MEF4CAP

Monitoring and Evaluation Frameworks for the Common Agricultural Policy

[27 July 2021]

Deliverable D2.1

Landscape of agri-food ICT technologies within EU

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Table of Contents

Executive summary

MEF4CAP is a H2020 project with the main purpose of delivering an innovation agenda and roadmap for future monitoring of EU agriculture Policy. The Common Agricultural Policy (CAP) post 2020 is targeted towards a wider range of objectives covering broader domains – agriculture sustainability, agri-environmental, food security among others. This fact implies that new data sources are required to measure the effects and performance of the Policy. Up to date, the main information sources in order to monitor and verify how well the CAP objectives have been reached are the applications by farmers for CAP payments (through the Integrated Administration and Control System - IACS) and data from national statistical agencies (e.g. Eurostat and the Farm Accountancy Data Network - FADN).

Given the new policy needs, an increase in the number and type of indicators is expected. New indicators have been identified, developed and tested to adapt to these new policy needs. More data will be required to adequately measure sustainability; therefore, it is vital to consider whether it is possible to utilise existing data sources more efficiently, avoiding duplication and potentially allowing scope for collection of new types of data e.g. measures of social sustainability and well-being. In order to make the future system cost-effective and limit the administrative burden on farmers, future monitoring and evaluation of the CAP will depend on a framework that is grounded in the trend of digitalisation. To this end, digital data from advanced data capturing methods – mainly ICT based mechanisms - will become essential.

WP2 of the MEF4CAP project focuses on reviewing and evaluating Information and Communication Technological developments in relation to agricultural sector. The main objective is to review and assess current and new technologies that are widely utilized or provide a potential benefit for data capturing and data processing in support of agri-food monitoring and evaluation objectives. There are various ongoing efforts in the ICT domain, sometimes in parallel, for resolving common challenges. The analysis conducted within this work package allows the identification and categorisation of technological solutions and trends with a clear potential or even a proven track record that can be exploited for addressing the data needs of the monitoring and evaluation frameworks for the agricultural and related policies.

This deliverable D2.1 “Landscape of agri-food ICT technologies within EU” is the first deliverable of WP2. The scope of this document is not to provide an exhaustive analysis of every kind of ICT related mechanisms that have been utilised at the agricultural fields but to provide an overview of technologies that can potentially be useful as additional data sources in the context of monitoring current and future CAP indicators. To this end, an extended technological review is presented in order to assess well-established legacy technology services, but also more advanced approaches that are currently in place for managing the necessary data flows in the agricultural sector. The ICT areas that have been selected for analysis demonstrate the potential to support the operation of contemporary CAP monitoring and evaluation frameworks, but also the relevant future needs. The ICT areas to be reviewed have been identified from an early stage during the specification of MEF4CAP Description of Work. These areas were further analysed within the WP2 Task2.1 activities where individual partners contributed based on their distinct field expertise on the potential of each technology in contributing as a data source in the context of CAP monitoring. The final list of technologies is the following:

- Telecommunication technologies
- Field Sensors
- Farm Management Information systems (FMIS)
- Field Machinery
- Earth Observation
- Livestock Management
- Pasture Management
- Financial management

Within this deliverable and for each of these areas an analysis on recent trends is presented along with the level of maturity, the respective adoption status, and observed barriers across EU countries. A first level outcome from the conducted analysis on ICT technologies is that there is no one-fits-all technological approach that is capable to provide all the necessary data for CAP monitoring. It is more a synergetic/complementary use of generated datasets that needs to be facilitated e.g. Earth Observation data products with data logs from Farm Management Information System.

The analysis of this deliverable continues on agricultural data sharing as a necessary step for regulating the way that enriched future data collections will be shared with authorised stakeholders including regional and national administrative authorities. Currently, in the EU but also on a global level there is a thriving community of experts from different disciplines (individual farmers, farmers' associations, data scientists, regulatory bodies, legal experts, information security officers) that aim to set up the basic rules and mechanism that will allow fair and responsible agricultural data sharing. In this context, such indicative initiatives that have significant role in shaping the overall ecosystem of agricultural data sharing are presented.

For data collections that are shared to be useful, it is necessary to be meaningful also. Thus semantics on agricultural data is also a topic that is currently under investigation by the research community. There is an obvious need to formulate, with common semantics, the digital evidence collected by the farms that will be shared with the monitoring authorities (e.g. Integrated Administration and Control System). The dominant efforts on this semantic interoperability for agriculture data are also reported in this deliverable.

An additional ongoing effort by WP2 (Task2.2) is the establishment of collaboration channels with numerous EU initiatives and research projects that their outcomes can directly or indirectly be exploited towards the digitisation of monitoring and evaluation frameworks for the future CAP. The recorded outcomes from these initiatives will be combined with outcomes from this deliverable (D2.1) in order to construct "D2.2 Best practises on the adoption of ICT agricultural technological solutions" to be delivered on M12. This deliverable will contain an analysis of best practices and lessons learned within the context of utilising agricultural technologies for the needs of future CAP monitoring.

A more detailed analysis on the usefulness of the presented information sources will be performed in the context of WP3. D2.1 will be utilised as input by "WP3 Current systems and future pathways" in order to confront the ICT developments with the data needs necessary for an enhanced monitoring and evaluation framework for a future and reformed CAP.

List of abbreviations

EC - European Commission

CAP – Common Agriculture Policy

CMEF - Common Monitoring and Evaluation Framework

PMEF - Performance Monitoring and Evaluation Framework

FADN - Farm Accountancy Data Network

ICT – Information and Communication Technologies

IoT – Internet of Things

FMIS – Farm Management Information System

IACS – Integrated Administration and Control System

PA - Paying Agency

DSS – Decision Support System

SF – Smart Farming

RS – Remote Sensing

EO – Earth Observation

UASs - Unmanned Aerial Systems

LPWAN - Low Power Wide Area Network

GPRS - General Packet Radio Service

LoRa - Long Range

LoRaWAN – Long Range Wide Area Network

FAO-UN - Food and Agriculture Organization of the United Nations

CTA - Technical Centre for Agricultural and Rural Cooperation

PAFO - Pan African Farmers' Organisation

DG CNECT - Directorate-General for Communications Networks, Content and Technology

DG AGRI - Directorate-General for Agriculture and Rural Development

ECU - Electronic Control Unit

EDI - Electronic Data Interchange

EARSC - European Association of Remote Sensing Companies

OCR – Optical Character Recognition

OWL - Web Ontology Language

List of figures

List of tables

1. Objectives and overview

Objectives

MEF4CAP is a H2020 project with the main purpose of delivering an innovation agenda and roadmap for future monitoring of EU agriculture Policy. The Common Agricultural Policy (CAP) post 2020 is targeted towards a wider range of objectives covering broader domains – agriculture sustainability, agri-environmental, food security among others. This fact implies that new data sources are required to measure the effects and performance of the Policy. Performance is the key idea in the new monitoring and evaluation framework of the CAP. At the same time, new technical developments, are enhancing the capability of providing, retrieving and integrating new data sources that are called to achieve those new data requirements. MEF4CAP brings together the expected needs for assessing the performance of the future Policy and the newest technologies to address those requirements.

WP2 focuses on ICT Developments of the agricultural sector. The main objective of this work package is to review and assess current and new technologies that are widely utilized or provide a potential benefit for data capturing and data processing in support of agri-food monitoring and evaluation objectives. There are various ongoing efforts in the ICT domain, sometimes in parallel, for resolving common challenges. The analysis to be conducted within this work package will allow the identification and categorisation of technological solutions and trends with a clear potential or even a proven success record that can be exploited for addressing the data needs of the monitoring and evaluation frameworks for the agricultural and related policies. Based on this analysis, a detailed description will be developed encompassing the characteristics of the technologies and the information management systems that will be mature enough for operational utilisation in the future towards the longer-term modernisation of monitoring and evaluation processes.

This deliverable D2.1 "Landscape of agri-food ICT technologies within EU" is the first deliverable of WP2 and documents the work conducted within Task2.1 "Review and assessment of established technologies". Within this task, an extended review has been performed in order to assess well-established legacy technology services, but also more advanced approaches that are currently in place for managing the necessary data flows in the agricultural sector, that can potential support the operation of contemporary CAP monitoring and evaluation frameworks.

WP2 is currently continuing this analysis in the context of "Task 2.2 Continuous monitoring and collaboration with EU projects and initiatives to review and assess" where interviews with selected H2020 ongoing projects and other initiatives are conducted. Through these collaboration sessions we aim to extract and record up-to-date technological developments in the agri-food sector. The realised collaboration activities are recorded in "D2.3 Identified New technological opportunities from Collaboration with EU projects and initiatives" which has the form of a living document which captures the various liaison activities and outcomes extracted by the collaboration efforts with EU projects and other related initiatives. Finally, and based on input provided by D2.1 and D2.3, the Deliverable entitled "D2.2 Best practises on the adoption of ICT agricultural technological solutions" will be produced and will contain the final outcomes on best practices and lessons learned with regards to the adoption of ICT technological solutions for the agri-food domain in the EU and how these solutions are related with future CAP monitoring.

WP2 Deliverables will also be utilised as input to WP3 "Current systems and future pathways" in order to complementarily analyse technological offerings and data demands of future monitoring and evaluation systems. The outcomes of this analysis will be recorded in "D.3.2. Potential of current systems and ICT developments for future data needs". In this scope, this deliverable (D21) can be considered as a generic analysis of the various ICT technologies that demonstrate an initial potential to act as information sources for the future CAP monitoring and evaluation framework. A more detailed analysis on the usefulness of the presented information sources will be performed in the context of WP3 where technical requirements of the new monitoring framework will be cross checked against the technological offerings.

Overview

Section 1, elaborates on the current status of technologies and their utilisation in the context of agriculture along with the analytical approach that is followed for reviewing and assessing technology needs of this deliverable.

Section 2 provides an analysis of the technological landscape where the various technologies have been categorised into different thematic areas, namely: Telecommunication technologies, Field Sensors, Farm Management Information systems (FMIS), Field Machinery, Earth Observation, Livestock Management, Pasture Management, Financial management.

Section 3 elaborates on the issue of data sharing within the agricultural domain. Given that recorded datasets need to be shared in order to be useful in the context of CAP, it is considered as crucial to review the various initiatives that are aiming to set the technological and regulatory environment of agri-data sharing.

Section 4 analyses existing efforts on harmonised agricultural data modelling in an attempt to establish an ecosystem of semantically interoperable data.

The discussion on the findings from this review will finalise this deliverable.

2. Introduction

The Common Agricultural Policy (CAP) is reformed in the light of new societal challenges approximately every seven years. The changes are based on evidence-based decision making which in turn implies the need for evaluations based on harmonised data and indicators. The European Commission (EC) has set up the Performance Monitoring and Evaluation Framework (the former CMEF, which is now known as the PMEF) to assess the performance of the CAP. The PMEF is a set of rules, procedures and indicators to evaluate the CAP. The PMEF provides key information on CAP implementation and supports the verification process on how well objectives have been reached. In order to evaluate the implementation of CAP objectives it is necessary to collect data related with defined indicators[1]. Currently the main data sources are:

- Application by farmers for CAP payments Integrated Administration and Control System[2] (IACS)
- Data from national statistical agencies, Eurostat and the Farm Accountancy Data Network[3] (FADN)

Given the new policy needs, an increase in the number and type of indicators is expected. New indicators have been identified, developed and tested to adapt to these new policy needs. More data will be required to adequately measure sustainability; therefore, it is vital to consider whether it is possible to utilise existing data sources more efficiently, avoiding duplication and potentially allowing scope for collection of new types of data e.g. measures of social sustainability and well-being. In order to make the future system cost effective and limit the administrative burden on farmers, future monitoring and evaluation of the CAP will depend on a framework that is grounded in the trend of digitalisation. To this end, digital data from advanced data capturing methods – mainly ICT based mechanisms - will become essential.

On the same time and at the farm level there is an ongoing adaptation of ICT mechanisms in support of every day operations. Consequently, there is a wide range of data flows to and from farms while part of these data are of relevance for policy evaluation and monitoring. A future monitoring system should make optimal use of these different sources of data and modern ICT based data capturing systems. As part of its ongoing move to simplify and modernise the EU's CAP, the European Commission is already adopting new rules that allow a range of modern technologies to be used when carrying out checks for area-based CAP payments. These include the possibility to completely replace physical checks on farms (On-The-Spot-Checks, OTSC) with a system of automated checks based on satellite data (Control by Monitoring), in combination with Internet of Things (IoT) and other digital technologies (Freire et al., 2019).

Although the adaptation of new technological solutions differs across Member States (Barnes et al., 2019), it is expected that in the near future farmers will have more access to digital data and will have the capacity to combine different types of data in their management systems. The future of farming involves engaged farmers being active users of agri-data as well important providers of data analysed by other parties. The necessary telecommunication networks and

[1] https://agridata.ec.europa.eu/extensions/DataPortal/cmef_indicators.html
[2] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/financial-assurance/managing-payments_en
[3] https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/farms-farming-and-innovation/structures-and-economics/economics/fadn_en

ICT tools will be in-place, facilitating innovative data capturing and sharing that will allow the mutual/bidirectional use of information resources among the participating stakeholders. This data sharing ecosystem will allow the design and implementation of advanced monitoring and evaluation frameworks, serving the implementation of the future CAP, but also going beyond this, developing advanced services targeting challenging areas such as food-security, EU Green Deal policy implementation, etc.

Figure 1 illustrates a conceptual view of data sources, data flows and data consumers within a future monitoring and evaluation ecosystem. Within this layered ecosystem established telecommunication channels allow the controlled information flow from the farm level to the Monitoring and Evaluation information processing entities and the opposite. Data which are initially generated by the various deployed sources (hardware and devices) are collected, stored, processed and managed by software systems in order to support the everyday activities that take place on the farm level. Selected datasets along with the respective extracted higher level information outcomes are feasible to be mediated with the use of the appropriate data sharing mechanisms that will facilitated (among others) authentication and access control, data confidentiality and identity protection, semantic interoperability, etc. Based on the collected data the Monitoring and Evaluation Framework of the future will be feasible to monitor environmental and policy indicators on a farm, regional and national level with more accurate and frequently updated evidences. On the same time useful information will be feasible to be provided to interested parties (e.g. farmers, farmers associations, advisor, regional policy administrators) based on extracted/aggregated outcomes on a regional level including parameters related with environment (e.g. carbon footprint, nitrates, pesticides use), agricultural processes (e.g. pests infestation, average harvested yield, crop types in the area, phenological stages), financial (e.g. average income, yield prices, agricultural inputs prices).

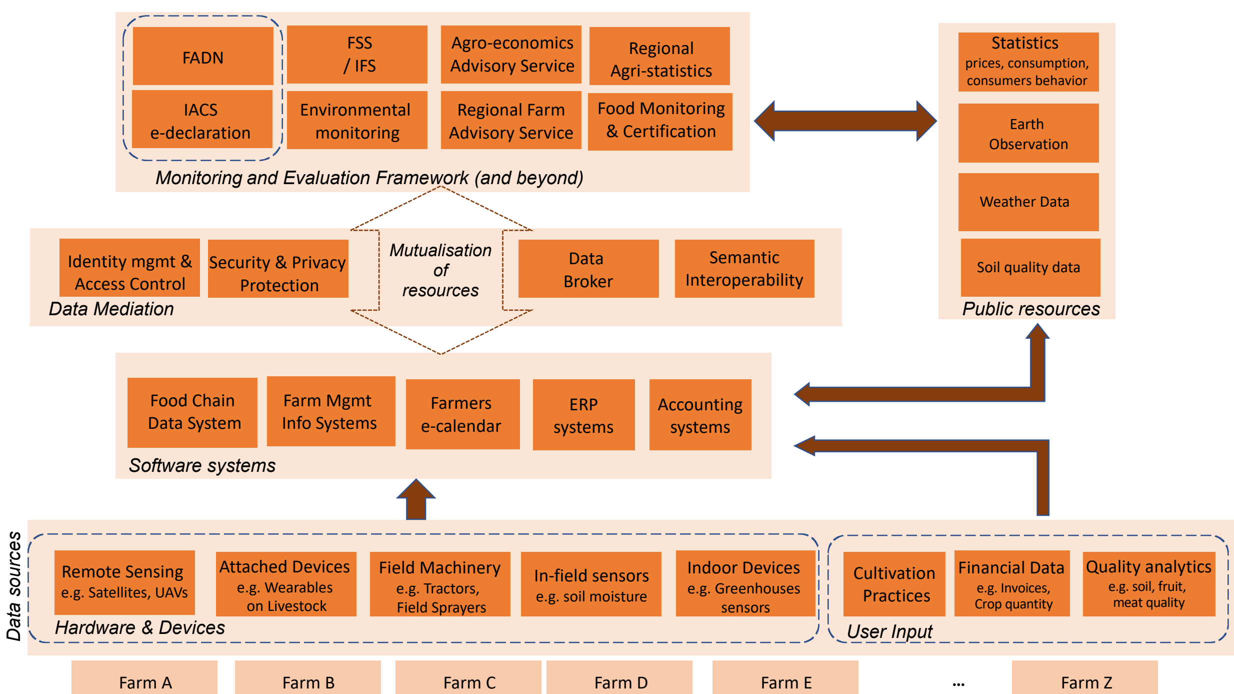

Figure 1. Conceptual view of data sources, data flows and data consumer

However, there are still various challenges that are currently hindering the envisioned approach. Among these issues is the different adaptation level of agricultural technologies across EU but also within Member States countries including also the issue of offered availability of digital infrastructures (also known as "digital divide") which is particularly evident to rural areas. In addition, not all farmers demonstrate the financial capacity to invest on ICT solutions in order to support their every-day tasks while not all technical solutions are capable to provide the same level of accuracy and granularity of collected data. Satellite based Earth Observation (EO) technologies are the key for large scale monitoring solutions. However, they still can't perform adequately to small area parcels (<1ha) that for example dominantly characterise the holdings of farmers in South-East Europe. In addition, the regulatory environment on data sharing including data ownership and the permission to share data is not yet clear. The same holds for technical and semantic interoperability of systems where heterogeneity demonstrated in terms of data models and data exchange mechanisms is also considered a crucial issue on exploiting existing data flows to a maximum extend. These issues will be analysed in the following section of this document.

3. Information and Communication Technologies in Agriculture

In this section an extended technological review is presented in order to assess well-established legacy technology services, but also more advanced approaches that are currently in place for managing the necessary data flows in the agricultural sector. The ICT areas that have been selected for analysis demonstrate the potential to support the operation of contemporary CAP monitoring and evaluation frameworks, but also the relevant future needs. The selected ICT areas have been identified from an early stage during the specification of MEF4CAP Description of Work. These areas were further analysed within the WP2 Task2.1 activities where individual MEF4CAP partners contributed based on their distinct field expertise on the potential of each technology in contributing as a data source in the context of CAP monitoring. The final list of technologies is the following:

- Telecommunication technologies
- Field Sensors
- Farm Management Information systems (FMIS)
- Field Machinery
- Earth Observation
- Livestock Management
- Pasture Management
  Financial management

For each category of technologies an analysis on recent trends is presented along with the level of maturity, the respective adoption status and observed barriers across EU countries.

3.a Telecommunication technologies

Connectivity of devices and sensors is among the most important aspects of agricultural data monitoring as it is a mandatory prerequisite in order to enable communication among entities and share recorded datasets. In 2020, for the first time, there are more IoT connections (e.g., connected cars, smart home devices, connected industrial equipment) than non-IoT connections (smartphones, laptops, and computers) (Lueth, K. L. 2020). Within the IoT telecoms ecosystem there are two major key drivers, the **cellular/mobile IoT**[4] which corresponds to the use of mobile networks for transferring IoT data (e.g. 2G, 3G, 4G, 5G) and the **Low-Power Wide Area Networks (LPWAN)**[5] technologies that are specifically designed to serve IoT devices and promise minimal power consumption and long ranges.

With regards to 5G networks, which are under deployment in our days, the aim is to provide virtually ubiquitous, ultra-high bandwidth, and low latency connectivity not only to individual users but also to connected objects. In 2020, 5G accounted for less than 1% of IoT connections, but it is expected to rise to 40% of all the overall 3.5 billion cellular IoT connections by 2030 (more details on worldwide 5G network availability are presented in Figure 2). The majority of 5G connections will not be significant until 2026, with 4G remaining the dominant technology

[4] https://www.gsma.com/iot/mobile-iot/
[5] "What is Low Power Wide Area Network (LPWAN) Technology?" https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/resources/innovation-technology/low-power-wide-area-technology

over the forecast period (Brown, A. 2021). However, for rural areas and with regards to agricultural use, the impact of the 5G rollout - especially for the first few years - is expected to be less significant than for urban areas. In order 5G to achieve high connectivity speeds, it is necessary to deploy a dense network of access points while there are significant connectivity problems in wooded areas. In addition, the lower population densities in rural areas and wider territories makes them less immediately profitable to invest in for the telecom companies. To this end, previous generations of cellular (4G, 3G, even GPRS) mobile networks are expected to dominate rural areas for the next years. It must be noted that these networks provide the best available coverage until now but devices utilizing these networks tend to be energy consuming (Mekki et al., 2019).

Figure 2. Adoption of 5G as of September 2020

The LPWAN includes a range of technologies focusing on the connectivity of small devices and sensors where the most widely utilized are NB-IoT[6], LoRa[7], and Sigfox[8]. LPWAN has become one of the faster-growing areas in IoT especially for smart agriculture applications. A forecast from IoT Analytics[9] estimates that more than 2 billion devices will be connected through LPWAN technologies by the year 2025. There have been several studies on LPWAN technologies applied to smart agriculture applications (Singh et al., 2020) and LoRa/LoRaWAN is among the mostly utilized in this domain as it demonstrates an open specification and there is already off-the-shelf hardware available for experimental research and rapid prototyping. Some examples of LoRaWAN use in agriculture are environmental monitoring in farms (Codeluppi et al., 2020), livestock monitoring (Grunwald et al., 2019), smart irrigation (Boursianis et al., 2020), offshore sea farms (Parri et al., 2020), and greenhouses (Singh et al., 2020).

There are various reports on the performance evaluation of LoRa especially with regards to network coverage and availability. Based on these reports, performance is highly affected by parameters like the terrain (e.g. mountainous environments (Iova et al., 2017), forests (Villarim

[6] https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/
[7] https://lora-alliance.org/

[8] https://www.sigfox.com/en

[9] https://iot-analytics.com/state-of-the-iot-2020-12-billion-iot-connections-surpassing-non-iot-for-the-first-time/

et al., 2019), temperature (Iova et al., 2017), nodes mobility (Ferreira et al., 2020). Overall coverage varies from a range of ~2km in dense environments to ~18km in open rural areas. Figure 3 provides a view of the various wireless communication technologies and their capabilities in terms of bandwidth and coverage.

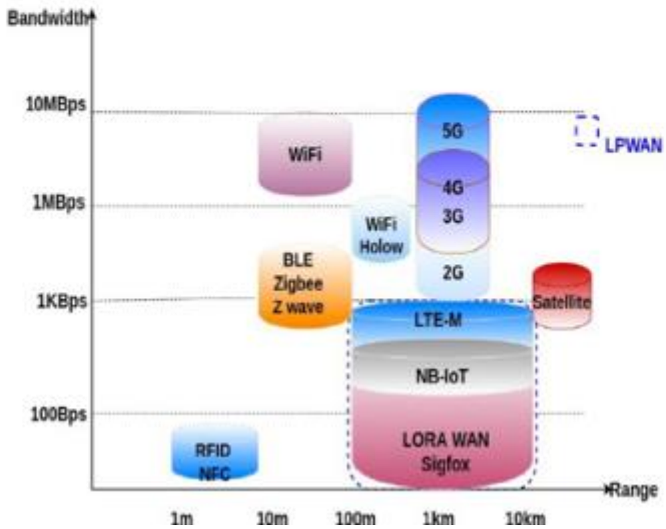

Figure 3. The bandwidth vs. range graph of wireless communication Technologies (Liya et al., 2020)

Overall and with regards to telecommunication capabilities it is projected that the existing rural-urban "digital divide" is not expected to change drastically especially with regards to upcoming telecom technologies like 5G. The "digital divide" on upcoming telecom technologies might be even more evident to regions sparsely populated due to the lack of commercial and business interest from telecom providers as Return on Investment (ROI) tends to be lower than in urban regions. This is also one of the main reasons that 5G is initially rolled out in big cities (Cavalcante et al, 2021). Landscape (e.g. mountainous and forest covered areas) is an additional parameter that will continue to affect the availability and the performance of IoT telecom networks.

In an attempt to address the "digital divide", EU policies are pushing better communication networks in rural areas while the needed hardware infrastructure is expected to become more efficient and with a lower cost. In this context, the EU announced[10] the launch of high-speed satellite broadband, to be available in all EU countries, having the Baltics as the starting point. Satellite Broadband, also referred to as internet-by-satellite, is a high-speed bi-directional Internet connection made via communications satellites instead of a telephone landline or other terrestrials means. Today, satellite broadband is completely comparable with DSL broadband in terms of both performance and cost with commercial offerings of 20 Mbps often with triple play (internet, TV and voice with the same internet). Whilst fibre offers superior performance, it typically takes time and is more expensive to roll out and so will not be available to all users within a reasonable time frame. On the contrary, satellite solutions are available immediately.

[10] https://digital-strategy.ec.europa.eu/en/news/europe-closes-digital-divide

Concluding, the availability of robust telecommunications networks is considered a prerequisite for the efficient use of almost all other technologies that will be described hereafter. High speed connectivity as this is promised to be offered by 5G will be an enabler for the deployment of more advanced technical solutions allowing real time processing of large volumes of data (e.g. online image analytics) and rapid responses with regards to decision making and control (e.g. remote control of machinery). However, in the context of the technologies that have the potential to support CAP monitoring it is more important that the availability and the undisrupted network coverage of more “traditional” telecom networks (e.g. 3G, 4G) at rural areas is ensured.

3.b Field sensors

Field sensors are sophisticated devices that are installed in the field and enable the detection, monitoring and recording of various parameters. Different types of sensors are used in agriculture for collecting data from different aspects such as crop monitoring, substrate monitoring and environment monitoring (Navarro et al., 2020). These sensors usually are connected with or attached on weather stations, which are deployed in strategic positions across the fields and are integral parts of smart farming systems. A smart farming system is based on the technology of wireless sensor networks and its implementation requires three main phases, i) data collection phase using the sensors deployed in an agricultural field, ii) data cleaning and storage phase, and iii) predictive processing using advanced data processing methods including Artificial Intelligence (Dahane et al., 2020).

There are various state of the art reviews (Brewster et al., 2017) (Rayhana et al., 2021) extensively analyzing the performance of - *in situ* - sensor technologies that are able to monitor the conditions around the areas that are deployed. A representative list of the main sensors deployed in the field is as follows:

- Atmospheric temperature, humidity and Barometric pressure sensors (Cao-Hoang et al., 2017)
- Wind direction and wind speed sensor (Cao-Hoang et al., 2017)
- Rainfall detection sensor (Cao-Hoang et al., 2017)
- Soil moisture sensor (Hatanaka et al., 2015)
- Soil salinity/conductivity sensor (Visconti et al., 2016)
- pH sensor
- Light intensity sensor
- Solar radiation meter (Mungai et al., 1997)
- Camera sensors[11]
- Ultra violet, multispectral sensor (Krueger A., 2014)
- Leaf moisture[12] (to detect small amounts of water or ice on leaf)
- Leaf/canopy temperature & humidity
- Evapotranspiration monitoring stations (Pelosi et al., 2020)
- Liquid Level sensors (Consales et al., 2018)
- Temperature and gas monitoring of silo/granary (Maier et al., 2010)
- Gas (e.g. CO2, Ammonia, Oxygen) monitoring sensors

[11] https://metos.at/cropview/
[12] https://www.campbellsci.com/lws

- Active Substance (Pesticide) Sensors (Skotadis et al., 2020)
- Digital (camera-equipped) insect pest traps (Preti et al., 2021)

With regards to CAP performance monitoring, individual field sensors may not be directly considered as a particularly useful source of information given that the individual recordings need further interpretation. Currently, there are various data sharing approaches under research where the direct provision of raw data to public authorities will be compensated through a rewarding scheme but there is no dominant, viable and mature business model yet. However, usually sensors are part of greater precision farming system or FMIS and provide the necessary input in order to proceed with decision making that will guide applied agricultural practices. In some cases, sensor recordings can be considered as additional evidences of recorded farm practices. For example, recorded alterations in soil moisture can be considered as a ground truth evidence that escort a recorded irrigation event on the farmers' calendar field book also allowing to infer the actual amount of water applied. This is the case for example in Figure 4 where we can detect the increase of soil moisture in different depths after an irrigation event (indicated as blue water drop in graph).

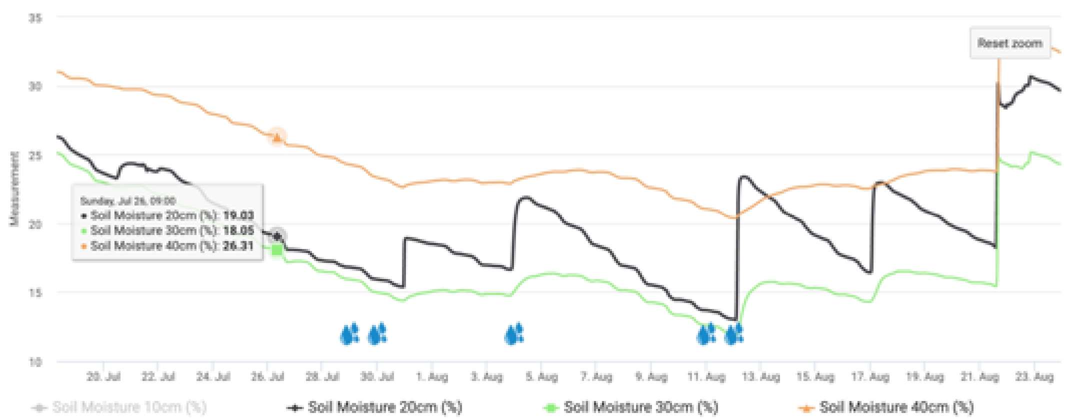

Figure 4. Recorded soil moisture changes escorting irrigation events (Adamidis et al., 2020)

In a similar manner the effect of irrigation on soil salinity at different depths is recorded in figure 5. It should be noted that changes in soil salinity are often associated with the dissolvent of fertilizers within soil due to rain or irrigation.

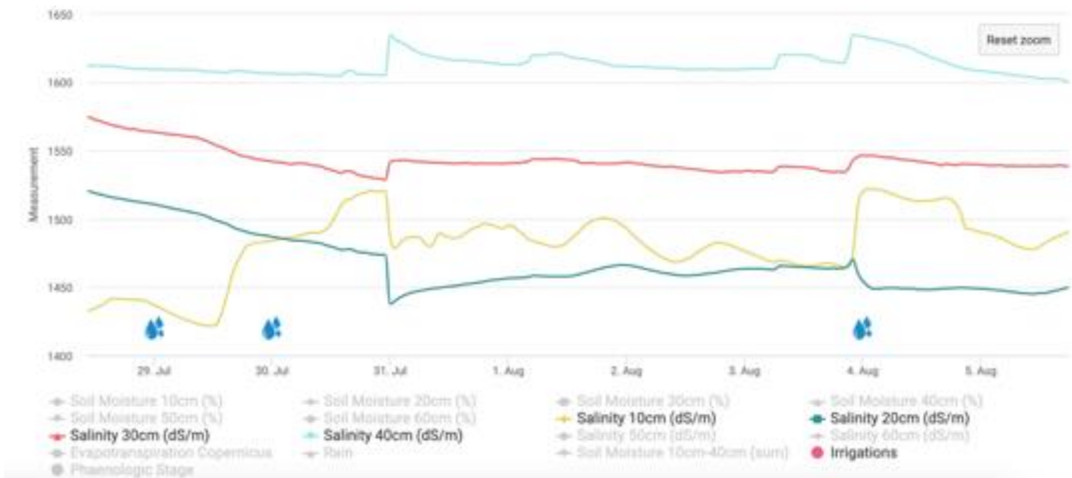

Figure 5. Example of Recorded soil salinity changes escorting irrigation events (Adamidis et al., 2020)

During the recent years, sensing technologies have greatly increased the spatial and temporal resolution of physical measurements, supporting for low-cost, automated measurement of many aspects of agricultural production that were previously only able to be measured in a limited way – for example at discrete points in time by a human observer conducting a field visit (Leslie et al., 2017). In general, the performance and capabilities are expected to further improve and the respective cost to drop. New type of sensors are expected to be able to monitor previously unavailable parameters and agricultural activities. For example, sensing approaches for automated and real-time pesticide detection – at the time of application- are currently investigated from the research community (Skotadis et al., 2020). On the other hand, in-situ monitoring systems still have to face challenges related with maintenance and re-calibration. For example, soil moisture sensors often need to get uninstalled from the ground in order to allow machinery to operate without damaging them and periodically to be recalibrated in order to correctly detect moisture levels (Kibirige et al., 2021). These facts increase the required labour activity and the complexity of the applied processes while questions rise with regards to the accuracy of measured data. On the contrary, earth observation monitoring technologies have a wider coverage and less required hardware maintenance, however, they provide less granular measurements compared with in-situ sensors. Table 1 provides a list of information types that are feasible to be monitored by existing sensing technologies.

Table 1. Data and Information types provided by typical smart farming field sensors

Category	**Type**
Weather	Atmospheric temperature, Humidity, Barometric pressure sensors,Wind direction, Wind speed, Precipitation, Solar radiation, Evapotranspiration
Soil	Moisture, salinity, conductivity, temperature, pH
Plant	Leaf/canopy temperature, humidity, leaf wetness (detect small amounts of water or ice on leaf), evapotranspiration

Camera, Ultra violet, Multispectral sensor	Crop type, phenological growth stage, yield estimation, yield maturity, insects population (traps), pests infestation
Silo/Granary/Tank	Liquid Level sensors, Temperature monitoring, Gas emitted in silo, Silo level monitoring
Gas sensors	CO2, Ammonia, Oxygen, Pesticides

3.c Farm Management Information systems (FMIS)

In smart farming applications, the measurement of several physical or physiological parameters is crucial and indispensable. Smart farming technologies (SFTs) can be divided into three main categories: farm management information systems (FMIS), precision agriculture (PA) systems, and agricultural automation and robotics. We consider that farm management information systems and precision agriculture systems are of more relevance with CAP monitoring and evaluation objectives given that the respective data collections may provide useful insights (FAO, 2021).

Farm Management Information Systems (FMIS) in agriculture have evolved from simple farm recordkeeping and operations planning systems in the 1970s into sophisticated and complex systems to support decision making and production management (Fountas et al., 2015). According to Burlacu et al. (2014), a management information system is designed in order to assist farmers with various tasks, ranging from operational planning, implementation and documentation to the assessment of performed field work. Boehlje and Eidman (1984) defined FMIS as electronic tools for data collection and processing with the goal of providing information of potential value in making management decisions. Lewis (1998) noted that an FMIS exists when main decision makers use information provided by a farm record system to support their business decision making. Sørensen et al. (2010a) defined an FMIS as a planned system for collecting, processing, storing, and disseminating data in the form needed to carry out a farm's operations and functions. Essential FMIS components include specific farmer-oriented designs, dedicated user interfaces, automated data processing functions, expert knowledge and user preferences, standardized data communication and scalability; all provided at affordable price to farmers (Murakami et al., 2007). To improve functionality, various management systems, database network structures, and software architectures have been proposed by a number of researchers. FMIS have increased in sophistication through the integration of new technologies, such as web-based applications and applications for smart phones and tables (Nikkilä et al., 2010). Moreover, technologies such as the Internet of Things and Cloud Computing are expected to leverage this development and introduce more robots and artificial intelligence in farming. This is encompassed by the phenomenon of Big Data where massive volumes of data with a wide variety can be captured, analysed and used for decision-making. Big data are being used to provide predictive insights in farming operations, drive real-time operational decisions, and redesign business processes for game-changing business models. (Wolfert et al., 2017).

The purposes of FMIS are to reduce production costs, comply with agricultural standards, and maintain high product quality and safety, guiding growers to make the best decisions possible (Fountas et al., 2015). Farm management software solutions support the automation of data acquisition and processing, monitoring, planning, decision making, documenting, and managing the farm operations (Köksal et al., 2019), and include basic functions for record keeping like crop production rates (harvests and yields), profits and losses, farm tasks scheduling, weather prediction, soil nutrients tracking, and field mapping, up to more complex functionalities for automating field management accounting for farms and agribusinesses (accounting, inventory management, or labor contracts). In some cases, FMISs are utilized for recording all applied agricultural practices (e.g. pesticides applications, fertilizers, irrigation, mowing, plowing). It should be noted that record keeping of some inputs (e.g. pesticides) is mandatory in accordance with relevant legislation (Directive 2009/128/EC) so in many cases FMISs provide a practical way for recording all relevant practices in one place. FMISs also provide exporting functionalities of logs which are complementary utilized during audits (e.g. organic practices, Good Agricultural Practices[13], etc.).

One of the first surveys on SF systems was conducted on 2015 (Fountas et al., 2015) where a large number of FMISs design approaches, solutions and commercial systems were evaluated in order to provide a basis for the development of future FMISs. The analysis resulted in a feature-based categorization of the systems which are summarized in Table 2.

Table 2. Categories of functionalities provided by FMISs

Function title	Function description
Parcels and farmers profiles	Full record of (relatively) static parcels' characteristics. These characteristics may include parcel's area in hectares, parcel's coordinates, type of current and previous cultivation(s), deployed systems (e.g. irrigations system's, irrigation water sources), etc. Data about the farmer (name, national id, age, address, income, etc.)
Inventory	Includes the monitoring and management of all production materials, equipment, chemicals, fertilizers, and seeding and planting materials. The quantities are adjusted according to the farmer's plans and customer orders. The inventory may also include invoices (hard copy or digital) and other evidences escorting the items of the inventory.
Field operations Management. Farmer's calendar or Field book.	Includes the recording of daily farming activities. This function also helps the farmer to optimize the use of inputs by planning future activities and monitoring the actual execution of planned tasks. Furthermore, preventive measures may be initiated based on the monitored data.
Exporting of basic reports	Generally, includes the creation of farming reports, such as planning and management, work progress, work sheets and instructions, orders, purchases, cost reporting, and plant information.
Exporting of reports for specific purposes	Includes the extraction of reports that contain information requested for specific purposes. For example, reports that are necessary in order to prove compliance with specific standards (e.g. organic standards, integrated crop management requirements, GlobalG.A.P., subsidies applications)
Advanced decision support on applied cultivation practices.	Provide recommendations on cultivation practices such as fertilization, pest management, irrigation based on various parameters such as environmental recordings, cultivation type and

[13] https://www.globalgap.org/uk_en/

	scientific algorithms. Often these processes are supported by the use of advance algorithms coded as software.
Machinery Management	Includes the details of equipment usage, the average cost per work-hour or per unit area. It also includes fleet management and logistics.
Finance management	Includes the estimation of the cost of every farm activity, input–outputs calculations, labour requirements, and so on, per unit area. Projected and actual costs are also compared and input into the final evaluation of the farm's economic viability.
Human resource management	Includes employee management, including, for example, the availability of employees in time and space. The goal is the rapid, structured handling of issues concerning employees, such as work times, payment, qualifications, training, performance, and expertise
Quality assurance and advanced monitoring.	Includes process monitoring and the production evaluation according to current legislative standards. In addition, advance monitoring processes e.g. carbon footprint calculation may be included.

A farmers' adoption study by Lawson et al. (2011) pointed out the benefits of introducing advanced FMIS in relation to budgeting procedures, field planning, and paperwork for subsidy applications and public authorities. The study compared FMIS adoption between northern and southern European Union (EU) countries and found that Northern European farmers are inclined to spend more time working with computers than their Southern colleagues, probably due to the more developed and more business-oriented types of farms that exist in Northern Europe.

A key point in FMIS development and adoption is the profitability of the system (Verstegen et al., 1995). Profitability indicators are important not only to the farmers who consider software investments but also to the developers who design and market FMIS. The benefits of a FMIS extend from the value of the improved decision-making process, which, however, is often difficult to quantify. For example, the benefit of using an FMIS could depend on the level of the user's experience. As a special case, Lewis (1998) noted that younger farmers with a relative lack of farming experience can particularly benefit from using an FMIS.

A study by Wageningen University (Robbemond and Kruize, 2011; Kruize et al., 2013), aimed at presenting the current situation of FMIS and the use of data standards, provided an overview of all the functionalities used and data standards offered by applications in the market through the creation of a reference model. Key points included the importance of a common data exchange between the FMIS and external factors, such as agricultural input suppliers, processors, data providers, and governmental offices.

Stakeholders and farmers may encounter difficulties in making proper decisions about agricultural management with the explosive amount of information (e.g. environmental, crop-related, and economic data) (Taechatanasat and Armstrong, 2014) because it is challenging for them to transfer these data into practical knowledge. Thus, platforms like decision support systems (DSSs) are needed and are often an integral part of an FMIS in order to assist farmers in making evidence-based and precise decisions. A short overview of Agricultural decision support systems follows.

Agricultural decision support system

ADSSs are designed to assist humans in making more effective decisions. In the field of agriculture, different stakeholders such as farmers, advisers and policymakers use software tools that facilitate farm management by gathering data from multiple sources, analysing these data and utilising a series of suggestions that are presented by different visual outputs. Many ADSSs are designed to support the concept of precision agriculture which seeks to provide a holistic approach to assist farmers with optimising resources (Paustian and Theuvsen, 2017).

Current ADSS available to farmers are not used to their full potential and are not adapted to the trade-offs and high complexity characterizing farmers' decision making (e.g., Eastwood et al. 2012; Van Meensel et al. 2012). This has been called the ''problem of implementation'' (Rossi et al. 2014) within the agricultural domain. The uptake and acceptance are low, partly because existing ADSS are based on what scientists and ICT system developers consider as necessary knowledge that should be implemented in the decision support, but in reality, they fail to capture the tacit knowledge and practical needs of farmers. Other reasons for the low adoption rate of ADSS by farmers are, e.g., a perceived problem of complexity, lack of observability, level of knowledge of the users, lack of confidence, poor user interface design, tedious data input requirements, low adaptation to the farm situation, no frequent information update, lack of incentive to learn and adopt new practices, and the fear of replacing advisors (e.g., Rossi et al. 2014; Van Meensel et al. 2012).

Concluding, FMISs can be considered as one of the most valuable information sources on a farm level. Especially, the functionality related with the digital recording of agricultural activities (also called "Farmer's Calendar", "Farm Log", "Field book") has the potential to contain all the relevant to CAP monitoring information (e.g. use of pesticides, irrigation, fertilizers). Table 3 summarizes the various information items that are maintained by FMISs.

Table 3. Information types provided by FMISs

Category	Information
Information on agricultural land	Area covered by parcel (in Hectars), polygon (coordinate) of the parcel
Crop type and land use	The use of parcel (if it was cultivated or not, pasture or cultivation) and the type of crop (arable, trees, vegetables, perennials, etc.)
Agricultural Inputs – Fertilisers, Pesticides, Irrigation	The type, amount and time/date of applied inputs for a parcel along with the
Agricultural practices – Farmers calendar or Field book	Partially includes the inputs mentioned above. A field book may also include day of planting, phenological growth stages, recordings of pest infestations, harvested yield, etc. In addition it may contains cultivation practices like Mowing and Plowing.
Agricultural practices – Organic cultivation practices	This information item refers to weather a cultivation is treated with a manner approved for organic agricultural products.

Livestock - Herd management	Total number of animals, type of animals, annual births/deaths, medicines utilised, animal feed utilized, etc.
Livestock Pasture management	Number of animals, type of animals.

3.d Agricultural machinery

During the recent years, agricultural machinery (e.g. tractors) are getting continuously more sophisticated and in our days are enhanced with data recording, processing and telemetry capabilities. Telemetry has been utilised extensively in agriculture during the past 10 years. It offers the possibility to gather data from machine Electronic Control Unit (ECU) thanks to CAN-Bus electronics. It allows usage analytics based on temporal profiles and current machine status. It facilitates the decision making in terms of operations and maintenance introducing predictive maintenance possibilities. Simple decisions based on position and date tracking are essential in agriculture to monitor the farming operations.

Telemetry linked with precision farming facilitates the integration of implement data and specific crop information based on ISO 11783[14] (ISOBUS). ISOBUS has different standards to facilitate communication between tractors and implement. Among those standards, *Task Controller* represent the most prominent approach in terms of field and crops specific data. There are three level of Task Controller according to the Agricultural Industry Electronics Foundation: Basic, Section Control and GEO.

Basic (TC-BAS) Describes the documentation of total values that are relevant for the work performed. The implement provides the values. For the exchange of data between farm management system and Task Controller the ISO-XML data format is used. Jobs can easily be imported to the task controller and/or the finished documentation can be exported later.

Task Controller geo-based (TC-GEO) Additional capability of acquiring location-based data – or planning of location-based jobs, as for example by means of application maps.

Task Controller Section Control (TC-SC) automatic switching of sections, as with a plant protection sprayer, seed drill or fertilizer spreader, based on GPS position and desired degree of overlap.

TC-BAS represents the main source of crop automatic data collection granule at parcel level. It covers most requirements about field books information collection in an automated manner and could be considered the simpler and more oriented data source for automatic machine data collection.

TC-SC is more oriented toward live machine operation closing sections according with the excluded areas. On the other hand, TC-GEO represents a more detailed source of information when precision farming is on the scope. It is foreseen that in future Variable Rate Applications (VRA) will represent an essential technique in the optimization of fertilizers and plant protection products according to Farm to Fork strategy and therefore prescription maps could be used as a source of more detailed information.

[14] https://www.iso.org/standard/57556.html

As a final note, the ISO 11783 (ISOBUS) standard for recording of machinery operations is a dominant data modelling approach utilised by key stakeholders (e.g. Agricultural Industry Electronics Foundation[15]) including industry (e.g. John Deere[16]). The dominant role of ISOBUS during the recent year allowed the development of interoperability enablers that support the integration of machinery related activity with the rest of the FMIS recordings[17]. This means that ISOBUS based recordings can act as additional – ground truth- evidences that will escort the farmers' field book recordings. For example, the recording in the field book of pesticides or fertilisers application can be escorted by the ISOBUS encoded activity of the machinery utilised for this application. However, ISOBUS is only useful when advanced machinery equipment are in use which might not be the case for less industrialised family farms (especially in the south-east Europe). Table 4 summarises the various categories of information items that can be provided by field machinery in the context of CAP monitoring.

Table 4. Categories of information items that can be provided by field machinery

Category	Comment
Information on agricultural land	Georeferenced data recorded during the use of machinery (tractor) can be utilized as evidences of the area and the location (polygon) of a parcel.
Agricultural Inputs – Fertilisers, Pesticides, Fuel	Georeferenced data recorded during the use of machinery can be utilized as evidences the various inputs that have been utilized (e.g. fertilisers, pesticides applied with the use of a machinery.
Agricultural practices – Farmers calendar or Field book	Georeferenced data recorded during the use of machinery can be utilized as additional evidences that escort recordings at the farmers calendar (e.g. part of the FMIS)
Financial data	Georeferenced data recorded during the use of machinery can be utilized as additional evidences escorting input/output financial records. For example, invoices of purchased chemicals linked with recordings of applied chemicals with the use of machinery. Fuel consumption recordings associated with recordings of machinery use.

3.e Satellite based Earth Observation & Remote sensing services

Advancements in Remote Sensing (RS) technologies over the past decade have meant that Earth Observation (EO) is now accessible like never before. Particularly, a substantial progress has been made bringing new technologies and new systems into operation, such as numerous sensors with unprecedented combinations of spatial, temporal, and spectral capacities of on-

[15] https://www.aef-online.org/about-us/isobus.html
[16] https://www.deere.co.uk/common/docs/services_and_support/stellarsupport/en_R2/ag_management_solutions/guidance_and_machine_control/isobus/PFP13080_ISOBUS_User_Guide_EN.pdf
[17] https://www.cema-agri.org/images/publications/position-papers/CEMA_PT3_-_2017_01_20_-_AEF-AgGateway_collaboration_web.pdf

board satellites' (e.g. Sentinels, Worldview) sensors and the advent of small Unmanned Aerial Systems (UASs) (Khanal et al., 2020). In addition to the impact of cloud, the EO service industry finds itself at the crossroads of two revolutions, the one of Big Data/Artificial Intelligence (AI) and the one of commercialisation of space (through its main drivers, small and micro satellites) (EARSC – ESA, 2019).

According to the survey accomplished by EARSC, the EO sector continues to grow at a good rate of 10% per year. The results for the year 2018 indicate that there are 515 European companies active in the sector which are employing some 8,400 employees and generating €1.25b of revenues. Each of these figures (figure 6 and 7) shows a growth of over 20% since the last survey (State and Health of the EO Services Industry 2017) (EARSC – ESA, 2019).

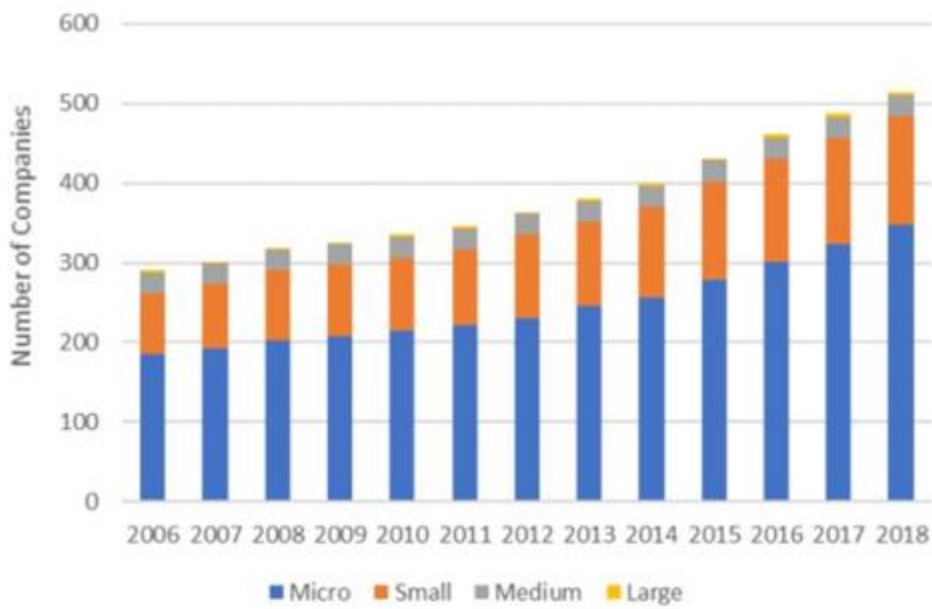

Figure 6. Growth in the number of companies (EARSC – ESA, 2019)

Figure 7 depicts the vertical market breakdown, with the segment of defence and security to present a growth from around 20% in 2016 to more than 30% in 2018. The second strong sales segment is agriculture and land with 12% of business generated.

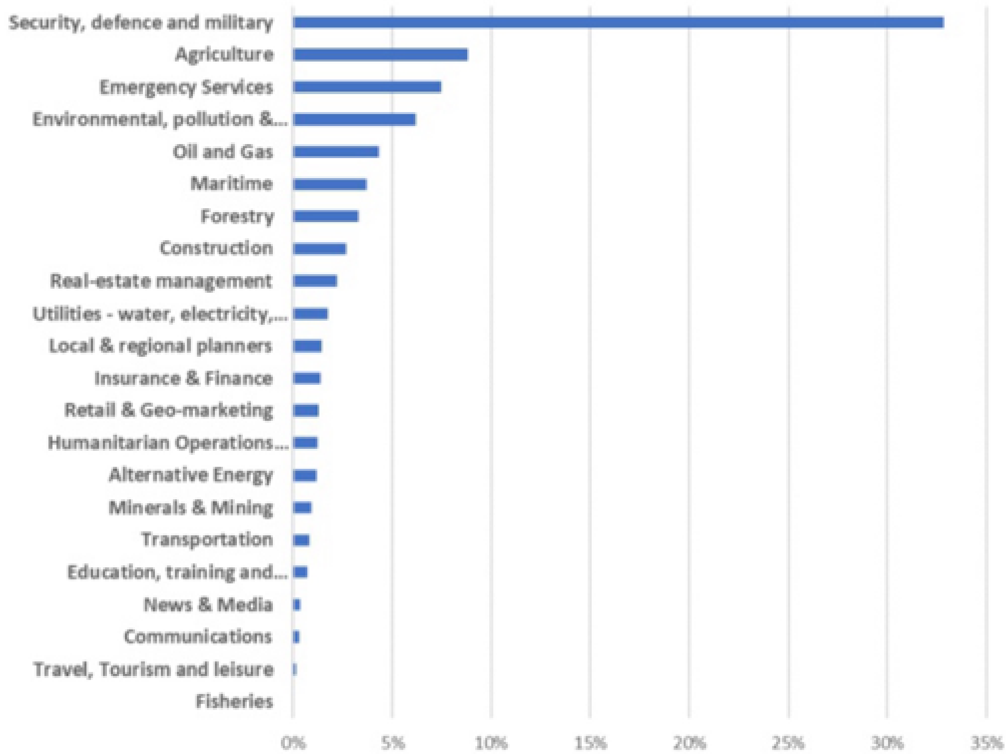

Figure 7. Market sector's sales in detail (EARSC – ESA, 2019)

This is due to the unique benefit of EO for global, repeatable, accurate and scalable environmental information, providing high-value, cost-effective insights to the agricultural sector and supporting: (i) the increased agricultural production through accurate decision support tools, (ii) the sustainable management of environmental resources such as land and water, (iii) the optimization of supply chains to reduce losses and improve food security, (iv) the accuracy of flood and drought warning systems, and (v) the affordable credit for farming inputs and insurance for crop and livestock losses (Caribou Space, 2020).

However, there are still various challenges that need to be addressed in order RS technologies to have an even higher adoption in commercial agriculture. Some of these factors include: (i) the lack of EO at sufficient temporal, spatial and spectral resolution, and at appropriate cost, which can be cost-prohibitive, especially for SMEs and/ or small farms (Sishodia et al., 2020), (ii) the complexity of accessing, storing and manipulating EO due to the requirements of a significant amount of technical knowledge and expertise to process them for real-world applications as well as computing infrastructure (Caribou Space, 2020), (iii) the lack of understanding of what types of EO can be produced and what are the benefits of the use as well as how to use this source of information (Caribou Space, 2020; Sishodia et al., 2020), (iv) the interoperability with data and tools from a variety of sources (Khanal et al., 2020).

With regards to agriculture and monitoring in the context of CAP - already since 1992 - satellite images are in use in order to control some of its area-based subsidies. This process is generally based on the interpretation of commercial & freely available satellite imagery or aerial photography. In 2015, the EU launched its own satellites (Sentinels[18]), under the Copernicus programme, providing freely available satellite imagery to all entities. That had a great impact on CAP monitoring as Copernicus Sentinels have been systematically delivering optical (multispectral) and radar imagery of high quality and spatial resolution enabling the development of new automated applications for agricultural monitoring. Lately, these technologies have been combined with machine learning and big data methods to provide timely, detailed and reliable information for predicting crop types and checking vegetation cover for different crops. EU Paying agencies are gradually adapting to the use of these technologies. In May 2018, some PAs started applying the so-called checks by monitoring to prepare for the upcoming CAP reform[19]. This approach uses automated workflows on Copernicus Sentinel data obtained every 5 days combining information provided by the farmers.

More specifically, EO data is combined with machine learning or other algorithms to provide:

- Crop type classification, using Sentinel image time-series and farmers declarations to automatically predict the different crop types.
- Parcel homogeneity detection, using Sentinel image time-series to automatically detect inter-field conditions and possible multi-crop parcel or illegible areas
- Agricultural activity detection (e.g. tillage, mowing, harvest), using Sentinel image time-series to monitor certain agricultural activities on individual parcels
- Field boundaries, using Sentinel image time-series and growing patterns agricultural field to delineate and trace field boundaries and monitoring fields parcels to clarify illegible features

Although all EU PAs either use or plan to use the new EO technologies for CAP monitoring, there are still some challenges that should be highlighted:

- Further development of AI frameworks on analysing the vast amounts of imagery data
- Big data and complex algorithms require significant changes to IT systems
- Provision of VHR imagery for dealing with small parcels.

Table 5 summarises the various categories of information items that can be provided by earth observation & remote sensing in the context of CAP monitoring.

Table 5. Information types provided by earth observation & remote sensing services

Category	Comment
Sensors	**Sentinel 1 -** Sentinel-1 is a two-satellite constellation (Sentinel-1A launched in April 2014 and Sentinel-1B launched in April 2016) providing C-Band SAR data continuity over Land and Ocean, following the retirement of ERS-2 and the end of the EnviSat mission. The

[18] https://sentinels.copernicus.eu/web/sentinel/home
[19] https://op.europa.eu/webpub/eca/special-reports/new-tech-in-agri-monitoring-4-2020/en/

	repeat cycle for a single satellite is 12 days and drops to 6 days for the constellation. Both Sentinel-1 satellites operate in the same orbital plane (180° phased in orbit). The C-SAR sensor offers medium and high-resolution imaging in all weather conditions, while it is also capable of obtaining night imagery and detecting small movement on the ground. Sentinel-1 SAR data is provided in 4 acquisition modes, 3 modes for land data (Interferometric Wide – IW swath, Strip Map – SM, Extra Wide – EW swath) and 1 mode for data over open ocean (Wave – WV).
	Sentinel 2 - The Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same orbit, phased at 180° to each other. It aims at monitoring variability in land surface conditions and its wide swath width and high revisit time (10 days at the equator with one satellite and 5 days with 2 satellites under cloud-free conditions resulting in 2-3 days at mid-latitudes) supports monitoring of changes to vegetation within the growing season. The Sentinel-2 L-2A products are atmospherically, terrain and cirrus corrected. The Sentinel-2 L-2A datasets contain several layers of information, including data from the on-board MSI sensor (13 bands, 443 nm – 2190 nm wavelengths, 10 – 60 m spatial resolution), as well as information over the cloud coverage, water presence, thin cirrus presence, etc.
	Landsat – 8 - Landsat-8 carries an Operational Land Imager (OLI) and a Thermal Infrared Sensor (TIRS) instrument on board. Surface reflectance data from Landsat-8 products are generated at 30 m spatial resolution UTM or Polar Stereographic (PS) mapping grid at GeoTIFF file format. Landsat8, launched in 2012, acquires images with 11 spectral bands; it has a revisit time of 16 days.
	MODIS - MODIS is a key instrument on board of NASA's Terra (EOS AM-1) and Aqua (EOS PM-1) satellites that plays an important role in studying land surface properties and processes and for the development of models to predict global change. It is a system of two sun-synchronous, near-polar

	orbiting satellites called Aqua and Terra that acquire daily images all over the world. Terra collects images in the late morning and Aqua in the early afternoon; they also have a night-time pass when they acquire in thermal bands. Terra and Aqua MODIS satellites capture the entire Earth surface every 1 to 2 days and acquire data in 36 individual spectral bands (400–14,400 nm) at resolutions of 250 m (bands 1–2), 500 m (bands 3–7), and 1000 m (bands 8–36).
RS of crop properties	**Vegetation Indices (VI)** combine the reflectance of 2 or more wavelengths in order to maximize their sensitivity to the biochemical or biophysical crop property of interest while minimizing external variation factors and often integer a wavelength sensitive to the crop property of interest and another one insensitive. **Biochemical crop properties** (chlorophyll, carotenoid, ratio carotenoid/chlorophyll and anthocyanin content, whose relative concentrations will directly impact crop color, nitrogen and crude protein content, content in plant structural materials, i.e. lignin and cellulose, water content and starch content) **Biophysical crop properties** (ground cover (also called canopy cover, green cover, vegetation fraction, fraction cover (FCOVER)), total or green Leaf Area Index (LAI), specific leaf area (the one-sided area of the leaf divided by the dry weight of the leaf), above ground biomass (wet or dry, total or leaf), canopy volume, plant height, flowering intensity, grain and biomass yield, Fraction of Absorbed Photosynthetically Active Radiation (fAPAR), crop growth stage and phenology)

3.f Livestock management technologies

Application of ICT in animal husbandry can be divided into 3 broad themes; breeding, animal welfare and herd management (Shalloo et al., 2018). The latter 2 have a focus on senor technology, whilst genomic breeding has a focus on data analytics, however animal sensors connect with genomic applications in the identification of inheritable phenotype traits. A good example are commercially available progesterone monitors in the dairy industry that allow farmers to manage fertility cycles but also can feed back information at the animal level into phenotyping for genetic merit (Guang-Min et al., 2017).

Breeding/Genomics

The adoption of genomic technology and ICT driven breeding programs is rapidly progressing with the potential to achieve large-scale gains at the animal level. Current genetic evaluation algorithms exploit only a small section of the genome- as sequencing becomes cheaper and easier it allows for quick detection of causal mutations. The use of machine learning analysis to national genomics databases, such as the Irish ICBF (Shalloo et al., 2018), exploiting genetic markers with a wider array of performance metrics is being investigated in the literature (Bo et al., 2018). A good example of current research “Genomic management Tools to Optimize Resilience and Efficieny”, GenTORE, a H2020 project which will develop innovative genome-enabled selection and management tools (Guang-Min et al., 2017).

Animal Welfare

The use of sensors to observe performance characteristics of animals in the context of welfare is now well established commercially (Knight C. H., 2020). Sensors on the animal monitoring movement, gait and feeding are available- alerting farmers to lameness, heat and other issues. The sensors are nano-electrical or mechanical integrated within networks, either dedicated low power farm networks (Neethirajan S., 2017) or existing 3/4g. Increasingly edge analytics are being designed to reduce network use and the harvesting of ambient energy is a current topic in the literature (Partha Pratim Ray, 2017) – so called internet of farms. The wearable devices exploit positional sensors and triaxle accelerometers. Rumen sensors deploy devices, bolus’, into the animals' stomach that communicates details of the rumen condition via a network (Bo et al., 2018).

Current examples of wearable devices that monitor individual animals are the MooMonitor+ (Knight C. H., 2020), or SmatBow (Neethirajan S., 2017) that monitor individual ruminant activity and feeds data to animal welfare DSS. The use of such devices is more common in the dairy industry rather than meat. These devices are used in both grazed and housed systems. Devices that measure jaw movement as used to monitor feeding, either at grass or in-doors (Partha Pratim Ray, 2017).

Herd Management

Application of ICT to herd management is advanced, and well developed in some areas, from simple online herd management software up to robotic dairy parlors.

Herd management software essentially digitizes the book-keeping of herd management recording non- real time info on each animal such as age, breeding performance etc. There are many examples of livestock management software and they often overlap with pasture management software (see 3g).

More advanced herd management is linked primarily to feed management and milking. Housed animals, intensive beef, pig and poultry systems, apply ICT at the housing level using sensors to control temperature, humidity, light levels etc. Atmospheric monitoring can be important in these systems to avoid welfare issues for animals and farmers, like detecting carbon dioxide, anomia and hydrogen sulphide. These systems can be retrospectively installed or built from scratch (Rodenburg J., 2017). New technology in housed systems involve machine vision systems observing cattle via video and detecting aberrant behaviour (Herlin et al., 2021). Other approaches are to use sound to detect issues, for example coughing in industrial piggeries to limit disease outbreak.

Robotic milking parlors are now routine technology in many parts of the world and rely on the integration of ICT across the farm to operate (Rodenburg J., 2017). Simple technologies such as RFID ear tags allow for identification of cattle as they approach the robotic parlour in grazed systems.

Virtual Fencing is where digital herd management links directly with precision paddock management. Virtual fencing controls where animals graze without the use pf physical fences relying instead on GPS enabled collars on the animal that provide an electric shock if the animal goes out of bounds. Typically, only the herd leaders are equipped with a collar. The technology is used in rangeland systems such as Australia and US but less so in EU (Herlin et al., 2021).

The use of drones in herd management is being explored, with drones used as shepherds to drive animals to the use drones in locating lost animals.

The lack of interoperable data standards in precision livestock systems has been identified as a barrier to growth (Bahlo et al., 2019).

Overall, there is great potential on the described technologies in order to act as livestock farming information sources related with CAP monitoring and evaluation indicators. These technologies can provide currently unavailable ground truth evidences on the number, the type, the behavior of animals along with recordings on consumed inputs and produced (food) products. Table 6 summarises the respective information items.

Table 6. Information types provided by livestock management technologies

Category	Information
Genomic	Genetic Quality, Breeding Indices
Animal Behavior -sensing technologies	Animal movement, Lameness Detection, Heat Detection, Grazing detection, cow localization, Rumen Condition
Herd management digital book-keeping	Number of animals, Type of animals, consumed inputs (water, food, medicine)
Video	Facial Recognition, Lameness condition, Body condition scoring
Herd Management	Virtual Fencing, Drone Herding, GNSS/3G Animal Location
Housing with atmospheric monitoring, sensing technologies, feed management and robotic milking	RFID sensors – number of active animals Atmospheric monitoring - Detecting carbon dioxide, anomia and hydrogen sulphide, calculating carbon footprint and other environmental indicators, feed management & milking - Monitoring consumption of food and production of food product (e.g. milk)

3.g Pasture management technologies

Application of ICT to Pasture Management breaks down into the well-developed paddock record management and feed budget software market and newer applications of sensor technology in measuring and analyzing the sward both directly and remotely.

Paddock Record/Farm Management software

The key to profitable and successful grassland farming is record keeping, planning and grass measurement, sustainable farming also requires management of nutrients on the grassland farm. Paddock Management software, for example the Irish PastureBase[20], collects data imputed from the farmer on grass covers, silage production, grazing times etc. The software should produce a feed wedge for forward planning of grazing needs on the farm. Nutrient Management Planning software estimates organic and inorganic nutrient loads on the farms and issues advice on application based on good practice and in some cases forecast weather conditions (Hedley, 2015).

Grass Measurement Technologies

Grass is conventional measured weekly across the farm using traditional techniques (most commonly it is estimated based on farmer experience). New technologies used by farmer in situ automate collection of some of this data. For example, automated plate meter technology feeding grass biomass data directly to smartphone application. A newer technology is the use of in-situ sensors permanently placed in the farm measuring grass levels, soil conditions etc. and linked via networks to farm management software. Commercial example included FieldSense[21] and FarmMote[22], Digital weather stations are increasing used on grassland farms and these observations can be fed into weather driven grass growth prediction models.

There are a number of projects exploring AI for analysis of images of grassland acquired form smart phone and drone in order to extract characteristics such as biomass, sward type or grass weed detection. In general, the approach is to implement these tools on mobile platforms, phones and tablets.

Most of the technologies currently focus on biomass and cover, however a number of sensors and approaches are in development for direct and remote measures of fodder quality (such as protein content).

Remote Measurement of Grass

The use of remote sensing in grassland management is growing but adoption of PA in grassland systems is far behind tillage (Lowenberg-DeBoer et al., 2019). For example, the SmartAKIS[23] portal, focused on digital advisory tools, has registered 430 digital farming products on the market, of these 55 are marketed at grassland farmers. Common PA services for tillage such as intra-field biomass variation, yield prediction, pest control, and control of variable rate

[20] PastureBase Ireland – Teagasc - https://pasturebase.teagasc.ie/V2/login.aspx

[21] https://www.anuland.ie/
[22] https://farmote.com/
[23] https://smart-akis.com/

technologies (VRT) on the farm are not always relevant to grassland farmers. But mapping based solutions for paddock design is commonly used.

A small number commercial services have created specific models to estimate biomass (kg ha-1) or growth rate (kg ha-1 day -1) of grass from satellite data and these are of more direct use. These figures can be directly fed into grass/feed wedge calculations for farms (for example https://Pasture.io).

These multispectral approaches form satellite are now being applied to drone measurement of grassland biomass services that are being developed.

In mountain or range pastoral systems the use of satellites for large scale mapping of grass growth and feed on demand models is common, exploiting especially the use of anomaly mapping[24]. The development of services based on sentinel-1 data, overcoming issues of cloud cover often present in grass growing regions is importantt[25]. The development of EO methods in grassland is likely to be equally driven by regulatory authorities and insurance companies as by farmers (Vroege et al., 2019).

Based on these, pasture management technologies demonstrate significant potential to act as information sources in the context of landscape management of the new CAP montirong and evaluation framework. Table 7 summarises the various information types/categories that can be monitored.

Table 7. Information types provided by pasture management technologies

Category	Information
Satellite	Green Cover, Relative performance, Biomass, Growth Rate, Sward composition, feed on offer, pasture condition, harvest yield
Handheld	Biomass, growth rate, crude protein, sward height
Smart Phone	Biomass, sward composition, weed identification
Drone	Biomass, Growth Rate, cover, intra-field variability, weed detection
In Field Sensor	Biomass, soil moisture, weather records
On machine	Silage Yield, VRT application (fertilizer), soil properties

3.h Platforms for financial information exchange

Farmers act within a network of commercial and governmental organisations. The information exchange between farmers and these organisations increasingly occurs through digital means. These digital information flows provide a wealth of information for policy evaluation and monitoring and have the potential to reduce transaction costs (e-declarations etc.). However,

[24] http://www.pasturesfromspace.csiro.au/
[25] https://vandersat.com/data/cloud-free-biomass/

the current farm information system is far from perfect to fulfil that potential. Situations differ considerably between member states and within regions between farmers but also with regards to the different information systems utilised. The overall ecosystem demonstrates significant heterogeneity both on utilised technologies but also on regional/national regulatory environment. With regards to agricultural financial information exchange we select to initially and mainly analyse historic and current status of the Netherlands as it can be considered one of the pioneering countries in automating the specific processes. In addition, applied practices in the Netherlands can also be considered as large scale use case that allows to extract significant results towards the future harmonisation of agricultural financial information exchange systems for all member states.

Historically, farm management information systems have two origins: farm accounting and farm field books. A century ago, in the Netherlands farm accounting was made obligatory for income tax reasons (Breembroek et al., 1996). That led to the establishments of cooperative farm accounting offices that also provided benchmarking. These data were used in the 1950s and 1960s in farm study groups to get grip on the mechanization of farming. In the 1960s the EU provided interest subsidies to farmers on the condition that they kept analytical accounts. Since the 1980s accounting has included volume data and that gave the option to calculate environmental indicators like the use of pesticides, antibiotics and nitrogen-surpluses (Poppe, 1992). For a short period, the Netherlands had its MINAS system, a policy instrument to manage nitrate and phosphate emissions that made mineral accounts with nutrient balances obligatory (Breembroek et al., 1996). By linking these to the fiscal accounts the auditability of the accounts improved as it made it less likely to 'forget' an invoice on e.g. feed (that is a deductible cost in income calculations but increases the nutrient input). The signature of an accountant under the calculations helps too.

As accounts come in rather late, based on invoices and often produced by specialised accounting offices, farmers used field books to make notes on treatments of animals (individual or at group level), crops and fields. These were digitalised as farm management information systems. Adoption was slow, as such records demand a lot of manual input. But they were more useful for operational management than the farm accounts. They have become more popular in the last decennia, as several information systems in the supply chain for tracing and tracking, food safety (GlobalGap etc.) and sustainability schemes (Animal welfare, organic, On the way to PlanetProof, etc.) are partly based on these records. Advanced management systems are also well integrated with obliged animal registrations and applications of CAP subsidies with their requirements for field maps (LPIS/IACS).

Integration of accounting and farm management systems has until now been problematic. There are differences in timing (a use of pesticides is sometimes recorded before the invoice of the supplier arrives) and in supporting institutions (accounting offices versus software suppliers) behind these services. Accounting also has to handle payments like total-sales bonuses or profit-sharing transfers by cooperatives that farm management information systems neglect for simplicity.

Digitalisation of data flows

The current data flows in Dutch agriculture are complicated (Figure 8). Farmers hardly sent invoices or dispatch notes. Accounting has been made easy in the past by the food processors by creating the invoices. For a dairy, that also measures the quantity and quality of the milk, it is easier to send 5,000 invoices to the supplying farmers than to handle 5,000 incoming invoices. Many invoices are still delivered by the post on paper, but digitalisation is slowly on its way. In the 1990s the accounting offices installed a system for Electronic Data Interchange (EDI) with a central hub (EDI-Circle, now part of the cooperative datahub JoinData) and in the livestock sector some of the invoices relevant for the MINAS system were digitalised. Accounting offices received payment data from the banks on magnetic tape already in the 1980s (far before the current PSD2 obligation for banks to make payment data digitally available). Linking these two flows made an early form of automatic coding possible – an early version of a practice now labelled as 'robotic accounting'. However, this best practice was not copied by other actors that send invoices. In recent years PDFs have been introduced in addition to or replacing paper invoices (e.g. by companies like UnifiedPost that handles the invoicing for large clients that have to print thousands of invoices). That is not always an improvement. Some are machine readable (e.g. with OCR technology), others are not. And some of them are not sent to or stored by the farmer but must be accessed on websites of the companies that create them. This can make accounting a search activity for the relevant documents on a wide range of password protected company web-sites.

Data from invoices and other documents has to be entered in software and coded (into types of costs and sales) and some of the data has to be allocated to crops, fields or animals. As long as data are not fully digitalised that is a labour intensive task and prone to errors. Some farmers do it themselves (using software linked to that of their accountant like Visma or Exact Online), most pay their accountant. Some digitalise their paper invoices with a smart phone and send them in a pdf or jpeg format to their accountant but this quality is often too low for using OCR techniques. The app AgriNota (developed by the agricultural accounting office Alfa Accountants) supports creating such pdfs and support farmers in managing them. There is specialised software for scanning with OCR (nearly 20 different brands, including Basecone, Blue10), that are linked to accounting software. Some applications can download pdf's from portals or websites of the trading partner. Often only the header and the total amount are scanned, not the individual lines of an invoice. That is fine for fiscal accounting but does not create management or sustainability information. One of the most advanced applications is Scansys that recognises the number of the Chamber of Commerce on the invoice and scans individual lines if a template for that firm has been created in advance. If the sender changes the format of the invoice, the template has to be updated.

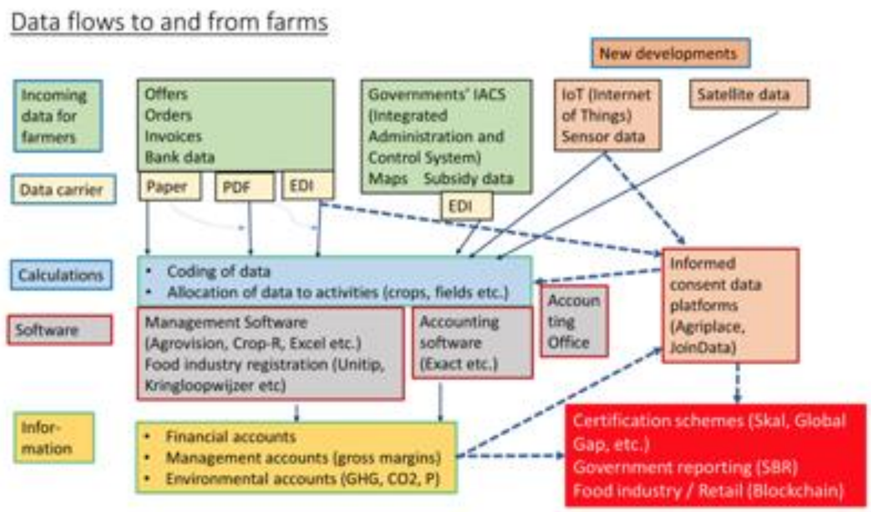

Figure 8. Data flows to and from farms (and their accountant)

Although scanned invoices help in documentation, even when OCR is problematic, the scanning itself is labour intensive: formats differ, staples and paperclips have to be removed. If OCR is used it has to be checked (one management software supplier even uses a service in Asia that visually compares the pdf with the OCR interpretation or even to manually enter the data). Practices between farmers and their accountant differ. One large agricultural accountancy company requests all invoices on paper, otherwise it charges up to one day for gathering and printing out the pdfs itself. Others require pdfs and charge for sending in paper. The situation is also confusing for organisations that certify farmers, such as the organic certification body SKAL. In times of COVID-19 digital compliance audits are attractive for certifying bodies, but they have to deal with many different practices by farmers and a variety of software. The Farm Accountancy Data Network is in a similar situation. It also leads to undesirable exchange of passwords for websites between farmers and accountants, advisors or inspectors to retrieve pdfs.

Digital Platforms

Digital platforms combine data to create services that users find useful, with a business model that maintains and innovates the platform. Data on and from the users are actively collected and analysed to improve the service. Especially that last characteristic distinguishes a platform from a simpler website where data are offered or exchanged and leads to important network economies: the more users there are, the better the services (e.g. via big data analysis and artificial intelligence) and the more attractive it becomes to use the platform (Mansell and Steinmueller, 2020). More users also lead to lower cost per user as the software has large economies of scale.

As platforms generate information based on data from groups of farms, they can reinforce the practice of benchmarking. There is a long tradition in Dutch agriculture of study groups of farmers, to jointly identify weak and strong points in their farms and farm strategies and learn from each other. Although farmers compete on the land market, they seldom do in the commodity market. Such study groups are a predecessor of the operational groups in the current CAP that work on a common innovation challenge. The EIP-Agri Focus Group

Benchmarking[26] argued that learning processes between farms could be improved by sharing data and identified 4 areas for improvement:

- Automatic data sharing based on data-authorisations,
- Benchmarking on sustainability and strategic changes,
- Business models and governance in benchmark systems and
- Benchmarking for small farms.

In the Netherlands a number of bottlenecks have been identified in the platform economy for arable farmers (Kempenaar et al, 2020). For farmers it is still impossible to bring all their data together in an easy to use, own dashboard. For arable farmers alone, there are up to 25 data platforms to be confronted with or to choose from. Most of them are product-based or for operational management.

For financial management and certification, these platforms include JoinData, a cooperative initiative of food chain companies to exchange data with the permission of farmers (including the older EDI-Circle application), and AgriPlace, a start-up where farmers can upload pdfs of their invoices for inspections and certifications and manage the transfer of these documents from one scheme to another.

All in all, it seems that the digitalisation in agriculture during the last decades has not reduced but contributed to administrative burdens of farmers as more data entry is asked by the food chain partners and the government to fulfil their information needs. It has delivered better operational technical advice and indirectly it has contributed to better prices for products in some sustainability schemes, but has also led to understandable complaints about red tape.

Other European countries

It is beyond the scope of this contribution to make a full survey for Europe on financial software platforms. Due to the PSD2 regulation in banking, all banks in the European Union are obliged to make the data on bank transfers digital available to the account holder, so farmers and their software providers and accountants can benefit from this opportunity. Information is lacking on the extent to which this is done.

The biggest challenge is then to link invoice data to the payment data and apply algorithms for the accounting – including sustainability accounting. From the FADN and PACIOLI community it is known that there are large differences between regions and member states on this topic. Some examples: Norway has copied the Dutch EDI-circle principles to exchange digital invoices between food processors or input manufacturers and farmers or their accountant. Denmark's agriculture and food sector has for many decades a central data procession center where cooperatives, advisory service and accountants link all data and provide farmers and advisors with the information they need. Essentially the exchange problem is solved as data handling is centralised in one organisation. Hungary has obliged companies to provide invoices in UBL (universal business language) and send a copy to the tax office. This obligation has been issued to prevent tax fraud, but in principle could also benefit farmers as it makes robotic accounting possible.

[26] https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-focus-group-benchmarking-final-report

Recently EU countries and the European Commission decided to introduce a European Standard for e-Invoicing in response to the many e-Invoice formats used across the EU. As it is stated in the respective reports[27] the varied formats cause unnecessary complexity and high costs for businesses and public entities. The rational is to move towards electronic invoicing mechanisms that comply with the European norm, however nationally specific rules will remain valid. This means that the Commission's initiative will result in a norm and not in a European e-Invoicing infrastructure. The latter will be supplied by service providers on the market. The deadline for EU countries to transpose e-Invoicing Directive 2014/55/EU into their national laws and comply with the European standard on e-invoicing was 18 April 2020. Public authorities across the EU should now be able to process e-Invoices respecting the European Standard. Towards the actual implementation of the digital transition for invoicing EU leverages the Connecting Europe Facility (CEF) where ready to use ICT Building Blocks are offered under the title e-Invoicing Building Block[28]. The e-Invoicing Building Block allows to Send and receive electronic invoices compliant with the European standard on e-Invoicing. In addition, this initiative offers the following auxiliary service:

- on-site training sessions and workshops for the public and private sectors
- supporting webinars
- a user community for online discussions and technical resources (validation artefacts, code lists, etc.) used to implement e-Invoicing when using the European standard and a conformance testing service

However, the integration of existing FMISs with EUs e-Invoicing system is not yet evident on a large scale.

Table 8. Information types provided by platforms for financial information exchange

Category – basic data	Information
Farm, farmer profiles and parcel information	Full record of the (legal) status of the farm, tax status (VAT obliged or not etc,), its owners including data about the farmer (name, national id, age, address, fiscal income, etc.) and data on static parcels' characteristics (cadastre data, use title (owned, rented etc). In some cases the legal structure can be quite complex (one farm, more farmers or one farmer owning several farms; farmers and farm households are not necessarily equivalent: a farm can have two farmers that live or live not in the same household, e.g. husband and wife, father and son).
Inventory and building information	Includes the monitoring and management of all production materials, equipment, buildings and other infrastructure. Inventories of animals, chemicals, fertilizers, and seeding and planting materials. Data are typically used to calculate the use of inputs during a period (accounting year, often the calendar year, but sometimes a harvest year like May-May or July-July) by

[27] https://ec.europa.eu/growth/single-market/public-procurement/digital/einvoicing_en

[28] https://ec.europa.eu/cefdigital/wiki/display/CEFDIGITAL/eInvoicing

	adjusting the purchases and sales with the beginning and end-inventory.
Purchase and sales data (UBL / paper invoices, self-created bills, dispatch notes)	Provides information on transactions with other parties: suppliers of inputs and services (including payments to landowners, personnel, taxes etc.) and cooperatives, food processors or other farms that buy products or services (like contract work) from the farm. Some farms create invoices for customers themselves. Invoices contain data on amounts and prices paid for individual type of products and services als well as their volumes. This includes fertilizers, pesticides, anti-biotics, water, etc. Used to calculate costs and sales (revenue), prices, quantities, use/consumption, and environmental impacts. Supports reconciliation with, and validation of, farm management information and financial accounts. The data set may also include the invoices itself (hard copy or digital) and other evidences escorting the items of the inventory. Specifications and particularities of production materials, chemicals, fertilizers (etc.) that support the interpretation of e.g. accountancy data through mapping and matching.
Bank data (and cash book data)	Data on individual bank payments (including credit cards etc.) that specify which trading partners (suppliers of inputs and services, buyers of products and services) have been paid or made payments to the farm. In principle digitally available to farmers (and with authorisations to their software and accountants) under PSD2. Some farms (especially those in short supply chains or regions where cash is still king) do cash transactions that are noted down on paper or in a cash register.
Production and operating data	Provides information on inputs and outputs (use, consumption, production, environmental impact, …) of e.g., agricultural, horticultural, dairy or veal enterprises (that are branches / activities within a farm). Often a lot of the input use (and sales) can be linked directly to certain crops and types of animals, but in some cases (e.g. fertilizers) a farmer has to note the allocation if interested in gross margins and costs of production of these branches or at field level. Typically includes pesticides and fertilisers use, on large farms sometimes also hours worked of personnel and machinery (fuel consumption) etc. [although other large farms use FMIS or ERP systems for this)

Category – derived data	**Information**
Accountancy data – balance sheet	Provides information on e.g., farm assets and debts (valuations) including livestock, crop and other product Inventories, loan balances, etc.. The balance sheet gives the farm manager a "snapshot" of the net worth on a specific date. The net worth is the value of all assets on the farm less the amount of money owed against those assets.
Accountancy data – cash flow	Cash flow statements provide information on the farm or farmers household on liquidity flows, e.g., farm sales and expenses, non-farm income and expenses and debt payments, but also changes in loans and money spend on investments. The projected monthly cash flow statement can be used to look ahead to the next year of operations. By projecting a cash flow for the next year, potential cash shortfalls can be noted and appropriate changes in the farm operation can be analysed.
Accountancy data – enterprise analyses	Provides information on e.g., farm sales and expenses in the form of gross margins and sometimes cost prices for different types of livestock and crops. Often including yields and other volume data.
Accountancy data – sustainability report (including material balances)	Provides information on the environmental, social and governance (ESG) indicators of the farm. Indicators are calculated on the basis of invoices and other accountancy data. Key performance indicators typically include use of antibiotics, pesticides, fertilizers (N, P, K) including manure, water etc. Includes where needed material balances (obliged for organic farms) that provide information on material flows through the farm. In combination with data on buildings and other technologies used, proxies can be estimated for the emissions of CO_2, NH_3, fine particles etc.
Accountancy data – profit and loss account and income statements	Provides information on e.g., farm income and expenses, interest payments, livestock and grain inventories, costs of depreciation, accounts payable and receivable. Year-to-year profits are calculated on the income statement (i.e. profit/loss statement). The income statement is used to calculate net family (farm) income.
Accountancy data – income taxes	Farm income and expenses, non-farm income and expenses, interest payments, depreciation schedules, resulting in the savings of the farm family (or families).

4. Agricultural data sharing

In the previous section an analysis of the main information sources for recording data related with agricultural practices was presented. These data after have been collected and stored within the various information systems needs to be shared in order to be further exploited including the objectives of monitoring and evaluation policies. To this end, it is widely recognized that making data more accessible to others, either as open data or through data sharing agreements, will increase the speed of innovation, as other organisations can also apply the data in their solutions more easily. For example, through investments in Sentinel satellites and the Copernicus program, a lot more satellite imagery has become available as open data, and using this data many different applications are being explored, providing a powerful example of what is possible at the EU level. In recent years, many demonstrations of the use of this satellite data for CAP monitoring occurred in the context of projects like SEN4CAP[29] while many Member State Paying agencies and precision farming equipment providers also experimented with this in order to develop applications.

Internationally, networks like Global Open Data in Agriculture and Nutrition (www.godan.info) increased the awareness of opening up data and sharing data across stakeholders, with 800 signatory organisations worldwide. As part of the European Open Science Cloud Developments, a lot of effort is placed on making data from research & innovation projects (e.g. H2020) more widely available for others to re-use to avoid duplication of efforts and increase the speed of innovations.

Currently, in the EU but also on a global level there is a thriving community of experts from different disciplines (farmers, farmers associations, data scientists, regulatory bodies, legal experts, information security officers) that aim to set up the basic rules and mechanism that will allow fair and responsible agricultural data sharing. The EU considers that it is crucial to upscale and implement the solutions now being developed and identify across the network critical success factors and good practices in the use of open and shared data, also making recommendations towards commonly shared guidelines between partners to ensure comparability and reproducibility. The following sections briefly present such indicative initiatives that have significant role in shaping the overall ecosystem of agricultural data sharing.

4.a European Strategy for Data

The European Strategy for Data[30] is an EU initiative that aims at creating a single market for data that will ensure Europe's global competitiveness and data sovereignty. Common European data spaces will ensure that more data becomes available for use in the economy and society, while keeping the companies and individuals who generate the data in control. The Commission has proposed a Regulation on European data governance as part of its data strategy. This new Regulation will play a vital role in ensuring the EU's leadership in the global data economy. Among the key objectives of the regulation is to empower **users to stay in control of their data**, and encourage the creation **of common European data spaces** in crucial sectors. These sectors include health, the environment, energy, **agriculture**, mobility, finance, manufacturing, public administration, and skills (Figure 9). In addition, and to further ensure the EU's leadership in the global data economy, the European strategy for data intends to:

[29] http://esa-sen4cap.org/

[30] https://digital-strategy.ec.europa.eu/en/policies/strategy-data

- adopt legislative measures on data governance, access and reuse. For example, for business-to-government data sharing for the public interest;
- make data more widely available by opening up high-value publicly held datasets across the EU and allowing their reuse for free;
- invest €2 billion in a European High Impact Project to develop data processing infrastructures, data sharing tools, architectures and governance mechanisms for thriving data sharing and to federate energy-efficient and trustworthy cloud infrastructures and related services;
- enable access to secure, fair and competitive cloud services by facilitating the set-up of a procurement marketplace for data processing services and creating clarity about the applicable regulatory framework on cloud framework of rules on cloud.

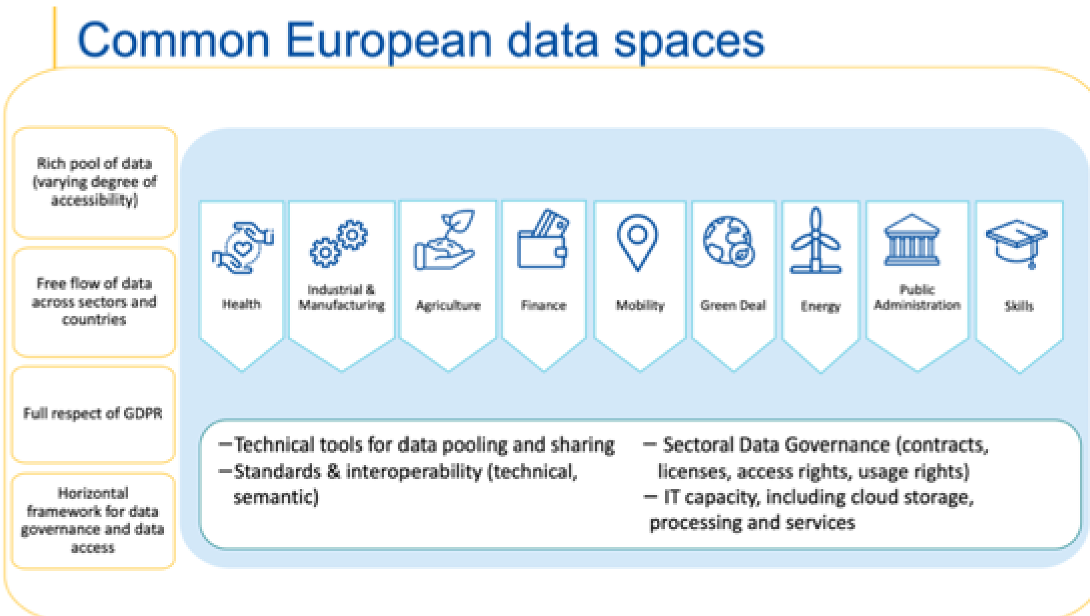

Figure 9. Envisioned Common European Data Spaces including Agriculture

In this context European Commission (EC) attempts to gather views from different stakeholders to gain insights on how to build a Common European Data Space for the agricultural sector. In February 2020, DG CNECT in cooperation with DG AGRI, organised a workshop and brought together key experts, scientists, IT and data specialists having as main topic the realisation of a Common European agricultural data space. The main questions that experts were asked their opinion are the following:

1. Is the federation of some of the Farm Management System (FMS) platforms and other data platforms feasible?
2. Assuming that the implementation option for the Common European Agricultural Data Space for agriculture is based on a federated distributed system of existing data platforms, what is needed to implement a European Data Space from a technical point of view (definition of the interoperability mechanisms)?
3. How can we reach an agreement on a set of interoperability mechanisms (avoiding locking into existing platform architectures)?
4. Are the suppliers of FMS ready to share their data? And willing to federate their data platform with other suppliers?

5. Which existing platforms supported by ecosystems (at regional or national level) are already sharing data? In which sub-sectors are they sharing the data?
6. Which public data sets would be of particular relevance for increasing the effectiveness of the Common European Agriculture Data Space?
7. Are their experiences with taking public data sets as input to FMS, farmers' applications or Agricultural Data Spaces?

The main outcomes and the proposed mechanism for overcoming these challenges are analysed in the report[31] that was published by the organising committee. However, these questions also denote key issues on data sharing that haven't been yet addressed that are also affect the design and implementation of policy and evaluation frameworks.

4.b FAO-UN on farm data management and sharing

The Food and Agriculture Organization of the United Nations (FAO-UN) considers agricultural data sharing as a key enabler towards the further future expansion of agriculture production. To this end, the "Farm data management, sharing and services for agriculture development[32]" book was jointly prepared by the FAO-UN and the Technical Centre for Agricultural and Rural Cooperation (CTA), as a result of the work funded by CTA with the Pan African Farmers' Organisation (PAFO). The book among others elaborates on "Data sharing principles" providing the principles and benefits of shared data, the potential of using and publishing data in agriculture, responsible data sharing practices for farm data, ethical and legal sensitivities of data-driven services and data protection. In detail, it addresses challenges in data sharing for smallholder farmers, issues regarding data ownership and data rights, outlines different roles of public and private data sources, challenges in reusing them in services for farmers.

Of particular importance for the implementation of monitoring and evaluation frameworks are the reported challenges related with the data sharing of small farm holders. As it is stated in the respective chapter understanding these challenges is essential to be able to create services and negotiate business models that meet farmers' needs and address their concerns. For smallholders, the two main challenges are: (a) to gain access to relevant and usable data and services; and (b) to make sure that any data they share does not actually weaken their position in the value chain (and ideally that sharing data actually benefits them). In both data sharing directions, smallholder farmers face big data asymmetries in relation to other actors in the value chain. Figure 10 illustrates the reported challenges when sharing and accessing streams of data from/to farm.

[31] https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=69566
[32] http://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1382042/

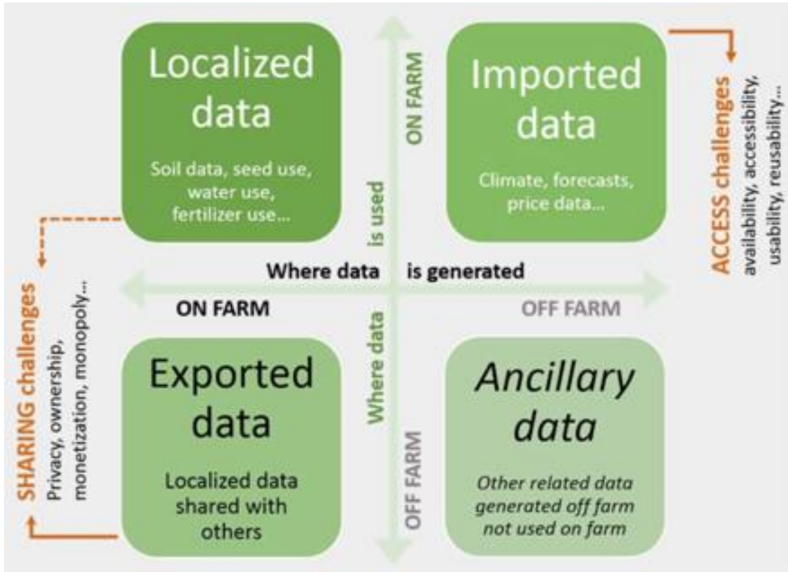

Figure 10. Challenges when sharing and accessing streams of data from/to farm (Maru et al., 2018)

4.c GAIA X – Agri Gaia

GAIA-X[33] is a relatively new initiative with representatives from politics, business and science from France and Germany, together with other European partners, aiming to create a proposal for the next generation of a data infrastructure for Europe. Among the core objectives is to define a secure, federated system that meets the highest standards of digital sovereignty while promoting innovation. This project is the cradle of an open, transparent digital ecosystem, where data and services can be made available, collated and shared in an environment of trust. Project GAIA-X' is trying to connect centralised and decentralised infrastructures in order to turn them into a homogeneous, user-friendly system. The resulting federated form of data infrastructure strengthens the ability to both access and share data securely and confidently.
At this stage GAIA-X data sharing mechanisms are still in the design phase. However, the functionality to be offered will link different elements via open interfaces and standards to link data and make them available to a broad audience. GAIA-X Hubs will be set up at a country level in order to animate the GAIA-X communities locally. Germany and France already has set up hubs. Netherlands, Belgium, Finland and Italy already announced to be in the process to do so.

A specialization of GAIA X on agriculture is the Agri-GAIA project[34] which aims to create an ecosystem for the SME agricultural and food industry based on GAIA-X data sharing mechanisms. Agri-GAIA aims to closes the circle from sensor data acquisition on the agricultural machine, training of the algorithms on appropriate servers and continuous updating of decision support algorithms. Data sharing will be based on appropriate interfaces and standards that will be developed so that a manufacturer-independent infrastructure for the exchange of data and algorithms to be created. Although the overall project is still in a design phase it is supported by key industrial players and governments.

[33] https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html
[34] https://www.data-infrastructure.eu/GAIAX/Redaktion/EN/Artikel/UseCases/agri-gaia.html

5. Agricultural data models

There is an obvious need to formulate, with common semantics, the digital evidence collected by the farms that will be shared with the monitoring authorities (e.g. Integrated Administration and Control System). Given the heterogeneity of the deployed smart farming technologies, data are expressed and exchanged through diverse custom information models particular to each proprietary platform. This issue characterises the IoT landscape in general, as the current ecosystem consists of platforms and proprietary systems that are mainly isolated and act as "vertical silos". These silos impede the creation of cross-domain, cross-platform and cross-organisational services, due to their lack of interoperability, standardization and openness. Most of the captured data are not currently exploited to their full extent, while in some cases interaction among IoT systems is a mandatory enabler for capturing the maximum potential value (Liu et al., 2015).

The need for the definition of common, and if possible standardised, syntactic and semantic information models, along with the appropriate technological tools (e.g. data translators) that will act as interoperability enablers on existing-already in use- legacy systems has been identified as a necessary step (Brewster et al, 2017). Information modelling approaches, tailored to the agricultural domain, are still somewhat fragmented, while standardisation efforts do not yet have enough visibility. However, there are significant efforts towards the realisation of agri-related data flows following the FAIR (Findable, Accessible, Interoperable, and Reusable) principles. Towards the same goal, standardisation bodies (ETSI[35]), technical alliances (e.g. Open Geospatial Consortium OGC - Agriculture Domain Working Group[36], AIOTI-Working Group on Smart Farming and Food Security[37]) and private standard organisations (e.g. GS1 and AgGateway) are all contributing on agri-data modelling harmonisation efforts.

In this section dominant approaches on data models for representing agriculture related information are presented. These models are considered as important toward the process of semantic interoperability among ICT systems (e.g. FMIS) utilised to facilitate everyday agriculture activities. Establishing a harmonised approach on formulating datasets recorded/generated by various technologies with common semantics is a crucial aspect prior their exploitation for the needs of new CAP monitoring and evaluation needs.

5.a Agricultural digital integration platforms

On 2019 EU funded under the H2020 topic "DT-ICT-08-2019 - Agricultural digital integration platforms" two Innovation actions aiming to push further the wide adoption of open, interoperable standards to ensure that all connected systems can talk to each other, allowing the farmers and relevant other stakeholders to pick and choose the most appropriate combination of tools from different suppliers. Although these mechanisms are mainly focusing on advanced decision support with regards to farming practices the fact that they are based on high level of interoperability of different systems through reference architecture, semantics technologies and standardisation framework are also of interest for the monitoring and policy evaluation frameworks. The two projects that are funded under this scheme are DEMETER and ATLAS.

[35] https://www.etsi.org
[36] https://www.ogc.org/projects/groups/agriculturedwg
[37] https://aioti.eu/agriculture/

The **DEMETER**[38] project, has already produced its first results on agricultural data interoperability namely the Agricultural Information Model (AIM[39]). The AIM follows a layered and modular approach, reusing as much as possible existing ontologies and vocabularies. In more detail the DEMETER AIM enables among others:

- eased interoperability with existing models by reusing available (well-scoped) models in the modules, instead of defining new terms, whenever possible,
- easy mapping/alignment with other models, by module instead of the whole model,
- easy extension of the domain/areas covered in AIM with additional modules,
- easy extension of the domain model, by modifying only specific modules,
- easy mapping to top-level/cross-domain ontologies.

The DEMETER AIM consists of a core metamodel, which follows the NGSI-LD[40] meta-modelling approach, in combination with a cross-domain ontology articulated by various generic models. The cross-domain ontology aims to provide common definitions for various agrifood domains and on the same time to avoid conflicting or redundant definitions of the same classes at the domain-specific layer. Some of the domain specific ontologies developed for the AIM model information such as crops, animals, agricultural products as well as farms and farmers.

The **ATLAS**[41] project aims to specify an open, distributed and extensible service interoperability network, based on a service-oriented architecture. The overall aim is to apply interoperability of sensors, machines and data services, from farm scale to global scale through interconnected service registries. First results are published in "D3.2 Service Architecture Specification[42]" having as the basic building blocks to realize data flows the "ATLAS Services" which are offered by the various agricultural technologies and participating systems. These services confront with standards imposed by ATLAS and enable the exchange of data in a formally defined and documented way. The exchange of data between services is designed to be peer to peer without any network centralistic component for specific distribution or steering of data flows. This approach is mainly chosen by the fact that a central data forwarding component would be in the need to be capable of shifting an immense amount of data between the peers.

However, ATLAS introduces the "ATLAS Service Registry" which implements functionalities for service discovery and for the registration of certified network participants. The Service Registry and its governance body ensure that any new service is conformant to the standard and that it meets quality-, safety and security requirements. As authors claim, this approach leads to a system of systems which aims to be open yet regulated, extendible but secure and easy to implement but flexible.

Another pioneering effort with large scale impact on applying smart farming technologies in EU but also in conceptualising and implementing the "system of systems" approach has been realised by the "**Internet of Fruits and Farms (IoF2020)**[43]" Innovation Action. IoF2020 started

[38] https://h2020-demeter.eu/
[39] https://h2020-demeter.eu/wp-content/uploads/2020/10/DEMETER_D21_final.pdf
[40] https://www.etsi.org/deliver/etsi_gs/CIM/001_099/009/01.01.01_60/gs_CIM009v010101p.pdf

[41] https://www.atlas-h2020.eu/
[42] https://drive.google.com/file/d/1-o4-WHp8hW_CSCTbxOcWvo-ZBy601wRs/view
[43] https://www.iof2020.eu/

on 2017 and completed in 2021 having executed more than 25 use cases on smart farming in almost all EU countries. Among the core objectives of this project was the establishment of system interoperability among agricultural systems. The work presented in Public Deliverable "Opportunities and barriers in the present regulatory situation for system development" provides a layered architectural approach modelling the mode of operation of various digital agricultural systems along with the Interoperability Points (IOP) where data sharing through the use of minimum interoperability mechanisms (data mappers/translators) can be applied. It should be noted that within IoF2020 the CEF Orion Context Broker was utilised in combination with SmartAgriFood data models in order to enable interoperability in semantic and syntactic level.

5b UN/CEFACT eCrop

The eCrop[44,45] is a generic standard supporting data modelling and data exchange in the supply chain for horticulture, fresh fruits, vegetables, flowers & plants and arable farming crops, including processed food. The supply chain consists of parties involved from retail to the grower including cooperatives and producer organization, food processors, other industries (pharma, chemical) auctions, packers and traders. The eCrop attempts to model a plethora of agricultural concepts including:

- the crop fields & aquaculture plots (location and polygon), the planned and/or actual crop (rotation) schema, treatment, plant health (animal health next phase), soil and water situation, crop observation data, supplies (seed, fertilizer, plant protection), operation advices and operation instructions and the logging report about operations and events.
- It also provides the necessary terms in order to support the modelling of Information about the production of the crop or product; information about treatment (crop protection, health agents, fertilizers, animal feed, use of energy and water and other necessary master data).
- Geo-information / location, (geographical characteristics such as point, line polygons, 2D, 3D) about the exact location of field operations to support spatial farming (or address, GLN or blue numbers).
- Information about labor (organizing of the labor in the companies on the supply chain level).
- Information about certificates (such as GlobalGap or SPS certificates, farm or product).

Overall, the eCrop is a complete standardised data modelling approach and is already widely utilised in various EU countries (Netherlands, Denmark, Estonia). However, it is mainly using XML schemas which is a limitation given the current trend of the utilisation of semantic web data modelling technologies (RDF/RDFS/OWL) by many information systems that aim to achieve semantic interoperability.

5.c ADAPT

AgGateway's ADAPT Framework[46] (Agricultural Data Application Programming Toolkit) is an open-source project designed to make it easy for various hardware and software systems that growers use in their businesses to seamlessly communicate with one another through a

[44] https://unece.org/trade/uncefact/xml-schemas
[45] https://unece.org/fileadmin/DAM/cefact/brs/BRS_eCROP_v1.pdf
[46] https://adaptframework.org/

standard industry framework. The ADAPT ISOXML Plugin makes it easier for Farm Management Information Systems (FMIS) to read and write data to/from displays and terminals that use the ISOXML specification. The plugin provides a standard that can either be adopted or used as a guide in developing other plugins that allow proprietary systems to "plug in" to the ADAPT framework. Participating companies will be responsible for completing their own implementation of mapping the Agricultural Application Data Model to their FMIS data model.

ADAPT has been developed over several years by a large, collaborative group of AgGateway members from a variety of manufacturer and agricultural software companies, who all recognized that the farmer and other agricultural users have a critical need to use data from multiple sources to improve decision processes. AgGateway's ADAPT Committee is currently coordinating with software companies on plug-ins needed for ADAPT's adoption. Several hardware and software companies are already in the process of developing plug-ins for their proprietary formats that allow the conversion from one format to another.

5.d ETSI-SAREF-Agri

The SAREF4AGRI[47] information model is an ETSI standard addressing the Smart Agriculture and Food Chain domain. It is an OWL-DL ontology that extends SAREF[48] for the Smart Agriculture and Food Chain domain. The intention of SAREF4AGRI is to connect SAREF with existing ontologies (such as W3C SSN, W3C SOSA, GeoSPARQL, etc.) and important standardization initiatives and ontologies in the Smart Agriculture and Food Chain domain, including ICAR for livestock data (https://www.icar.org/), AEF for agricultural equipment (http://www.aef-online.org), Plant Ontology Consortium for plants (http://archive.plantontology.org), AgGateway for IT support for arable farming (http://www.aggateway.org/). As an extension of SAREF, which is a semantic model for IoT that describes smart devices and applications in terms of their functions, services, states and measurements, SAREF4AGRI is concerned with the description of proximal sensors that measure a variety of relevant parameters for agriculture, including: (on animal) movement, temperature, etc., (in the soil) moisture/humidity, Ph value, salinity, compaction, (on plant) plant colour (NDVI), etc. The measurements from these sensors need to be integrated by a decision support service to enable the planning of (for example) a treatment plan for animals (in a livestock scenario), or a decision to irrigate or harvest (in an irrigation, horticulture or greenhouse context).

5.e Agricultural data taxonomies

Less integrated approaches but really useful towards the common representation of agricultural terms are the well-established taxonomies EPPO, AGROVOC.

AGROVOC (http://www.fao.org/agrovoc/)

AGROVOC is the largest Linked Open Data set about agriculture available for public use and facilitates access and visibility of data across domains and languages. It offers a structured collection of agricultural concepts, terms, definitions and relationships which are used to unambiguously identify resources, allowing standardized indexing processes and making

[47]https://www.etsi.org/deliver/etsi_ts/103400_103499/10341006/01.01.01_60/ts_10341006v010101p.pdf
[48] https://saref.etsi.org/

searches more efficient. AGROVOC uses semantic web technologies, linking to other multilingual knowledge organization systems and building bridges between datasets. It currently consists of +39,100 concepts and +826,000 terms in up to 40 languages and continuously expands.

Individual users and computer programs can access the taxonomy of agricultural terms through webservice endpoints (e.g. https://agrovoc.fao.org/browse/agrovoc/en/) and retrieve terms that are uniquely identified.

For example, the term "***pesticide application***" corresponds to the globally unique identifier – also known as Uniform Resource Identifier (URI): https://agrovoc.fao.org/browse/agrovoc/en/page/c_27879

An example of the provided information that correspond to "pesticide application" URI is presented in figure 11.

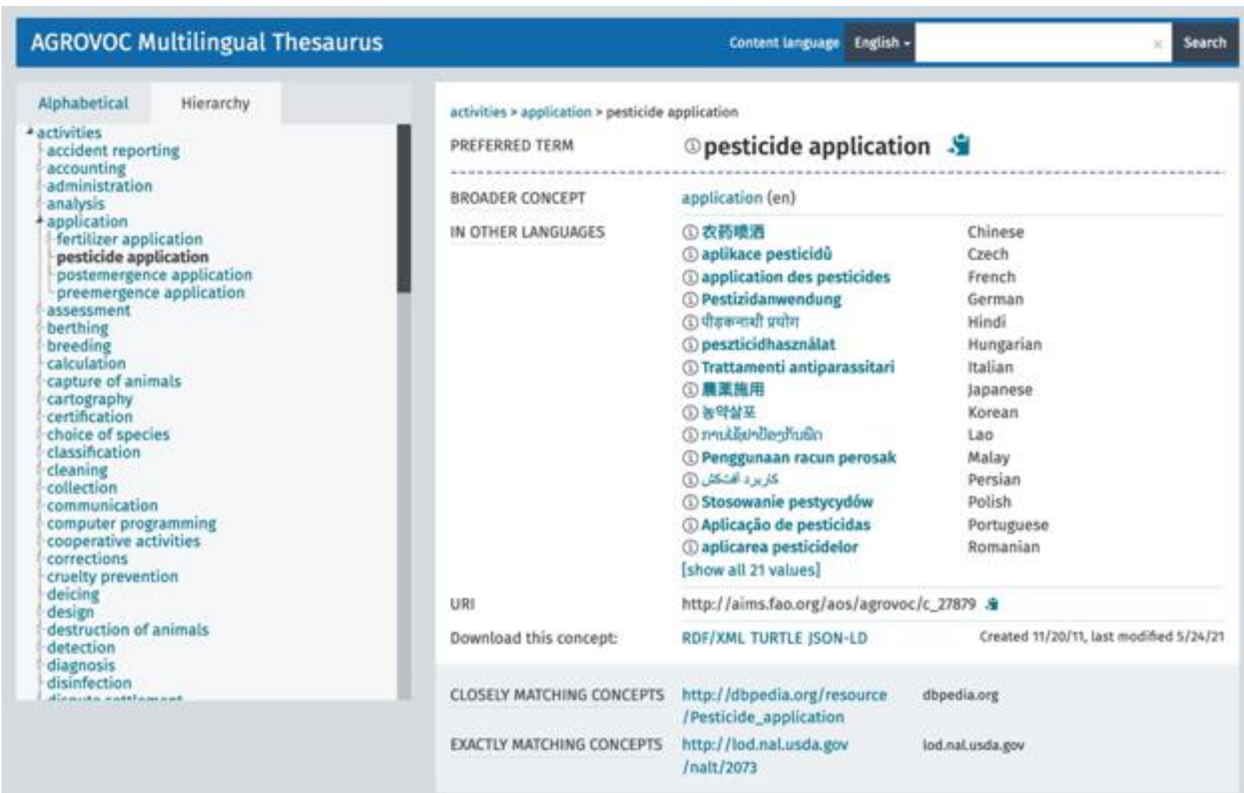

Figure 11. AGROVOC data correspond to term "pesticide application"

Conclusions

This deliverable provides a wide overview of Information and Communication related Technologies (ICT) that are currently having a dominant role in agricultural practices. Even though we are still experiencing the first steps of ICT adoption in support of every day cultivation activities the generated impact is high while the expected overall innovation potential is even more promising. The scope of this document is not to provide an exhaustive analysis of every kind of ICT related mechanisms that have been utilised at the agricultural fields but to provide an overview of technologies that can potentially be useful towards data sharing in the context of current and future CAP. To this end, selected technologies are presented along with the information entities that can directly (raw data) or indirectly (inference/processing of data recordings) been extracted. The overall objective is to create a first analysis (filtering) that will support MEF4CAP to further evaluate the technologies that can be exploited in order to support the CAP monitoring and evaluation framework of the future.

The ICT areas reviewed have been identified from an early stage during the specification of the MEF4CAP Description of Work. These areas were further analysed within the WP2 Task2.1 activities where individual partners contributed based on their distinct field expertise on the potential of each technology in contributing as a data source in the context of CAP monitoring. To this end, the following ICT agricultural areas have been selected as the most promising:

- Telecommunication technologies
- Field Sensors
- Farm Management Information systems (FMIS)
- Field Machinery
- Earth Observation (EO)
- Livestock Management
- Pasture Management
- Financial management

A first level outcome from the conducted analysis on ICT technologies is that there is no one-fits-all technological approach that is capable to provide all the necessary data for CAP monitoring. It is more a synergetic/complementary use of generated datasets that needs to be facilitated. For example and as it is analysed with the respective sections, earth observation and remote sensing technologies can provide useful outcomes in large scale for whole areas allowing to detect information types such as crop type, specific agricultural practices applied (mowing, ploughing), rotation of cultivation, etc. However, this is only applicable for relatively large parcels which is not the case for various EU countries especially for those located in South Europe (Greece, Cyprus, South Italy).

In addition, EO technologies are not able to capture details on in-situ/farm level data for example the amount of agricultural inputs (fertilisers, pesticides, irrigation) applied. This is where ICT technologies related with “FMIS”, “Field Machinery” and “Financial Management” can provide useful input. Recordings from digital field books (farmer’s calendar) escorted by ground truth evidences (e.g. sensor recordings, tractor’s navigation data, and invoices issued during the purchase of chemicals) can provide detailed insights on farm level.

However, even if the various information items are available by the various ICT technologies utilised it is also necessary to be shared in a meaningful manner. To this end, it was considered as important to also review the current status on the issue of “agricultural data sharing” as a necessary prerequisite for sharing data recordings with any 3rd party. As it is denoted from various key stakeholders and organisations it is particularly important to facilitate agricultural data sharing and there are significant efforts tailored to this scope, however the appropriate regulatory environment is still under formulation.

With regards to the data modelling of datasets to be shared, a review of dominant agricultural data modelling approaches was presented given that establishing a harmonised approach on formulating datasets recorded by various technologies with common semantics is a crucial aspect prior their exploitation for the needs of new CAP monitoring and evaluation needs. As it was evident by the presented initiatives the overall ecosystem is highly fragmented without having yet a dominant data harmonisation approach. In one hand, standardised data modelling approaches are already published and in use in various countries but in some cases these standards are not adequate to model all the required information aspects. In addition, in some cases there are parallel data modelling standards something that imposes the need for cross standard interoperability mechanisms.

The analysis presented in D2.1 will be continued:

The outcomes of this deliverable will act as input to “WP3 Current systems and future pathways” in order to confront and make a judgement of the analysed ICT developments with the data requirements (analysed by WP1) that are necessary for an enhanced monitoring and evaluation framework for a future and reformed CAP.

Outcomes of D2.1 will be combined with the ongoing analysis on recent developments and outcomes delivered by EU research projects and other related initiatives. The combined analysis will be presented in “D2.2 Best practises on the adoption of ICT agricultural technological solutions” which aims to provide a best practices and lessons learned analysis on the adoption of ICT technological solutions in agriculture in the context of future CAP monitoring and evaluation.

D21 will be utilised as the bases for conducting a future trends analysis on which ICT technologies and capabilities are expected to be dominant for the agricultural domain in the near and long future (D2.4 Emerging ICT technologies for the agricultural domain).

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