and the security of data systems, and enforcing privacy, is a key focal point of R&I activities carried out under Horizon Europe Cluster 4 following a cross-sectoral approach. In addition, the development, testing and validation of blockchain technologies and means to increase cybersecurity are supported under the Digital Europe Programme. The AgData Partnership will not focus on the development of such technologies. However, they are to be used and, where needed, adjusted to sector-specific conditions and requirements, to allow for a functional, resilient and trustworthy data ecosystem.

4.2.4 (R&I) Activities

1) **Take stock of the existing data ecosystems, including data types, data flows, data holders and users**, achieve the "umbrella effect", and explore how existing initiatives for improving governance of agricultural data (e.g. legal frameworks, codes of conduct, contracts, licenses) support data access, sharing and use of data in agriculture.
2) **Develop and implement innovative solutions and services that enable the (temporary) storage, maintenance, conversion and analyses of personal data** (e.g. by pseudonymisation, differential privacy, generalisation, suppression and randomisation, synthetic data)
3) **Develop harmonised approaches and processes that enable easier access and use of data held by public sector bodies for the purposes of scientific research**.
4) **Provide legal interpretation services for members of the partnership and end-users, including** in the fields of data ownership, data access rights and data re-use opportunities, the use of AI, considering the evolving legal framing conditions.
5) **Highlight the potential use of the Common European Agriculture Data Space for innovative data-based solutions for the public and private domain.**
6) **Provide feedback on novel policy instruments to facilitate data sharing and re-use. Develop policy recommendations for their further development.**
7) **Develop actions at EU level to increase trust in agricultural data sharing** by establishing appropriate mechanisms for control by affected groups and data holders. Due consideration to be given to the changing legal framing conditions.
8) **Develop frameworks for the sharing, use and re-use of agricultural data** that has been generated or collected by public sector bodies or other entities using public funds.

9) **Explore mechanisms for "data brokerage services" that are able to foster further trust in the data economy** as well as public authorities for voluntary data sharing practices between farmers, companies and policy-making or in the context of obligations set by EU or national law.
10) **Link data sources following the approach of "trusted intermediaries" and test the regime established through the DGA.**
11) **Test the means of data altruism set up with the DGA.**
12) **Implement privacy preserving analytics, such as Multi-Party Computation (MPC).**
13) **Explore business and administrative models that stimulate incentives for the use and re-use of agricultural data**, especially sensitive data categories, both for the public and the private sector, considering different business and governance structures relevant in the context of agricultural data, such as cooperatives and contractors. Due consideration to be given to the evolving Common European Data Spaces.
14) **Identify and develop structures for the long-term funding and maintenance of data-based solutions and services developed within the partnership** giving due consideration to the evolving data ecosystem (see Section 4.1).
15) **Test and embed innovative technology in agricultural applications to ensure trust**, and decrease the risk of cybersecurity attacks in the agricultural value chain network[84] as well as in B2G and G2B data sharing settings beyond pilots, and focusing on larger scale implementation.
16) **Develop standards for data quality and data processing** building on existing and evolving cross-domain standards for findability/interoperability of public and scientific data. Avoid the development of new standards (see also Section 3.1), whereby consistent use of (open and widely accepted) formats and standards will increase re-usability and interoperability of agricultural data.

4.3 Ensuring uptake & Innovation management of results of the partnership

The partnership aims to boost the uptake of data-based solutions developed within AgData by end-users. It is not sufficient to ensure end-user uptake in terms of bringing data-based solutions for agriculture to the market and/or making them visible for public bodies. There are several barriers to the uptake and effective use of the data technologies and data-based solutions in agriculture, which need to be considered within the partnership. Also, the uptake of data-based solutions by the public administration and the wider innovation ecosystem would benefit from facilitation and innovation management.

It is well known, that the uptake of data and data technologies by agricultural stakeholders will help to increase environmental and economic performance as well as to facilitate monitoring and evaluation. However, as the introduction of this innovation can generate undesired trade-offs, proposed data-based solutions need to take into consideration the agricultural sector specific conditions. In the following, challenges related to the uptake of data-based solutions, which fall into the scope of AgData and can (partly) be addressed by the partnership[85] are outlined. While the listed challenges are of more general nature, the partnership also has to account for the differences between countries in the public

[84] As outlined in the Partnership document, the partnership Agriculture of Data does not envision to cover the whole food systems and aspects of traceability in the value chain, which will be covered under other EU-funded initiatives, including under Horizon Europe Cluster 6 and the DEP.

[85] There are general challenges to the uptake of digital technologies in agriculture, and subsequently also of data-based solutions in agriculture, which are not in the scope of the partnership, e.g. weak connectivity in rural areas.

and private domains, especially regarding previous experiences in the handling of data, use of data-based solutions, and the uptake of innovation.

Challenges

For farmers & farm advisors, challenges linked with the uptake of innovative data-based solutions include:

- **High costs** of data-generating technologies, such as sensors, making such applications affordable only for large scale and specialized farms. This might be combined with a lack of motivation to adopt more sustainable practices, which do not appear to benefit the farmer in the short- or medium-term.
- **Lack of data literacy** and mis**trust in AI** among the vast majority of farmers makes them feel that they will lose control over the farm decision systems. The complexity of the data intensive technologies requires a minimum level of knowledge and skills preventing uptake by certain users (e.g. older farmers).
- **Lack of clarity** in questions related to data ownership, and whether data belongs to farmers, Agricultural Technology Providers, machine producers or other stakeholders, such as data collectors (if not farmers), landowners or even financial lenders. This generates mistrust and insecurity about data sharing.
- **Lack of interoperability of devices** makes it burdensome to use certain applications, feed additional data into applications, and to adopt new data-based solutions.

In the case of policy-makers and the public administration, challenges linked with the uptake of innovative data-based solutions include:

- **Lack of awareness and lack of capacities to deal with innovative data-based solutions and to reflect on possible benefits for the political-administrative systems**;
- **Legal uncertainty in the adoption of novel approaches towards policy monitoring**; compliance with monitoring requirements needs to be assured;
- **Investment costs for running the data and computing infrastructure** needed to adopt data-technology-based solutions;
- **Lack of data interoperability between various systems within countries and between countries. This hampers** adoption of data-based solutions across the whole of Europe;
- **Short timespans in policy decision-making processes** hamper the consideration of dedicated data-based solutions that contribute to specific policy objectives;
- **Need to find a common approach** across EU Member States and candidate countries, in the case of the monitoring of some policies.

In the case of innovators/other actors in the innovation ecosystem, challenges linked with the use of data for agricultural applications include:

- **Legal uncertainty as regards the reuse of data-based solutions offered** (e.g. if requirements of the General Data Protection Regulation (GDPR) only apply to the original data-based solutions) and intellectual property[86];
- **Costs for the reuse** of certain data-based solutions;
- **A lack of findability** of data-based solutions;
- **Uncertainty regarding the constant provision of a data-based solutions**, which may serve as input to other data-based solutions.

Some of these challenges will also be addressed through activities related to data governance, data standards, ethics, and security, as will be outlined in the next sub-section.

Generally, not only to achieve the ambition of end-user tailored results, but also for their dissemination, the promotion of data utilization and data technologies in the agricultural sector is ideally performed through a participatory process, in which data solutions are co-designed between the different stakeholders engaged in the process, e.g. researchers, agriculture cooperatives, companies, Innovation partnerships and extension groups.

Two additional key principles to overcome many of the above-listed challenges are that

a) "**Multiplier**s" transmitting the added value of the results of the partnership in a trustworthy way to targeted end-users are to be considered in the activities of the partnership; and
b) **Outreach activities** have to be target-group specific.

This implies for instance, that farm advisors as well as persons linking up to the relevant governmental/administrative bodies at European and national levels as well as Innovation brokers, such as DIHs, are to be involved.

Communication and dissemination activities are to be implemented to support the partnership in its exploitation of the potential of EO, environmental, agricultural and other data, in combination with data technologies to enhance climate, environmental and socio-economic sustainability and productivity of agriculture and to strengthen policy monitoring and evaluation capacities. This will be done by creating a communication, dissemination and exploitation plan and supporting tools for all actors, including farmers, involved in the partnership. Using effective communication through traditional and innovative communication channels, the partnership will widely communicate, disseminate, promote and transfer its activities and results to multiple audiences beyond the project's own community. The ultimate outcome is an increased uptake by practitioners and to improve stakeholder engagement, including the wider public, demonstrating the impact of the partnership.

Innovation management is a crucial component for the success of the partnership as it ensures that the research results are further used for commercial and non-commercial purposes. It will contribute to achieving the project objectives, facilitate the exploitation of results and enhance the expected impacts of a project.

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[86] A particular challenge for "innovators" is the changing legal environment. In the context of the development and application of data-based solutions in agriculture, more (forthcoming) legislation than explicitly introduced in this section is relevant, including dossiers in the fields of AI liability, product liability, and a proposal for a machinery regulation, which have to be considered in the development of innovative solutions and the provision of assistance to innovators and end-users. Also the work of the Expert Group on B2B data sharing model contracts will be taken into consideration.

To maximize the impact of innovation resulting from the partnership, the implementation of innovation management tools and techniques will be vital. Structured ways of running corresponding activities will contribute to the innovative capacity and performance of the partnership, especially as regards the capitalisation of data-based solutions by other innovators, who build upon them to develop other data-based solutions.

4.3.1 (R&I) Activities

To make the results of the partnership widely available, allow for their effective use and further capitalisation, the following activities are foreseen:

1) **Generating evidence of the value of data and data technologies** for end-users. There is a need to demonstrate to end-users the benefits of the uptake of data technologies (see Sections 3.1, 3.2 and 3.3).
2) **Develop approaches to communicate evidence of the value of data and data technologies** to end-users. Due consideration to be given to the strong need for demonstration of benefits in order to encourage the uptake of data (and digital) technologies and data sharing.
3) **Develop user-friendly data platforms to overcome the complexity and findability barrier**s. Farmers, public bodies and innovators should be empowered to easily find and access the products developed by the partnership and to assess the relevance for their work with a high-level of interoperability with commonly used systems (see Sections 3.1 and 4.2).
4) **Set-up a two-way interactive and participative e-platform** for the partnership supported by a knowledge hub and digital support tools to reach out to targeted end-users and multipliers and link up to existing platforms (preferably available in all local languages).
5) **Develop innovative tools in support of capacity-building to increase competences related to data technologies and data literacy, including under "real-life" conditions. Due consideration to be given to** existing structures such as AKIS and TEF, including training programs, discussion forums and platforms for farmers, other land users and the public administration to enable and facilitate the knowledge and use of data. Particular focal points may include trust in data sharing and its added value, and convincing evidence of medium-term returns for the adjustment of production approaches.
6) **Contribute to and/or develop training in advanced digital skills** as supported under the DEP[87] following an interdisciplinary approach to develop persons with dual background (i.e. in agriculture and advanced technologies), to strengthen capacities to develop tailored data-based and digital solutions for the sector; such capacity building on the side of multipliers will also have the effect that digital solutions are explained to farmers and their advisors in a more feasible way.
7) **Develop innovative approaches to encourage the adoption of sustainable farming practices, through the development of "persuasive technologies".** The purpose of such ICT-based solutions is to influence users to act in a more sustainable way (see Dutta et al., 2014; Seidel et al., 2013).[88]

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[87] In this context, reference to the DEP is not made because of possible synergies in funding trainings in advanced digital skills, but especially because of the probed design of rolling out trainings in advanced digital skills at universities in cooperation with businesses.

[88] Such ICT systems are now in use in various fields, such as energy consumption, health transport habits, as well as education and training. Environmental awareness systems that aim to increase the user's awareness of their current (unsustainable) behaviour, this can be achieved by making visible a certain behaviour and a particular model of activity that promotes sustainability.

8) **Set-up and strongly involve national mirror groups** (see partnership documents) in the development, testing, validation and communication of data-based solutions relevant for policy-making (implementation, monitoring, evaluation).
9) **Develop new modalities to connect policy-makers, scientists and other stakeholders** for systemic innovation in the field of climate adaptation of agricultural systems.
10) **Develop innovative business and governance models** for the sustainable management of data flows, giving due consideration to the **changing legal environment and aspects related to intellectual property rights.**
11) **Actively promote and support open science.**
12) **Develop and (re) use tools for information, communication and collaboration within the sector and between end-user groups,** including the production of material (e.g. policy briefs and newsletters) and organisation of participatory communication events, international conferences, seminars, workshops and brokerage activities. These should involve various stakeholders, and media professionals. They should also take advantage of tools provided for Horizon Europe implementation, such as the Horizon Europe Dash board, Horizon Results Booster, Innovation Rader etc.

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6 Annexes

6.1 Data

6.1.1 Earth observation and environmental data

Earth observation (EO) and environmental data provide key information on our planet Earth's physical, chemical, and biological systems. While EO data is captured via remote sensing technologies, usually involving satellites carrying imaging devices[89], environmental data is collected in the field by e.g. proximal sensing, field sensors, machineries, from local to national scale (observational networks), within (living) labs or long-term experiments. EO and environmental data is of great value to agriculture as it promotes process understanding, enables farmers to react to environmental changes and increase productivity, and helps to reduce the use of environmental pollutants. According to EUSPA,[90] EO data can be used in agriculture at local, national and global levels. The EO data can be used to develop services for farmers and to assess the impact of agriculture on the environment, supporting the development of accountable policies. However, some challenges remain. We need fast and reliable ground-truthing of EO to be able to measure crop and soil status and use these data (e.g. in precision agriculture). Ground-truthing includes the measurement of biophysical and biochemical variables (Hank et al., 2019) weeds, pests, diseases, yield, and yield quality. There is also great potential in estimating GHG emissions and measures that optimize land use in relation to carbon capture and biodiversity, nationally as well as globally. Dedicated downstream services and applications may help assessing agricultural land use and trends, crop conditions and yield forecasts, helping to preserve the environment and sustain productivity while facing current grand challenges such as climate change.

Europe can build on a solid ground of EO facilities and expertise, and already today EO is heavily used in the agriculture sector. The satellite missions of the Copernicus programme are the backbone of the European EO community. Its flagship, the multi-spectral Sentinel-2 mission, delivers global coverage of the land surface at medium resolution and are routinely used for a variety of applications in agricultural monitoring and farm management. At the same spatial scale, the synthetic-aperture radar (SAR) system, Sentinel-1, delivers frequent and weather independent information about the status and condition of the agricultural landscape. A huge potential for agricultural applications is seen in the development of the Copernicus Sentinel Expansion Missions.[91] With the current and planned products of the Copernicus Land Monitoring Service[92], the EU already provides a portfolio of readily available data products at EU level. The validation and valorisation of those products for sustainable agriculture applications is still in its early stages.

Environmental data is provided by meteorological agencies, agri-research institutes, environmental agencies (e.g. EEA), and observational networks (e.g. Eionet). In the context of the partnership, it can be used, e.g., to develop decision support tools for farmers as based on optimization models, reduce negative impact of current agricultural models, improve pest- and nutrient management and irrigation systems or support the development of more sustainable agricultural production. However, in many cases, data are not freely accessible or are difficult to find, not well described and/or not stored in standardized formats and in open data infrastructures. The EU has set ambitious goals for spatial data

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[89] https://joint-research-centre.ec.europa.eu/scientific-activities-z/earth-observation_en
[90] https://www.euspa.europa.eu/european-space/euspace-market/earth-observation-market#:~:text=The%20EO%20value%2Dadded%20services,bn%20total%20revenues%20by%202031
& https://www.euspa.europa.eu/sites/default/files/uploads/euspa_market_report_2022.pdf
[91] https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions
[92] https://land.copernicus.eu/

infrastructures and environmental data interoperability. The INSPIRE directive obliges member states to describe and arrange access to data and metadata services within defined spatial data themes. In addition, the new “Open data – availability of public datasets” initiative identifies data from environment and agriculture as one of the “high value” datasets, promoting the use of application programming interfaces (API’s) and availability in a machine-readable format.”

The potential for the use of big data analytics in the field of Earth and environmental observation is high, offering the possibility to analyse patterns leading to a critical mass, higher efficiency and a sufficient amount of information to base decisions on. In order to generate ‘big data’ sets capable of delivering added value to EO, reliable reference data, i.e. environmental data, is required from across Europe representing different biogeographic, climatic and production conditions.

6.1.2 Socio-economic data

In order to better understand the dynamics of the agricultural sector and to set goals for agricultural policies that can be verified, socio-economic data should be considered and combined with environmental ones. However, socio-economic data are often hard to manage as they are typically semi- or unstructured. Socio-economic data are often collected and stored using different formats and standards from environmental ones. The main connection to different types of data are the geographic dimension.

Data about humans and human activities

Socio-economic data are data about humans, human activities and the space and structures used to conduct economic activities. In particular they include demographics (age, sex, ethnic and marital status, education); housing; migration; transportation; economics (personal incomes, employments, occupations, industry, regional growth); retailing (customer, locations, store sites, mailing lists etc.).

Socio-economic data can derive from different sources: field surveys, government statistics, governments’ administrative records, secondary data collected by other stakeholders such as government agencies, research community, non-governmental organizations and private businesses. Recently socio-economic data are increasingly collected in digital form by private sector companies.

Quantitative socio-economic data, which can be disaggregated, focusing on individuals and single entities or aggregated if describing a group of observation, are used in theoretical and methodological approaches embedded in micro-economics, modelling and econometrics in order to study the relation between demand, supply and patterns of information use.

Qualitative socio-economic data, such as opinions, stakeholders' inputs, conclusions of evaluations, as well as scientific and experts' advice are used to identify relevant dynamics and trends.

The combination of qualitative and quantitative data is the key to understand what data are needed and what problems need to be solved in the agricultural sector and how the use of data can move from only automation to augmentation, allowing humans to do things additional to what they could do without the use of data (Brynjolfsson, 2022).

Socio-economic datasets relevant for the partnership

The main institution working on socio-economic data in Europe is EUROSTAT which produces European Statistics in partnership with National Statistical Institutes and other national authorities in the EU Member States, creating the so called European Statistical System (ESS). EU agricultural statistics collected by Eurostat come from a variety of sources: surveys, administrative data, data from farms and other businesses, as well as farm-level data from agricultural censuses and samples.

In order to align the goals of the CAP with the ones of the Green Deal, the "Farm to Fork" and the Biodiversity strategy, the current data collection from individual farms in EU (Farm Accountancy Data Network – FADN) has been enlarged to include data related to social and environmental practices of each farm. While FADN was looking at incomes and functioning of the instruments of the CAP, the new Farm Sustainability Data Network (FSDN) will integrate economic and environmental data.

Focussing on supporting sustainable production, also market prices of agricultural commodities and inputs, such as fertilisers and energy, are to be taken into consideration as they influence farm management decisions, including on agri-environmental matters.

Socio-economic data relevant to the Agriculture of Data partnership are also included in the Digital Economy and Society Index (DESI), which summarises indicators on Europe's digital performance and tracks the progress of EU countries. Since 2014, every year, DESI includes country profiles to monitor Member States' digital progress. This is interesting data, even if it is still not sufficiently disaggregated.

Main issues in using socio-economic data

However, still several issues are related to make data interoperable in order to enhance the use of socioeconomic data in agriculture. There is still a need to standardize a set of key indicators through survey questions so that responses are meaningful to all Europe. The creation of ontologies for socio-economic concepts can assist in their inclusion into the quantitative databases. Finally, the development of a blueprint for data interoperability would make socio-economic data usable in different domains.

- In a recent report of the EU Court of Auditors on the use of data for CAP design, monitoring and evaluation it was underlined that the EC holds large amounts of useful data. To design, monitor and evaluate the CAP, DG AGRI possesses large volumes of mainly administrative data (e.g. market prices and payments, and farm accountancy data) that it mostly receives from the Member States, which collect the data in order to carry out the policy. However, according to that report, the EC uses conventional tools such as spreadsheets to analyse the data it collects from the Member States.[93] A **better organization of the databases** could facilitate the use of data for policymaking and their integration in other domains. The lack of standardization and limitations due to data aggregations reduce data availability and usability. (ECA, 2022)
- In addition to that, most of the socio-economic data comes from farmers and farm activities. In this sense several **ethical aspects** should be considered. EU Code of conduct on agricultural data sharing by contractual agreement signed by Copa-Cogeca together with other organizations, give a farmers' perspective on data ownership, including definition of what data are and how to regulate their use.

6.2 Farm Data

6.2.1 Farm data (on-farm generated)

Farm Data describe various conditions and processes in farms. Farm data is mostly generated on the farm, either manually or by automated data collections (machine data incl. farm robots).

There is a lot of variation in the types of data generated by farms across agricultural domains, geographic areas, and production lines. **Farm data**, as understood according to the concept of data sovereignty, **includes farm-specific data that is either raw data from farm processes or environment,**

[93] It is to be noted that, since the audit, steps have been undertaken to enhance data bases at the disposal of the European Commission to evaluate and develop policies, e.g. in the context of the CAP post 2022; see e.g. Regulation (EU) 2022/1475.

or data that is created by combining, processing, and analysing from various sources (Data Act, ref.). Examples of farm data are field operation plans (seeding, fertilizing, spraying, harvesting), logistics plans, market foresights, and data-based farm-, field-, or product-specific environmental indicators such as carbon footprint or water footprint. Most data are not kept physically at the farm, but hosted in different locations by different operators, and under different agreements as regards to the data usage.

Tools for data entry at the farm vary. Manually input data is needed for instance to verify conformance to agricultural subsidy rules. FMIS are popular tools to collect and store data at the farm, and different decision support apps can be either incorporated with FMIS or used as separate mobile applications on-field. Mobile applications are used for instance for recording of pest observations and sharing of pest data within farmer networks. Product value chains and the participation in policy programmes or labelling schemes may also require various level of recording to create traceability. Follow-up data on the environmental actions at farm may be part of the product commitment.

Often data is not collected by the farm, but by external companies. Companies may offer, for instance, fodder harvest as a service, or crop analysis data using equipment that farms do not have themselves e.g., UAVs. Data use is agreed with the farm and often the company’s business idea builds at least partly on the cumulating data in their control.

Automated data collection at the farm and machine data

Modern farms collect vast amounts of data automatically, using sensors and machinery. Automated data sources include farming equipment and sensor systems such as local weather stations and soil sensors. Some measured variables are controlled by the farmer, while others such as weather are beyond his control. This monitoring is not just for data collection and follow up of the product chain, but also a feedback loop to the farm itself so that the farmer can use the data where needed to optimize the farming processes and make informed decisions. Some data sources provide data for different models (DSS, pest risk models, growth models for instance) or are used directly at the farm. Other data streams work “behind the scenes” e.g., by sending a signal when a machine part malfunctions.. Findings from the data matter when they can be transformed into knowledge and clear implementation strategies. For modern farms this may mean the need for a clear description on how these strategies will be efficiently implemented by the farms’ machinery fleet.

Automatic data collection is essential in precision agriculture. In cultivation, agricultural inputs such as fertilizers or agrochemicals can be effectively allocated within the field by employing variable rate technologies (VRT) and the crop production process can be assessed by yield maps. In practice, operation plans are communicated from software to tractors and their implements using machine readable prescription maps (task files), and a geolocated log is collected. Most modern machines and FMIS also support wireless transfer of log data from completed tasks. Communication between machines often follows standards such as ISO11783, but proprietary communications schemes and code lists are also used widely. Together with yield maps and data on crop growing conditions, farm machinery data forms an accumulating spatial data bank of the fields and their operations. This kind of automated data collection gets more common as old machinery is being replaced by new over time. In practice, farm machinery data are often hosted by software companies or machine vendors, and interfaces to farmer users provides needed tools for farm decision making and analyses.

On-farm data from agricultural machinery is seen to have great potential for agri-environmental monitoring and even creation of farm specific measurements, reporting and verification (MRV) of environmental emissions. However, there are several challenges to overcome. Machinery data alone is not sufficient, and to access missing bits of data (such as composition of a given fertilizer or agrochemicals), their data sources should be available as well. Not all environmentally relevant parameters are recorded, and when data is available, its accuracy may vary (for instance, inaccurate information from manure spreading vs. high resolution yield maps). Understanding of the detailed data requirements is often lacking, so there is no consensus on, for instance, what additional measurements or registrations are needed for reliable policy monitoring or carbon and nitrogen cycle modelling.

Increasing interest to data from outside the farm

There is currently an increasing interest in data collected by farms by various actors: science, policy makers, environmental protection agencies, and other actors in the food industry. For instance, soil samples or soil scans taken to follow up soil condition and nutrient status may form valuable in-situ data when employing remote sensing for larger areas, and crop and yield data can give valuable insights to aerial yield estimates. Also, other farms may be potential users for farm data. Less equipped farms could benefit from part of the data coming from well-equipped farms when data will be shared.

The agricultural sector is one of many where the value of data is now recognized, and control over data is competed over on several arenas (open standards vs. vendor lock-in, goals to fair data economy, GDPR, FAIR[94] principles). At EU level, there is interest to increase farmer's data sovereignty and opportunities for monetizing the data. At the same time, the legislative requirements towards farmers to provide data for control and statistics are increasing.

Farm data describe conditions and processes in farms.

Data hosted by the authorities

The Integrated Administration and Control Systems (IACS) form the core of the governance infrastructure of the EU's Common Agricultural Policy (CAP). IACS and the Land Parcel Identification Systems (LPIS) managed by the Paying Agencies contain critical spatial data for the government and data on the monitoring of payments of agricultural subsidies. These systems can form interlinkages with commercial Farm Management Information Systems (FMIS) operated by the farms. Realizations of these data ecosystems vary between Member States, but the shared requirements support European interoperability and scalability.

The EU has also set ambitious goals for spatial data infrastructures and environmental data interoperability. The INSPIRE directive obliges Member States to describe and arrange access to data and metadata services within defined spatial data themes including, for instance, agricultural facilities. In addition, the new "Open data – availability of public datasets" initiative identifies data from agricultural parcels as one of the "high value" datasets, promoting the use of application programming interfaces (API's) and availability in a machine-readable format.

[94] Findable, Accessible, Interoperable, Reusable