MEF4CAP

Monitoring and Evaluation Frameworks
for the Common Agricultural Policy

Deliverable D2.2

Best practices on the adoption of ICT agricultural technological solutions

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Executive summary

The future CAP will be an important instrument in managing the transition to sustainable food production systems and to strengthen the efforts of European farmers to contribute to the climate objectives and biodiversity commitments of the EU. Given the new policy needs, an increase in the number and type of indicators is expected. Consequently, new data sources will be required, and existing data sources need to be exploited more efficiently, avoiding duplication and potentially allowing scope for collection of new types of data.

Among the objectives of the MEF4CAP project is to analyse agricultural technologies and their potential contribution to CAP monitoring and evaluation. The first outcomes on this analysis are documented in D2.1 “Landscape of agri-food ICT technologies within the EU” and D2.3 “Identified new technological opportunities from collaboration with EU projects and initiatives”. This deliverable, entitled D2.2 “Best practices on the adoption of ICT agricultural technological solutions” aims to go a step further and describes exemplar, real-world cases of agricultural technologies utilization that will concurrently address multiple purposes addressing both the need for sustainable and transparent farming practices. In the context of MEF4CAP project the term “best-practices” is associated with the following set of high-level principles that ICT agri-tech solutions need to address:

a) Support the realisation of good and sustainable agricultural practices that provide clear benefits for the farmers and the environment.
b) Technologies of a high TRL level with significant penetration in agricultural production.
c) Complementarity and interoperability among different technologies.
d) The use of technologies generates farm level ground truth evidence (e.g., data logs) about the applied agricultural practices that can potentially be utilised for the monitoring and evaluation of relevant policies.

Based on the introduced high-level principles a set of exemplars use cases are selected representing different aspects of the agricultural production. Of course, the selected use cases are not exhaustive for the agricultural domain and many other paradigms may exist, however the objective of this exercise is to go beyond the typical high-level agri-tech state-of-the-art review and offer to the readers a close look on the actual digital logs and examples of technologies utilisation. The selected use cases are focusing on the following domains:

- **Variable Rate Application technologies as a mean for monitoring of applied phytochemicals**

There is an ongoing trend towards the digitisation of the equipment that is utilised for applying agrochemicals (pesticides and fertilisers) which can potentially allow on the one hand to implement better cultivation strategies and on the other hand to generate and record field evidences of their utilisation. VRA technologies are inherently generating extensive data logs reflecting the applied inputs (e.g. seeds, fertilisers, pesticides). In addition, there is already a

dominant data modeling approach (ISOBUS) for agricultural machinery operations which allows the extraction of data logs in uniform manner. However, ISOBUS is not designed for CAP monitoring purposes so the respective datasets need to be semantically enhanced with additional information elements. In addition, VRA is implemented mainly with the use of modern and expensive machinery which are utilised in large commercial farms. Penetration and utilisation of VRA enabled farm machinery is rather low in EU countries where small and fragmented farms are the majority (e.g. South Europe).

- **Agricultural decision support systems and monitoring of cultivation practices**

Farm Management Information Systems (FMISs) are usually offering, the functionality related with the digital recording of agricultural activities (also called "Farmer's Calendar", "Farm Log", "Field book"). FMISs when combined with emerging technologies and data sources like IoT enabled sensors and Remote Sensing applications can offer predictive insights in farming operations and drive real-time operational decisions. This functionality is also associated with the term Agricultural Decision Support Systems (ADSS). Many ADSSs are designed to support the concept of precision agriculture aiming to provide a holistic approach to assist farmers with optimising inputs (e.g. fertilisers, pesticides, water, and fuel). FMISs demonstrate the potential for supporting the farmer on optimizing farming practices and generate extensive logs that can act as farm level data sources for the need of CAP monitoring and evaluation. FMISs can act as the digital gateway of the farm offering controlled exchange of data with authorized 3rd parties. Some of the key issues that have been identified towards the large-scale realisation of such a monitoring approach are related with: a) the specification of common communication protocols and semantics that will address the heterogeneity introduced by the differences of the various commercial FMISs, b) means for evaluating the quality (e.g. in terms of accuracy, reliability, time-resolution) of FMIS data logs, c) FMISs users' acceptance, cost and ease of use.

- **Dairy/animal production pasture management and monitoring of livestock/farming activities**

Existing pasture management systems usually combine Earth Observation data with information provided by the farmer (grass growth rates, etc.). Those services have been developed with the grassland farmer in mind, are able to provide actual data in yield of grass and will populate feed planners and grass wedges for the farmer client. Increasingly these systems are also incorporate DSS functionalities in terms of fertiliser planning and monitoring of fodder quality. Pasture management databases can be considered as software systems that are turning farmer provided information (growth rates etc.) into actionable data for the farmer (grass wedge, growth forecasts etc.). Other data, such as soil test results, livestock numbers and fertiliser usage allow for a full profile of each paddock to be created creating feed wedges, rotation plans, yield curves etc. Given the dependency of these systems on farmer input, issues of data quality and accuracy are emerging. In addition, the current percentage of farmers who engage with the systems to this extent is small. The key to improve engagement is to provide new tools (grass growth forecasts) and new ways to interact (mobile collection app). Since this service - and other similar - are entirely voluntary and self-selecting the use of data forms, these services may not be appropriate for population level statistics – and hence CAP monitoring and evaluation – until a certain penetration is achieved.

Currently multiple sources of agricultural data exist and there is clear potential for data aggregation along with the additional value this can bring in monitoring new CAP indicators. A crucial parameter is to achieve increased, large-scale, penetration and utilisation of such technologies in order to also be utilized for CAP monitoring and evaluation. However, it is important to ensure from an early stage that the new monitoring approaches should not end up being seen as a form of surveillance introduced to penalise farmers more easily for non-compliance. It is crucial to the new monitoring approaches to be utilized in order to inform and guide farmers and interested parties on their performance connected to the CAP rules and objectives as well as providing them a better decision making with less bureaucracy.

List of abbreviations

API - Application Programming Interface

CAP - Common Agriculture Policy

CSA - Coordination and Support Actions

CSV - Comma-Separated Values

CMEF - Common Monitoring and Evaluation Framework

DG-AGRI - Directorate-General for Agriculture and Rural Development

EC - European Commission

EO - Earth Observation

EU - European Union

FADN - Farm Accountancy Data Network

FDIS - Field Data Information System

FMIS - Farm Management Information System

GAEC - Good Agricultural and Environmental Conditions

GHGs - Greenhouse Gases

HPC - High Performance Computing

IACS - Integrated Administration and Control System

ICT - Information and Communication Technologies

IDM - Individual Decision Making

IoT - Internet of Things

LOD - Linked Open Data

LPIS - Land Parcel Identification System

LULUCF - Land Use, Land Use Change and Forestry

MS - Member States

NDVI - Normalised Difference Vegetation Index

OTSCs - On-The-Spot-Checks

PA - Paying Agency

PMEF - Performance Monitoring and Evaluation Framework

RS - Remote Sensing

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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 the 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 technological 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 agriculture policy and the newest technological solutions to address those requirements.

WP2 of the MEF4CAP focuses on reviewing and analysing ICT developments related with the agricultural sector that can be utilised in support of CAP monitoring and evaluation objectives.

This deliverable (D2.2) describes exemplar, real-world and cases of digital agricultural technologies utilisation that are concurrently serving two objectives:

a) **The implementation of good and sustainable agricultural practices that provide clear benefits for the farmers and for the climate.**

b) **The provision of farm level ground truth evidence of the applied agricultural practices that can potentially be utilised for the monitoring and evaluation of agricultural related policies (CAP).**

For the analysis conducted in this deliverable the outcomes of MEF4CAP - D2.1 “Landscape of agri-food ICT technologies within the EU” where considered as a starting point. In D2.1 an inventory of innovative but also mature enough agricultural technologies is presented along with an evaluation of their potential for contributing in CAP monitoring. In D2.1, technologies like Remote Sensing, Farm Management Information Systems, IoT enabled Agricultural Decisions Support, Farm Machinery were evaluated as the key enablers that are currently transforming agriculture and hence where among the criteria for selecting the exemplar use cases that are analysed in this deliverable. Based on the analysis in D2.1 it was evident that technologies like satellite-based Earth Observation (EO) are currently the main technical tools for large scale monitoring. However, EO monitoring tools demonstrate significant limitations that can be addressed through the integration and complementary utilisation of ICT tools that operate at farm level, namely Agricultural Decision Support Systems, FMIS and farm machinery with data logging mechanisms.

Outcomes documented in D2.3 “Identified new technological opportunities from collaboration with EU projects and initiatives” were are also considered for selecting the use case that are analysed in D2.2. D2.3 outcomes are based on a number of collaboration activities (workshops and interviews) with EU projects and a review of their published outcomes. In projects like NIVA, Demeter, IoF2020, various demonstration cases and pilots are realised where agricultural technologies are utilised in a similar context and with similar objectives of our analysis. Hence the outcomes of these cases are also incorporated in our analysis.

In addition, the outcomes extracted from deliverables "MEF4CAP - D1.1: Evolution of the CAP and related policies (the emerging sustainability agenda)" and "MEF4CAP - D1.2: Future CAP developments and their impacts on administrative use and data providers" were also considered in order to get a high-level overview of the indicators that are introduced. However, a more detailed analysis on the required data needs imposed by the new CAP indicators and the availability of data items by the ICT developments will be conducted by WP3.

Overview

The sections of this deliverable are structured as following:
Section 1, presents the objectives and an overview of this deliverable.
Section 2, provides introductory information with regards to CAP developments and agri-tech.
Section 3, provides background information on CAP developments and indicators, overview of ICT technological solutions for the agricultural sector and relevant outcomes from selected EU research projects and initiatives.
Section 4, provides real world use cases of agricultural technologies utilisation and analysis from the perspective of CAP monitoring and evaluation.
In Section 5, conclusions and key findings are presented.

2. Introduction

According to the Commission's staff working document entitled "Analysis of links between CAP Reform and Green Deal[1]" the Common Agricultural Policy (CAP) plays a key role in supporting Europe's agricultural sector – even more at present due to COVID-19 pandemic that is also putting a strain on the resilience of European farmers. CAP will be an important instrument in managing the transition to sustainable food production systems and strengthen the efforts of European farmers to contribute to the climate objectives of the EU and to protect the environment. Moreover, given that agricultural land and forest cover 80% of the EU territory and that a substantial share of EU funding for biodiversity comes from the CAP, the CAP will play a major role in supporting the achievement of the EU biodiversity commitments for 2030. In addition, on the 11th December 2019, the Commission adopted the Communication on "The European Green Deal" which resets the Commission's commitment to tackling climate and environmental-related challenges and to implement a new growth strategy that aims to transform the EU into a fair and prosperous society, with a resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. In the framework of the European Green Deal, the Commission adopted in particular a Farm-to-Fork strategy, a Biodiversity strategy, a proposal for a Climate Law and a new action plan for the Circular Economy, all of which address issues relevant to agriculture and rural areas.

In order for the various policies to effectively be implemented it is now necessary the respective monitoring indicators to be specified along with the necessary data sources. To this end, the 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 to relevant indicators[2]. Currently the main data sources are:

- Declarations by farmers for CAP payments Integrated Administration and Control System[3] (IACS)
- Data from national statistical agencies, Eurostat and the Farm Accountancy Data Network[4] (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.

[1] https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/sustainability_and_natural_resources/documents/analysis-of-links-between-cap-and-green-deal_en.pdf
[2] https://agridata.ec.europa.eu/extensions/DataPortal/cmef_indicators.html
[3] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/financial-assurance/managing-payments_en
[4] https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/farms-farming-and-innovation/structures-and-economics/economics/fadn_en

More data will be required to adequately measure for example sustainability and well-being; 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. 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.

There are various challenges that need to be addressed towards the integration of the various technological solutions. For example, Earth Observation (EO) technologies are the key for large scale monitoring solutions. However, they still can't perform adequately in respect to small area parcels (<1ha) that for example dominantly characterise the holdings of farmers in South and East Europe. In addition, performance related with optical imagery is affected by weather parameters e.g. cloud coverage, which is often the case at North European countries. Additional challenges with regards to the exploitation of agricultural data streams from innovative sources are related with the data sharing regulatory environment including issues like data ownership, data privacy, and data secrecy. Another crucial issue for exploiting existing data flows to a maximum extent is the technical and semantic interoperability of systems and the heterogeneity in terms of data models and data exchange mechanisms.

The MEF4CAP project – in the context of WP2 – creates an inventory of ICT based solutions (D2.1) that are either mature or demonstrate strong potential toward the further digitalisation of the agricultural sector and that can contribute to CAP monitoring and evaluation mechanisms. This inventory is based on a state-of-the-art review on published scientific articles and technical reports which were analysed through the prism of CAP monitoring needs.

In addition, and in order to also capture the most recent research outcomes on CAP related agricultural technologies a series of liaison activities have been initiated with the most prominent EU projects in this domain. The aim was to record - besides the current landscape of ICTs - relevant agricultural technological developments that are not yet widely deployed or that are still under research and development but have the potential to be adopted on large scale in the years to come.
This deliverable aims to go a step further by combining findings from previous works in order to specify a set of best practices and lessons learned with regards to the utilisation of ICT technological solutions for the agri-food domain in the EU and how these solutions on the same time can support future CAP monitoring and evaluation frameworks. Towards this scope a set of real-world cases are presented where the most prominent technologies are utilised in agricultural production environments. To support the argument that ICT developments can support both sustainable farming practices but also to increase food production transparency examples of the actual evidence (data-logs) generated by the utilised technologies are provided. This analysis aims to go a step deeper from the generic ICT developments state-of-the-art reviews and offer to the readers a close look on the actual nature of the digital evidence.

3. CAP developments and technological solutions

3.1 Future CAP developments and data needs

Since its introduction, the CAP has evolved significantly. Developments were brought to provide solutions to the new needs emerging over time, with an eye always on a pertinent use of taxpayers' money (accountability)[5]. But over the last years, climate change has now become a key concern for the EU, and the CAP has sharpened its focus on environmental and climate protection. Generation of GHGs and other environmental concerns related to air, water and biodiversity have become more prominent and all have a strong connection to agriculture. Therefore, environmental and resource efficiency in agricultural production along with carbon sequestration though forestry and other means are now vital.

Reflecting these concerns, the European Green Deal (European Commission, 2019) and Farm to Fork strategy (European Commission, 2020) set out an agenda for change that will need to be addressed by the agricultural sector. The integration of economic, social and environmental sustainability is the issue which the new CAP needs to tackle. Ultimately, this involves a constant widening of the CAP's objectives. It can be expected therefore that the CAP 2023-27 will place stronger emphasis on the achievement of a range of environmental goals, while at the same time promoting the modernisation/digitisation of agriculture, so that it can adapt to the changes required and also provide the income and lifestyle necessary to make agriculture an attractive career choice.

The uptake of new technologies, and more specifically ICT technologies, is crucial for EU farmers in order to address climate breakdown while optimising farm income and making farming more sustainable and competitive. These are indeed objectives which are pursued by the European Commission with the current revision of the EU's CAP[6]. Indicators are necessary to monitor policy objectives because it is important to understand current conditions in order to set future targets for improvement. Indicators can then be used to monitor progress towards these goals. In addition, indicators that relate to different objectives can be evaluated together to assess the synergies and trade-offs that occur in achieving particular objectives (Latruffe et al., 2016).

Following Table 1[7] presents example indicators related with CAP Strategic Plan regulations associated to Green Deal targets.

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[5] https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/cap_briefs_10_simplification.pdf

[6] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) […] https://ec.europa.eu/commission/sites/beta-political/files/budget-may2018-cap-strategic-plans_en.pdf

[7] https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/sustainability_and_natural_resources/documents/analysis-of-links-between-cap-and-green-deal_en.pdf

Table 1. Indicators of the CAP Strategic Plan Regulation associated to Green Deal targets

Green Deal targets related to the agricultural sector[18]	Impact indicators/ Context indicators	Output and result indicators
• Reducing by 50% the use and the risk of chemical pesticides by 2030 • Reducing by 50% the use of high-risk pesticides	I.27 Sustainable use of pesticides: reduce risks and impacts of pesticides	R.37 Sustainable pesticide use: share of agricultural land concerned by supported specific actions which lead to a sustainable use of pesticides
• Reducing by 50% the sales of antimicrobials for farmed animals and in aquaculture by 2030	I.26 Limiting antibiotic use in agriculture: sales/use in food producing animals	R.36 Limiting antibiotic use: share of livestock units concerned by supported actions to limit use of antibiotics
• Reducing nutrient losses by at least 50% in 2030	I.15 Improving water quality: Gross nutrient balance on agricultural land	R.21 Sustainable nutrient management: share of agricultural land under commitments related to improved nutrient management
• Achieve 25% agricultural area under organic farming by 2030	C.32 Agricultural area under organic farming	O.15 Number of ha with support for organic farming
• Completing fast broadband internet access in rural areas reach		R.34 Connecting rural Europe: share of rural population benefitting from improved access to services and infrastructure through CAP support
• Increasing land for biodiversity, including agricultural area under high-diversity landscape features	I.20 Enhanced provision of ecosystem services: share of UAA covered with landscape features	R.29 Preserving landscape features: share of agriculture land under commitments for managing landscape features, including hedgerows

As it is analysed in MEF4CAP's "D1.1: Evolution of the CAP and related policies", (Donnellan et al., 2021) the CAP Common Monitoring and Evaluation Framework (CMEF) has already a substantial set of indicators[8], but these are collected at a relatively aggregate level and say little about the specifics of individual farms. Since policy influences the decisions of individual farmers, it makes sense to develop an indicator framework that has a high level of spatial detail.

[8] https://agridata.ec.europa.eu/extensions/DataPortal/cmef_indicators.html

This spatial detail can also account for farm-specific differences, such as differences in climate and soil characteristics, which may be important in the context of sustainability. Technological developments in data collection, data processing, data management and data analysis make the provision of data with high spatial resolution that are also viable and affordable. There may also be the possibility to scale up this farm level detail in order to provide regional and national impacts on an aggregated level.

Based on the review conducted by WP1 on the future CAP reform -beyond 2027- the capacity to produce indicators is expected to continue to increase reflecting technological developments. Likely, it is the level of spatial detail and the level of integration of indicators that will need to be emphasised beyond 2027, with the individual indicator themes remaining in line with those identified as necessary in the period to 2027.

Based on the findings of "Deliverable 1.1 - Evolution of the CAP and related policies" (Donnellan et al., 2021) it is concluded that there is a requirement at EU MS level for:

1) a considerable amount of additional environmental data. At the core of this should be data that addresses the priorities set out in the EU Farm to Fork Strategy. This would include data on GHG emissions and sequestration, fertiliser use, pesticide use, organics, and other on less intensive agricultural systems that can deliver high environmental benefits, forestry products and ecosystem services as well as bioenergy.

2) some additional data for the social dimension. In this regard, quality of life measures seems to be particularly important. Quality of life potentially spans a wide range of concerns, from social isolation to access to facilities and broadband, to work life balance, stress, mental health, physical health and gender inequalities.

3) some additional data for the economic dimension, particularly with respect to risk management and the distribution of value added in the food chain.

4) if possible, some data on innovation, since innovation will be vital in ensuring that EU agriculture can achieve the ambitions of the Farm to Fork Strategy.

3.2 Agricultural technologies and CAP monitoring

As part of its ongoing move to simplify and modernise the EU's CAP, the European Commission is adopting new rules that will allow a range of modern technologies to be used when carrying out CAP controls. One of the key organisations towards the digitisation of CAP monitoring process is JRC[9]. JRC supports the implementation of the Common Agricultural Policy (CAP) and its instruments, such as the Good Agricultural and Environmental Conditions (GAEC) standards and the Farm Advisory System (FAS). As it is stated, the final aim could be the possibility to completely replace physical checks on farms with a system of automated checks based on

[9] https://ec.europa.eu/jrc/en/research-topic/agricultural-monitoring

analysis of satellite-based data in combination with Internet of Things (IoT) enabled sensors and other digital technologies. Up to date, the main technological solutions that are utilised for CAP monitoring are Earth Observation based technologies in a process also known as control with remote sensing (CwRS). Recently, the use of geotagged photos captured by mobile devices is also utilised in a pilot phase[10]. However, there is still great potential which is currently not enough researched in utilising agri-tech based solutions in the context of CAP monitoring. Taking into consideration the fact that farming activities across different regions in EU are highly diverse, the use of ICT based solutions for performing automated CAP controls is getting even more challenging.

WP2 of the MEF4CAP project focuses on reviewing and analysing Information and Communication related Technologies of the agricultural sector in the context of CAP monitoring and evaluation. The overall objective is 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 new agricultural and related policies (future CAP).

3.2.1 Landscape of agri-food ICT technologies within the EU

Deliverable D2.1 (Kalatzis et al., 2021) performed a state-of-the-art review of ICT developments that are currently having a dominant role in agricultural practices and that can potentially be useful towards data sharing in the context of current and future CAP. To this end, selected technologies were presented along with the information entities that can directly (raw data) or indirectly (inference/processing of data recordings) been extracted. The overall objective was to create a first analysis (filtering) that will support MEF4CAP project to further evaluate the technologies that can be exploited in order to support the CAP monitoring and evaluation framework of the future.

According to the conducted review different technologies for performing automated CAP controls are currently under evaluation by EU experts (e.g. JRC), especially those relying on free-access Earth Observation data. Other technologies exploiting complementary data sources (e.g. images captured by drones or field-data captured by farmers' devices) are being explored, but still with limited validation for the moment. Technical validation must especially address aspects such as accuracy/tolerance of measurements, calibration, training, etc. which are essential to ensure validity of the controls.

In the context of MEF4CAP, the following ICT data sources have been identified as the most important in the context of future CAP monitoring:

- Telecommunication technologies
- Field Sensors
- Farm Management Information systems (FMIS)
- Field Machinery

[10] https://marswiki.jrc.ec.europa.eu/wikicap/images/c/ce/Geotagged_JRC_Report1.pdf

- Earth Observation
- 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, 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 Member States.

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 areas 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. IoT 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 recorded by the various ICT technologies, it is also necessary that these are shared in a meaningful, secure and trusted manner. There are currently various ongoing efforts that aim to formulate the technical means (e.g. standards and protocols) but also the regulatory environment of agricultural data sharing.

With regards to agricultural data formats and data interoperability approaches, a review of dominant agricultural data modelling approaches is conducted in D2.1 (Kalatzis et al., 2021). As it is stated in this deliverable, establishing a harmonised approach on the semantics of the datasets recorded by various technologies is a crucial aspect prior their exploitation for the needs of new CAP monitoring and evaluation needs. As it was evident by the presented data harmonisation efforts, the overall ecosystem is highly fragmented without having yet a dominant global data modeling approach. For specific technologies there are already standardised data models that are widely utilised like the ISOBUS (ISO 11783) for data items related with machinery (tractors) operations.

3.2.2 Identified new ICT technological opportunities

WP2 Deliverable 2.3 (Kalatzis et al., 2021) focused on capturing technological developments, ICT solutions and methodologies in the agri-food domain that are not yet widely deployed or that are still in research and development phase. Towards this scope, a series of liaison activities with the most prominent EU projects and organisations were realised aiming to identify if and how their outcomes can directly or indirectly be exploited towards the digitisation of monitoring and evaluation frameworks for the future CAP. The conducted analysis of the current results for each project was based on two main sources:

a) Review of already published results. The main sources of information are published deliverables, information available at project's website, and presentations (slides) available from various public events.
b) Analysis of the meeting minutes recorded during the sessions (on-line meetings) organised with the MEF4CAP project.

For each project, a short summary of outcomes was provided, including also the relevance of the project's objectives with the MEF4CAP, the project's direct or indirect relation with CAP monitoring and evaluation as well as the potential for future collaboration activities. Based on the selection of the current most promising ICT solutions and the realised liaison activities, a mapping is presented in the following table that links the MEF4CAP's technological areas of interest and the potential contribution by the collaborating projects.

Table 2. Mapping of collaborating projects and further synergies

Initiative name	**CAP related technological opportunities**
H2020 DEMETER Building an Interoperable, Data-Driven, Innovative & Sustainable European Agri-Food Sector	• Telecom technologies • Field sensors • Farm Management Information systems • Agricultural machinery • Agricultural data models • Piloting of farming technologies
H2020 ENVISION Monitoring of Environmental Practices for Sustainable Agriculture Supported by Earth Observation	• Satellite based Earth Observation & Remote sensing services • Pasture management technologies
FaST - Farm Sustainability Tool	• Satellite based Earth Observation & Remote sensing services • Farm Management Information Systems
Open IACS Open LOD platform based on High Performance Computing capabilities for integrated administration of Common Agriculture Policy	• Agricultural data models and • Data sharing strategies

Initiative name	CAP related technological opportunities
H2020 MIND STEP Modelling Individual Decisions to Support the European Policies Related to Agriculture	• Platforms for financial information exchange • Agricultural data models and • Data sharing strategies
H2020 DIONE Advanced monitoring for modernising CAP	• Satellite based Earth Observation & Remote sensing services • Field sensors
H2020 NIVA New IACS Vision in Action	• Satellite based Earth Observation & Remote sensing services • Geotagged photos • Farm Management Information systems • Agricultural machinery • Agricultural data models • Data sharing strategies

A detailed analysis on the realized meetings, including dates, participants, extracted outcomes from the analysis of the meeting minutes and planned next steps are available in "D2.3 Identified new technological opportunities from collaboration with EU projects and initiatives".

4. Use of agri-tech solutions and CAP monitoring - benefits and challenges

The objective of this section is to elaborate on use cases of agritech utilization that today can be considered as pioneering but on the same time demonstrate strong potential of becoming common practice in the near future. The adoption of digital agricultural technologies can be considered as a tool that concurrently facilitates implementation of sustainable agricultural practices and increased transparency of agricultural production supporting data-driven policy monitoring and evaluation. To this end, the following criteria are introduced -considered as best practices on agritech utilization in combination with the need for policy monitoring- that drove the selection of the exemplar cases:

a) The selected technologies support the implementation of sustainable agricultural practices and provide clear benefits for the farmers and the environment.
b) The selected technologies belong to a high TRL and already demonstrate significant penetration in agricultural production for EU.
c) The selected technologies are capable to interoperate in combined-complementary manner.
d) The use of technologies generates farm level ground truth evidence (e.g., data logs) with regards to the applied agricultural practices that can potentially be utilised for the monitoring and evaluation of agricultural and environmental related policies.

The selected exemplar cases are based on real-world applications that have been identified through a state-of-the-art review analysis of numerous reports and scientific articles on agri-tech developments in EU. The initial part of this analysis was conducted for the needs of deliverables D21 and D23 and more details and references are available in the respective reports.

The selected cases are demonstrating the complementary use of various agricultural ICT technologies that have been identified as dominant from an early stage of MEF4CAP project and have been analysed in the respective deliverables. It should be noted that the selected use cases are not exhaustive for the agricultural domain and many other paradigms may exist, however the objective of this exercise is to go beyond the typical high-level agri-tech state-of-the-art review and offer to the readers a close look on the actual digital logs and examples of technologies utilisation.

4.1 Variable Rate Application technologies and monitoring of applied phytochemicals

There is a significant need for optimizing the use and the monitoring of phytochemicals for agricultural purposes e.g. fertilisers and pesticides. The use of phytochemicals has serious environmental, public health and financial consequences and for this reason in EU currently are invested significant efforts for reducing or at least optimizing their use. These needs are also reflected by the existing and upcoming strict legislation for pesticides use. This section initially presents an analysis on the current status for pesticides monitoring which results to the need for improved monitoring mechanisms, and the demonstrated potential of Variable Rate Application (VRA) technologies implemented by agricultural machineries. The application of phytochemicals is greatly optimized through the use of VRA technologies, while on the same time VRA mechanisms also generate digital evidences that are useful in various manners including CAP monitoring.

4.1.1 The need for Plant Protection Products monitoring

The need for monitoring of Plant Protection Products (PPPs), commonly known as pesticides, is particularly important and their use is currently regulated in EU under a very well established and stringent legislative framework[11] which is constantly updated with scientific data and revised taking into account consumer and societal demands. EU countries must implement the requirements of the Sustainable Use Directive[12] (SUD) through their National Action Plans[13] (NAPs). These actions are also relevant to Green Deal's strategies: Farm to Fork[14] and Biodiversity for 2030[15], while maintaining a strong correlation with the specific objectives of the common agricultural policy (CAP) and each country's strategic plans[16].

The main targets of SUD are the achievement of a sustainable use of pesticides in the EU, to reduce the risks and impacts of pesticide use on human health and the environment, to promote the use of Integrated Pest Management[17] (IPM) and of alternative approaches or techniques, such as non-chemical alternatives to pesticides. The NAPs (under revision every five years) contain quantitative objectives, targets, measurements and timetables through following actions[18]: a) training of users, advisors, and distributors, b) inspection of pesticide application equipment, c) the prohibition of aerial spraying, d) the protection of the aquatic environment and drinking water, e) limitation of pesticide use in sensitive areas, f) information and awareness raising about pesticide risks and g) systems for gathering information on pesticide acute poisoning incidents, as well as chronic poisoning developments, where available. The following two subsections elaborate on the processes applied for monitoring the use of pesticides on country level and the potential of utilizing innovative technological solutions for achieving monitoring on farm level.

4.1.2 Quality and quantity indexes for PPPs use in the EU

Following the obligations set out in Article 15(1) of the SUD, two harmonized risk indicators[19] (HRI 1: use and risk of pesticides, HRI 2: number of emergency authorisations) were established in order to monitor the quantity and the nature of plant protection products (PPPs) used in the Member States. These indicators are utilised to calculate and to identify trends in the use of certain active substances, and to identify priority items, crops, regions or practices that require

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[11] https://ec.europa.eu/food/plants/pesticides_en
[12] https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides_el#about-the-sustainable-use-of-pesticides
[13] https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides/national-action-plans_en
[14] https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en
[15] https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en
[16] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-strategic-plans_en
[17] https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides/integrated-pest-management-ipm_en
[18] https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides/main-actions_en
[19] https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides/harmonised-risk-indicators_en

particular attention or good practices, while in parallel to annually communicate the results of these evaluations to the Commission and to other Member States and make this information available to the public. HRI 1 is calculated by multiplying the annual quantities of four groups active substances placed on the market by the relevant hard weighting for each group, followed by the aggregation of results of these calculations. HRI 2 is calculated by multiplying the number of authorizations granted for PPPs under Article 53 of Regulation (EC) No 1107/2009 for each group of active substances, by the relevant hazard weighting, followed by the aggregation of results of these calculations. For example, the trends in HRIs for the European Union published on 10 August 2021 for the period 2011-2019, show a decrease of 21% since the baseline period in 2011-2013, and a 4% decline compared to 2018 for HRI 1, while for HRI 2 an increase of 55% since the baseline, but a 5% decrease compared to 2018.

Problems identified

The Commission is currently evaluating the Directive and will issue an impact assessment of its possible future revision, while the past years several reports from countries have been submitted, consultation events and stakeholder workshops have taken place, countries' NAPs revised, strong and weak points of SUD's implementation have been identified. A report[20] from the Commission to the European Parliament and the Council in 2020 made strong remarks on the latter. More specifically the most prominent issues identified were that: a) only a small minority of Member States identified specific examples of useful targets and indicators based on the review of the initial NAP, b) just 20% of revised NAPs set high-level, outcome-based targets as part of a longer-term strategy to reduce the risks and impacts of pesticide use, c) the assessment of the implementation of IPM by Member States continues to be the most widespread weakness in the application of the SUD. Despite the weaknesses in NAPs, Member States have made progress in implementing the SUD. Their majority have established comprehensive systems for the training and certification of operators, and a range of measures for water protection and the safe handling and storage of pesticides. On the other hand, the enforcement of IPM is low and there is limited evidence that IPM principles are systematically applied.

The Commission considers IPM as one of the cornerstones of the SUD, and that its full implementation is necessary in order to reduce dependency on pesticide use. It is upon the Member States to implement the eight general principles of IPM as listed in Annex III of the SUD, however they have not converted them to prescriptive and assessable criteria to be applied by users (e.g. farmers, agronomists). Therefore, Competent Authorities have limited evidence that IPM is systematically applied. Among Member States there is a great variability of how IPM is promoted, connection structures between researchers and farmers exist and practical advice being made available to farmers.

Room for improvement

Regarding IPM, the Commission has been organizing BTSF[21] courses for training governmental officials for the betterment of the framework that Member States will measure IPM

[20] https://ec.europa.eu/food/system/files/2020-05/pesticides_sud_report-act_2020_en.pdf
[21] https://btsfacademy.eu/training/

implementation. The Commission also called Member States to reduce the dependency on the use of pesticides, promoting precision and digital farming, and to focus more on non-chemical alternatives and low-risk PPPs.

As for HRIs, the Commission has committed to develop a more sophisticated indicator to show the trend in the risks associated with emergency authorisations (HRI 2). In the future and when data becomes available, it is envisaged to develop additional indicators to facilitate monitoring specific aspects of SUD. These indicators could be based on organic farming, certification of sufficient knowledge acquired by professional users and inspection of pesticide application equipment.

In cases where Member States fail to meet their obligation under the SUD, the Commission is currently considering taking further steps, including infringement procedures. In conjunction with the evaluation of NAPs' quality, the Commission will prepare a legislative proposal to revise the SUD taking under consideration the targets set by Farm to Fork and Biodiversity strategies. The CAP currently supports, and the future CAP strategic plans will continue to support, many aspects of the sustainable use of pesticides as Member States will now have to demonstrate how these plans will contribute to long-term national targets set in the context of environmental and climate legislation, including SUD. On a national level, collected data on pesticides utilisation refer specifically to sales and not on the use of pesticides as no data from individual producers are collected. The consumption of pesticides in agriculture would best be indicated by the rates applied by the farmers. These data are, however, not available today[22]. It can be assumed that sales data (retailer points) and consumption data (farmers' use) could be the same but this is not always the case. In addition, evidences on the use of pesticides are only gathered at least after one year of their use.

According to the "Report of the European Court of Auditors on Sustainable use of plant protection products"[23] EU rules on statistical confidentiality on PPPs utilization is quite restrictive. EU requires the annual data collection of active substances contained in PPPs sold and their respective utilisation for selected crops. However, these data collections and respective aggregated statistics are not allowed to publicly disclose the identity of individual PPP producers, the identity of PPP users, and the overall utilization of specific Active Substance on regional/country level. According to EU regulations statistics active substances need to be aggregated into major groups, such as insecticides, fungicides and herbicides.

Professional PPP users have to keep records of the products they use for at least three years. In addition, IPM principle number 8 requires them to check the success of their plant protection measures based on records of PPP use and on pest monitoring. There is no EU requirement for

[22] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides#Key_messages
[23] "Special Report 05/2020: Sustainable use of plant protection products: limited progress in measuring and reducing risks" https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=53001

users to keep records of other IPM actions, and the Commission has encouraged Member States to introduce such obligations in national law.

4.1.3 Monitoring of applied chemicals on farm level

As it was analysed in the previous section there are currently no robust mechanisms for monitoring pesticides use on farm level. Research community works on various approaches in order to resolve this issue. In this context, there is great potential for monitoring PPPs field application through the use of state-of-the-art technologies and more specific agricultural machinery. There is an ongoing trend towards the digitization of the equipment that are utilized for applying agrochemicals (pesticides and fertilisers) that can potentially allow on the one hand to implement better cultivation strategies and on the other hand to generate and record field evidences of their utilization.

Variable Rate Application (VRA) technologies (Fastellini et al., 2020) allow to apply agrochemicals (and seeds) based on a predefined logic and according to the detected needs of the various areas/zones of the field. For example, the variable-rate sprayers allow the farmers to apply pesticides using the correct amount based on the canopy size, season, and growth phase of the plants. Some examples of such commercial grade systems are available through an interactive inventory of advanced spraying equipment developed by the H2020 INNOSETA[24] project: https://platform.innoseta.eu/list?type[]=5. In most of the cases the smart spraying solutions include functionalities for extensive recording of data related to dosing volumes, spraying conditions (e.g. humidity, wind), speed and the trajectory of the vehicle where the nozzles are installed. Agricultural systems employing variable-rate application are combined with intelligent control systems and can significantly reduce agrochemicals use and off-target environmental pollution. VRA systems are divided to map-based and sensor-based:

- The map-based application of chemicals is pre-planned and based on prescription maps that have been generated through field monitoring technologies. For example, in the work presented in (Campos et al., 2020) prescription maps for a vineyard were generated after a detailed canopy characterization, using a multispectral camera embedded on an unmanned aerial vehicle, throughout the entire growing season. The maps were obtained by merging multispectral images with information provided by a decision support system. Canopy characteristics are crucial for accurately and safely determining the pesticide quantity and volume of water used for spray applications in vineyards. The inherent variability, especially in large parcels, has led to increased interest in the development of advanced sprayers that could modify the spray application parameters in order to adapt the amount of PPP to the canopy structure. The overall flow of map-based VRA can be summarized within the following steps: a) Scan of the field, b) identify zones, c) create a prescription, d) send prescription to sprayer (usually installed on a tractor) and e) execute the prescription-apply chemicals.

[24] http://www.innoseta.eu

- Sensor based VRA (Abbas et al., 2020) operates in real-time mode and is based on input received by sensors that are attached on the variable rate applicator. The target detection methods include a range of remote sensing technologies including laser and vision scanning systems, ultrasound, infrared, and spectrum analysis systems. For pesticides application on plants and trees the objective is to obtain an accurate and detailed three-dimensional image of the canopy in order for the spraying nozzles to adapt accordingly the spaying operation. In the case of weed detection computer vision methods are utilized aiming to detect the targeted area and spot spray.

Besides the offered benefits in terms of optimization of the use of PPPs advanced VRA technologies are also offering the benefit of extensive logging. Especially in the case of map-based application the prescription maps contain all the necessary information of the quantity of the PPP to be applied along with respective areas (coordinates) of the field. A typical scenario includes that the prescription map is expressed in a machine-readable format that is loaded to the computer system of the sprayer and contains information on the coordinates, the dose, and other metadata referring to the machinery and farm. Log data referring to the executed task are returned to the Farm's Information System which are utilized to document the performed work and to monitor work performance for business purposes (figure 1). For example, an agricultural contractor can verify the performed work by showing the measurement data to the customer. Researchers such as biologists and agronomists, can also benefit from the increasing measurement capabilities and use generated dataset to model crops and agronomic phenomena, verify hypotheses and produce new knowledge (Kaivosoja et al., 2013).

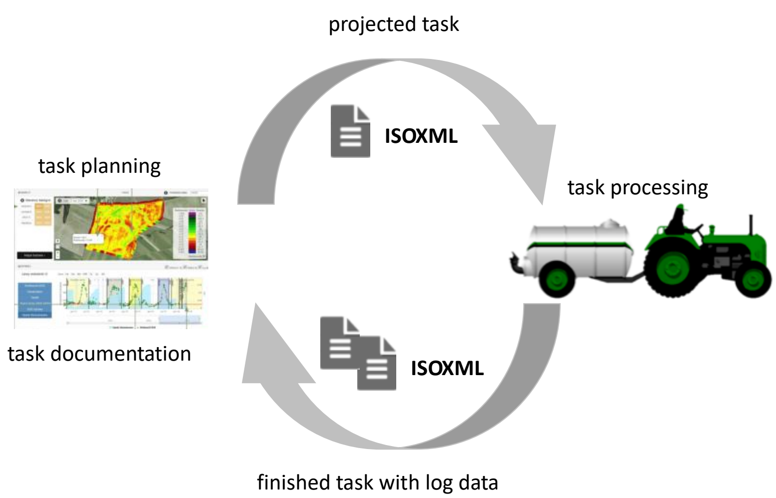

Figure 1. Information flow of VRA task among information system and machinery

In most cases farm's machinery is often a mixture of older and newer machines from a number of manufacturers, therefore there is a strong need for compatibility between different brands. A dominant data format for expressing such information is ISOBUS (ISO 11783[25]), which is an open standard for interconnecting electronic systems developed to support agricultural

[25] https://www.iso.org/obp/ui/#iso:std:iso:11783:-1:ed-2:v1:en

machinery operations. It allows communication between sensors, actuators and controllers, enabling a standardised exchange of data (expressed in XML) between tractors, implements and onboard controllers of different brands. One of the key benefits of ISOBUS standard is that is applicable for different type of tractors and machinery including also old vehicles. The ISOBUS system is currently being maintained, updated and marketed by the Agricultural Electronic Industry Foundation (AEF, 2019).

The simplest ISOBUS system consists of a tractor Electronic Control Unit (ECU), an implement ECU and a universal user interface called universal terminal (UT) or virtual terminal (VT). These devices form the basic structure used to control the tractor and implement combination. There can be additional devices attached to the system, such as a positioning device (GNSS – EGNOS/GALILEO), or a task controller (TC). The task controller can be used to control, implement, as well as to store the data logged in an executed field operation[26]. A TC that is capable of location-specific control and logging is called TC-GEO and a TC that is capable only of data logging is called TC-LOG. Figure 2[27] provides an illustration of the core components of ISOBUS supported devices deployed on agriculture machinery.

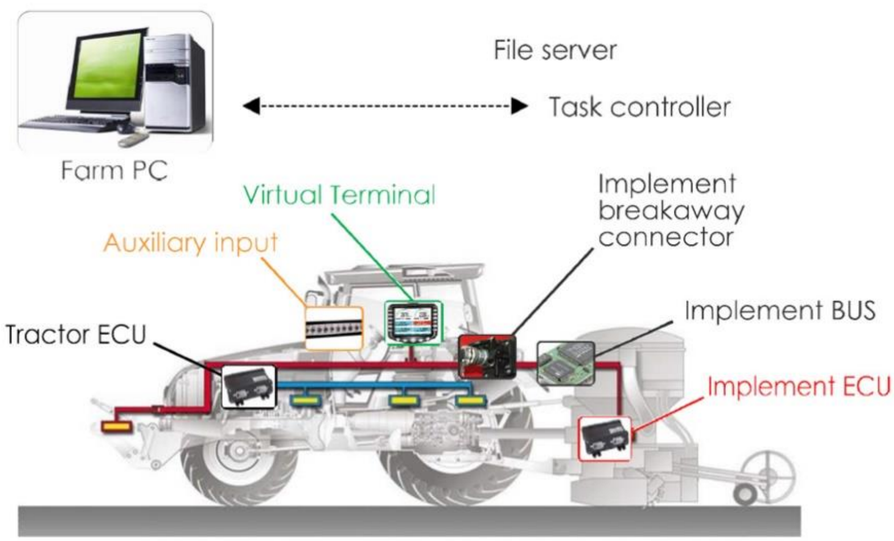

Figure 2. The core components of ISOBUS

As it is described in Kraatz et al. (2019), ISOBUS data items are expressed in XML format (called ISOXML) having several mandatory and optional attributes that correspond to the parcel's coordinates (polygon), the farm's identifier, the parcel's identifier, the type of the operation, the applied PPPs, start/end time of the operation, etc. Each attribute corresponds to specific xml schema tags usually represented by a shortcut of three characters. Some of the attributes hold references to other elements in the structure. The full ISOXML data model dictionary of reserved terms that allow to model in detail the main operations that may take place with the

[26] https://www.iso.org/standard/61581.html
[27] https://www.embitel.com/blog/embedded-blog/what-is-isobus-learn-about-its-architecture-and-diagnostic-applications

use of agricultural machinery is available on line here: https://www.isobus.net/isobus/dDEntity/index
A simple ISOXML example follows:

```
1:<FRM A="FRM1" B="Hof Herrmann"/>
2:<PFD A="PFD1" C="Exx_Platz" F="FRM1">
3:    <PLN A="1">
4:          <LSG A="1">
5:                <PNT A="2" C="52.28.." D="8.02.."/>
6:                <PNT A="2" C="52.28.." D="8.02.."/>
7:                <PNT A="2" C="52.28.." D="8.02.."/>
8:                <PNT A="2" C="52.28.." D="8.02.."/>
9:                <PNT A="2" C="52.28.." D="8.02.."/>
10:         </LSG>
11:   </PLN>
12:</PFD>
```

This sample corresponds to an operation took place in a farm called Hof Herrmann and a field called “Exx Platz”. The field (line 2) has a reference to the farm (line 1) at the attribute F. Part of the field element is a polygon (line 3) with a line element (line 4) and five points (line 5-9) for the field border.

In Backman et al. (2019), the Cropinfra platform for independent research data collection is presented. Authors introduce data processing and communication mechanisms for collecting data from ISOBUS compliant machines operating in farming environments as well as older/proprietary systems. The collected data are stored to cloud-based database for further analysis mainly focusing on research objectives e.g. as a reference measurement system to verify the correct operation of the machines as well as to produce data for biological research purposes. The conceptual overall structure and the different devices and services that are involved in order to facilitate data collection from farm machinery is illustrated in figure 3. Cropinfra platform introduces a number of software modules (colored in green in figure 3) that are deployed and operate at the various layers of the ISOBUS data generation/collection process. The bottom (measurement) layer contains the physical modules (sensors and implements) that realise the various operations. On the data capturing layer various ECUs support the connection with the physical modules, receive the analog signals and transmit them to the ISOBUS communication (CAN) bus. Above the ISOBUS CAN, there are control and logging devices (VT/TC) that capture, utilize and store the measurements locally. Finally, at the top layer data transfer and storage means are available. The specified approach supports data collection and data transfer also for legacy machines with limited ICT capabilities. Finally, Cropinfra data capturing and data transfer mechanism can operate in both bulk and real-time mode.

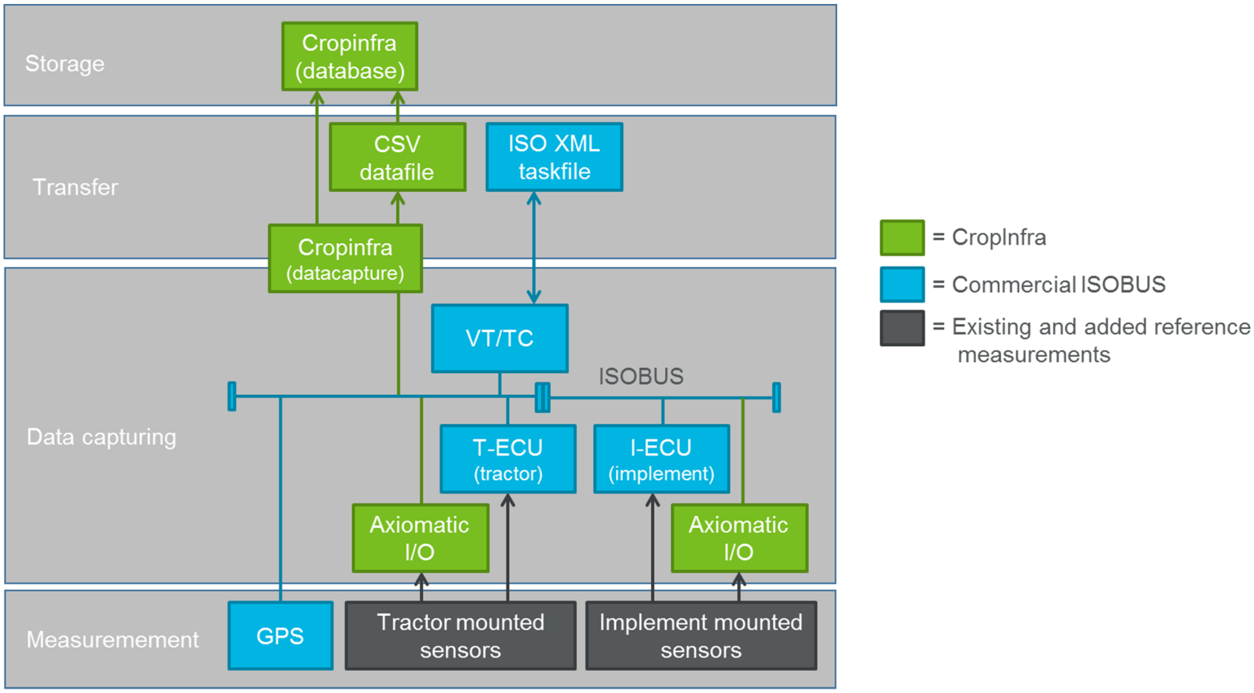

Figure 3. Conceptual view of the Cropinfra-ISOBUS approach for data collection from farm machinery

The Cropinfra platform and the respective data collection mechanisms have been utilized by numerous research projects already and the collected data sets are currently utilised as valuable training data sets for machine learning and other artificial intelligence methods. Although this approach focuses on data collection for research purposes it can also be considered as an initial proof of concept of how it is feasible to introduce data collection mechanisms tailored to the ISOBUS protocol specificities serving additional purposes such as CAP monitoring.

The NIVA Project[28] is also evaluating the use of data logs generated by agricultural machinery as evidence for the need of CAP payments (subsidies applications and evaluation). As it is stated, in the "Use Case 4b[29]" description, the main objective is to reduce the administrative burden, by facilitating data flow from farm machinery to administration (e.g. Payment Agency) and to simplify governance due to the increased data quality (precision in time, location and activity). The use case focuses on data generated during the sowing of a catch crop and the concerned data involves information from the machine such as geometry (type, polygon), location and rate of application (kg/m^2) and complementary information from FMIS: farm id,

[28] https://www.niva4cap.eu/

[29] https://www.niva4cap.eu/uploads/USE%20CASE%20PROGRESS/NIVA_UC_progress_for_webpage_UC4b_31Mar2021.pdf

farmer id, farm plot, catch crop, physical process (when, how), mixture (percentage), crop (botanical), specific crop (species). In this use case the role of the FMIS is crucial as it receives and validates the data files generated during the execution of the task by the agricultural machinery and then sends them to the server system of the national Paying Agency (PA). According to the use case description the communication between Farm machine and FMIS is using ISOXML standard. However, the communication between FMIS and the PA is realized through another standard, namely UN/CEFACT "eCrop"[30]. The farm machine provides evidences of rate, location, geometry whereas the FMIS provides data about the farmer, plot, crop, activity, product (which are not present in the machinery logs).

4.1.4 Cloud computing environments of machinery providers

This section presents cloud computing environments of machinery providers that have a dominant role in the market. As it will be evident modern machinery are supported by cloud computing facilities where all collected data on farm activities, applied records and VRA prescriptions, are stored and made available for visualization, processing and sharing. These data sources are off value and highly relevant as supporting ground truth evidence for the needs of policy monitoring and evaluation. It should be noted that the content presented in this section is based on information available on respective machinery manufacturers' websites.

MyJohnDeere™

MyJohnDeere is a platform that can help improve machine uptime, logistics management, and agronomic decisions. This centralised, cloud-based farm management system allows producers to access, view, archive, manage and share a wide variety of data. Tools in the Operations Center provides the user with the ability to analyse, edit, and make collaborative decisions from the same set of information to get higher yields and reduce input costs.

[30] https://unece.org/fileadmin/DAM/cefact/brs/BRS_eCROP_v1.pdf

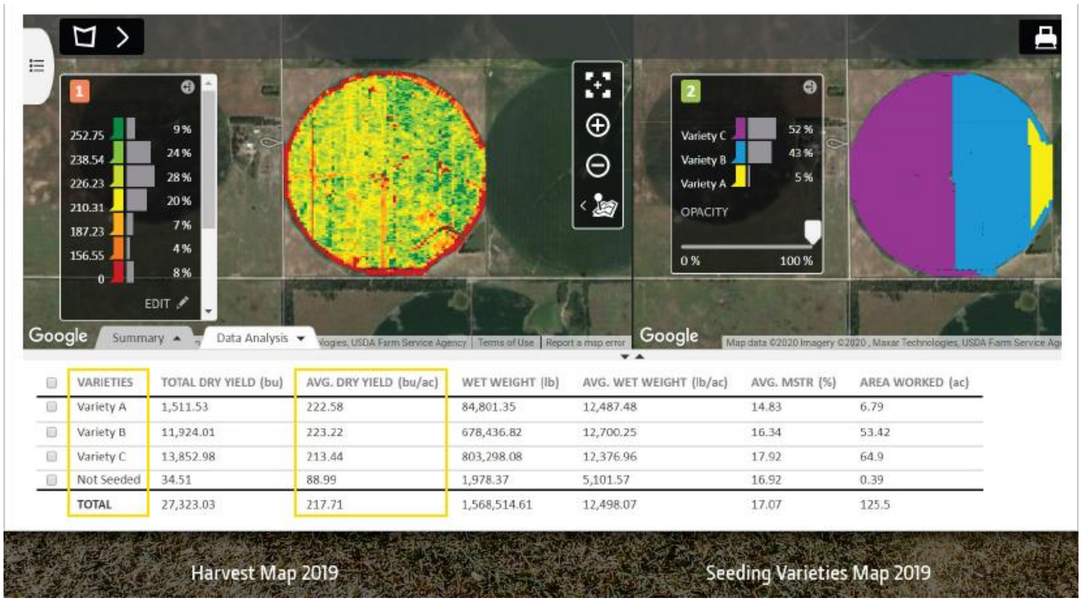

Figure 4. MyJohnDeere™ Harvest and Seeding varieties maps

The user can remotely monitor the machine location history and can quickly access productivity, fuel levels, inputs used (record keeping) or a variety of other relevant information. Moreover, the operation center includes agronomic tools that allows the user to create prescriptions, analyse and compare yield data or as-applied data as in other similar types of software.

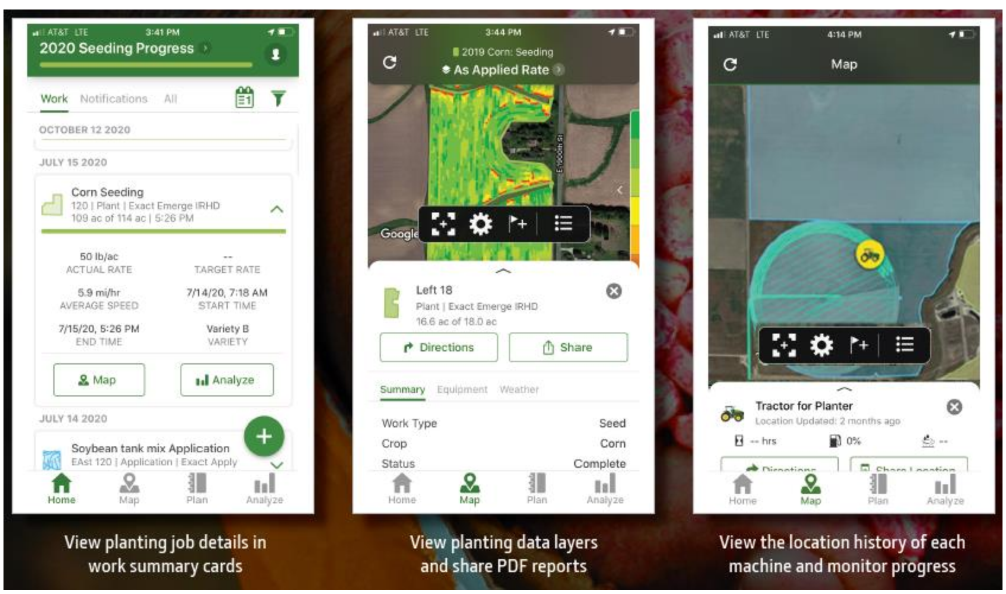

Figure 5. MyJohnDeere™ mobile phone interface

<u>The customer is in control of the collected data and can share it with dealers, crop consultants (agronomists), and/or anyone in their network of trusted advisors; securely, from any Internet-enabled device or by using a USB device</u>. Moreover, MyJohnDeere Operations Center supports integration with other selected smart farming systems via a cloud-to-cloud connection in order

to perform advanced data analysis, compare information to other data sets, and create detailed Variable Rate Application (VRA) maps for seeding, fertilising and spraying.

Data sources utilised:
Production Data which is information about the performed work with the equipment along with the location where the work is performed. For example:

- field task/practices details
- area worked
- route travelled
- crop harvested and yield data (by field)
- planting maps and crop variety performance
- agronomic inputs applied (pesticides, fertilisers)

Machine data which is information regarding machine health, efficiency, and function. Such data comprises of the following:

- machine health indicators, settings, and readings (Average Engine Load Factor, Average Engine Speed -RPM, Average ground speed)
- machine hours or life
- fuel consumption
- machine location (history and real-time)
- diagnostic codes
- software and firmware versions
- machine attachments, implements or headers

Administrative data which is information that help in supporting the account and system activities. For example:

- data sharing permissions
- users linked to the account
- machines, devices, and licenses linked to the account
- number of acres and size of files
- information about how you the account is used

AFS Connect™
Advanced Farming Systems (AFS) Connect™ is an integrated solution that links the farm, fleet and data and assists producers informed, data-driven, management decisions. AFS Connect™ system uses a combination of GPS satellites and cellular technology and the centralised control center streamlines the user's access to critical farm, machine and agronomic real-time and historical data from a computer or tablet/mobile device throughout the entire crop production cycle. The system enables viewing, editing, management, analysis and utilisation of agronomic data collected. Upon permission, AFS personnel can monitor the tractors or combines and provide support for any issues.

With AFS Connect™, growers can connect multiple machines in a field to ensure all operators work together efficiently by sharing coverage maps and predefined (AB) guidance lines for all seasons of use. In addition, the system provides producers with the following benefits:

- Enabling section control based on operation coverage at the field level
- Helping save on costly inputs by preventing overseeding in previously planted areas
- Gathering more accurate data on tillage, planting, seeding, nutrient application, spraying and harvest
- Ensuring parallel passes by all equipment
- Providing accurate yield maps where less-than-full swath is used
- Preventing operators from accidentally making skips and control overlaps

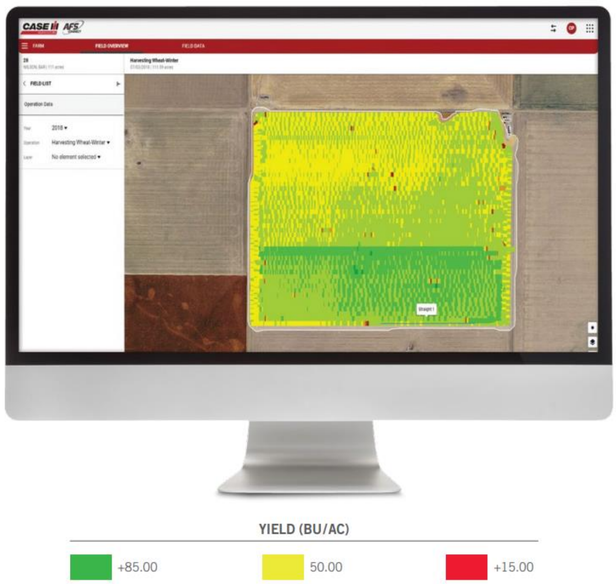

Figure 6. AFS Connect™ yield map

This system gathers data throughout the year and visualises the performed field operations in order to provide better agronomic insights of the overall operational performance. Moreover, AFS Connect™ supports two-way wireless transfer/exchange of data with other selected third-party partners such as AgDNA, Cropio, Farmers Edge™, Trimble® Ag Software and more.

Data sources utilised:

- field task/practices details
- area worked
- route travelled
- yield data (by field)
- planting maps
- agronomic inputs applied (pesticides, fertilisers)
- fleet
- machine health indicators, settings and readings (Vehicle speed, Water temperature, Oil pressure, Engine load, Fuel level, Upcoming service interval, Fault codes, machine hours)
- fuel level and consumption

- machine location (history and real-time)
- software and firmware versions
- machine attachments, implements or headers

New Holland MyPLM™

The MyPLM Connect Farm web platform uses a combination of hardware, application software installed on such hardware, and software services delivered over the internet through the site. The service application software permits the gathering of data and information from vehicle, machine and equipment assets equipped with system supported telematics devices as well as from wireless data collection device assets (e.g., mobile phones, tablet computers, etc.). Moreover, the application may also gather data and information from third-party online data and information services such as weather service data.

MyPLM Connect Farm web platform gives the producers power and flexibility to manage their farm activities, view field boundaries, inspect in-field machine metrics and visualise field-specific data, such as activity layers, scouting observations and soil zone data in near real-time. Some of the latest added features include support for prescriptions, tillage and large square balers; new layer visualisations; machine utilisation maps and more. Users have access to field-specific data, such as activity layers, scouting observations and soil zone data.

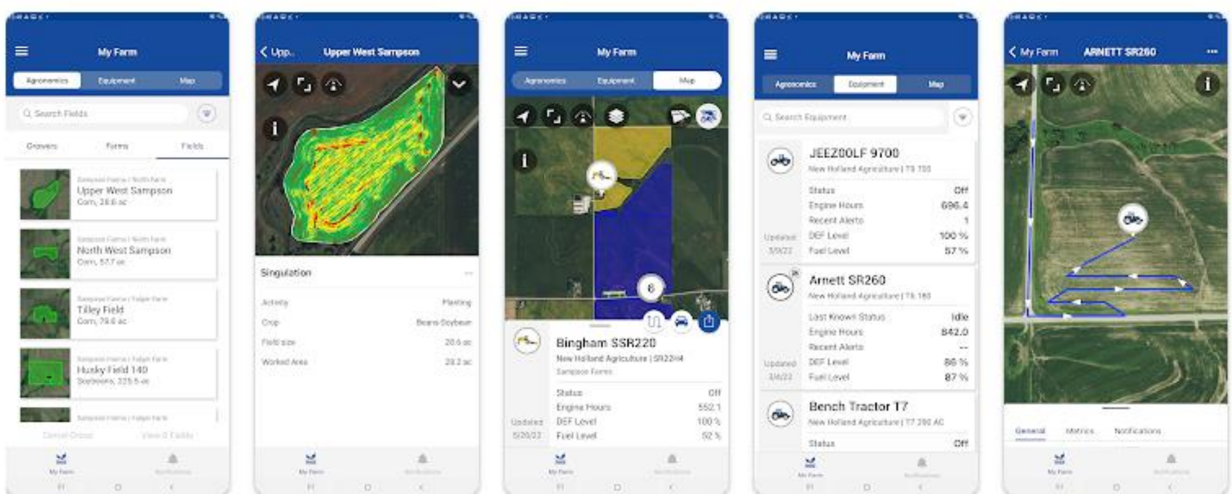

Figure 7. New Holland MyPLM™ mobile phone interface

MyPLM Connect Farm web platform offers the following solutions:

- View of the farm's field boundaries and provision of turn-by-turn directions to fields
- Manage Planting, Spraying and Harvest activities remotely
- Track the status of in-field machinery and analyze their critical metrics directly from a mobile device
- Track input usage, seeding records and harvest yields
- Add scouting information to fields with photographs
- Track input rate performance while on-the-move

- View critical performance analytics on every field and activity on the farm

Figure 8. New Holland MyPLM™ yield map

According to the vendor the platform's information and analytics allow the producer to make better decisions, lower the input costs, boost the produced yield while maximizing the farm management process as a whole.

Data sources utilised:

- field task/practices details
- area worked
- route travelled
- field boundaries
- yield data (by field)
- moisture information
- planting and VRA prescription maps
- agronomic inputs applied (seeds pesticides, fertilisers)
- machine health indicators, settings and readings (Engine speed [rpm], Engine oil temperature, Hydraulic oil temperature, Engine coolant temperature, Hydraulic oil pressure, Engine coolant level [%], Battery voltage, Diesel Exhaust Fluid (DEF) level [%], Vehicle ground speed)
- fuel level and consumption
- fleet related information
- machine location (history and real-time)
- machine attachments, implements or headers

Trimble® Ag Software

Farmer Pro is a cloud-based mobile farm management software providing functionality related to crop health imagery, work orders, grid or zone soil sampling workflows, managing grain contracts, and more. It can also be used for field record keeping, real-time fleet tracking and utilisation, field map layering and for performing profitability analysis based on collected field data. Users can input, access and share records in real time from their devices. The interesting for our analysis features of Trimble Ag Software is related with farm data compatibility and connectivity agreements with other third-party farm management software platforms such as the machinery providers presented in sections above, namely John Deere Operations Center, Case IH Advanced Farming Systems (AFS) Connect™, New Holland Precision Land Management (PLM) Connect, and others. In figure below the compatible types of data and data transfer methods are noted for Trimble Ag Software – FarmerPro.

	File Transfer Method	Data Compatibility							
File Type	Data Direction	Clients, Farms, Fields	Resources (Materials, People, Equipment, Crops, etc.)	Boundaries	VRA Prescriptions	Task Data (As Applied, Yield, Coverage, etc.)	Guidance Lines	Feature Layers	Work Orders
Trimble[1] – AgGPS, AgData	From Device – Direct with display or USB	✔	✔	✔		✔	✔	✔	
	To Device – Direct with display	✔	✔	✔	✔		✔	✔	✔[2]
	To Device – USB	✔	✔	✔	✔		✔	✔	
CNHi – CN1, ISOXML	From Device – API					✔[3]			
	From Device – USB	✔	✔	✔		✔	✔	✔	
	To Device – API				✔				
	To Device – USB	✔	✔	✔	✔		✔	✔	
John Deere – GS3, GS4	From Device – API	✔		✔		✔[3]			
	From Device – USB	✔	✔	✔	✔	✔	✔	✔	
	To Device – USB	✔	✔	✔	✔		✔	✔	
AGCO – ISOXML	From Device – API					✔[3]			
	From Device – USB	✔	✔	✔		✔	✔	✔	
	To Device – API				✔[4]				
	To Device – USB	✔	✔	✔	✔		✔	✔	
ISOXML (includes Mueller, TopCon, CLAAS, and others)	From Device – USB	✔	✔	✔		✔	✔	✔	
	To Device – USB	✔	✔	✔	✔		✔	✔	
Raven Slingshot	From Device – API or USB					✔[5]			
	To Device – API or USB				✔				
Ag Leader – agdata, agsetup	From Device – USB	✔	✔	✔		✔			
	To Device – USB	✔	✔	✔	✔				
Precision Planting – 2020	From Device – USB	✔	✔	✔		✔			
	To Device – USB				✔				

Figure 9. Trimble's Compatibility with other farm data platforms [31]

Overall, this software can collect, process, share and visuallise data from the following sources.

<u>Data sources utilised:</u>

- field task/practices details
- area worked

[31] https://agriculture.trimble.com/software/farm-data-compatibility/

- route travelled
- field boundaries
- yield data (by field)
- weather forecasting
- planting/spraying maps
- VRA prescription maps
- agronomic inputs applied (seeds, pesticides, fertilisers)
- grid or zone soil sampling, including navigation to sample sites
- real-time fleet location, current status and utilisation history
- satellite imagery (UAV)
- farm record-keeping

4.1.5 Conclusions on monitoring via VRA technologies

There already available mature mechanisms that support the planned and accurate application of agricultural chemicals (or seeds). New technologies require extensive logging which in turn contributes to make the overall food production process traceable and quantifiable. The VRA data logs generated during tasks execution demonstrate significant potential for CAP monitoring and evaluation. As it was evident in this analysis sharing of data logs generated by various ICT sources is already taking place in support of tracking and optimization of agricultural practices. These processes are feasible to be extended in order to also address the needs of policy monitoring and evaluation. Some of the core challenges that need to be addressed are the following:

- ISOBUS is a dominant data modeling approach for agricultural machinery operations. ISOBUS is not designed for CAP monitoring purposes, so the respective datasets need to be semantically enhanced with additional information elements. These additional elements can be provided by a FMIS that supports operations of the same farm.

- ISOBUS provides specifications for efficient communication among the different hardware elements of the agricultural machinery. There is still no dominant approach for communicating generated ISOBUS datasets with third parties (ensuring interoperability in syntactic level). The role of a FMIS system can be crucial for addressing this issue acting as a communication gateway with authorized 3rd parties (e.g., CAP monitoring and evaluation agencies) enabling the controlled and authorized communication of ISOBUS datasets.

- There are still no mechanisms to verify the actual composition of the inputs (fertilisers, pesticides, seeds) that are applied through the agricultural machinery. Although VRAs generate extensive logs of the performed operation it is hard to get evidence through ISOBUS on the type of the applied content.

- VRA is implemented mainly with the use of modern and expensive machinery which are utilized in large commercial farms. Penetration and utilisation of VRA enabled farm machinery is rather low in EU countries where small and fragmented farms are the majority (e.g. South Europe). Recently there have been VRA solutions (e.g., Augmenta LiveVRA Services[32]) that are deployed as add-on also on non-modern machineries/tractors which significantly may reduce the cost. A cost benefit analysis on the use of such technologies it is necessary, however it is a complicated tasks and dedicated methodologies need to be developed. This is the main objective of the recently start Horizon Europe Quantifarm[33] project.

- Interoperability issues - The combined use of technologies of different scope from different vendors introduces interoperability issues with regards to differences in data formats and ways of interaction among the systems. This is a wider issue for the agriculture sector and currently various research initiatives are developing data models and interoperability enablers (more details on this in "D2.1 Landscape of agri-food ICT technologies within EU", section "4. Agricultural data sharing" and section "5. Agricultural data models"). Interoperability of machinery related datasets can be considered as a better addressed issue, due to the wide acceptability of ISOBUS standards, especially when comparing with other agricultural technologies. However, integration/harmonisation with data sets generated by other type of technologies, e.g., IoT sensors, Integrated Pest Management, e-Invoices are issues that need further research.

- Privacy protection and data ownership- The extensive recording of various parameters relevant to the farm, the farmer, farm's financial outcomes, type of agro-chemicals applied, quantity of harvested yields, etc. are all sensitive information raising privacy and competition related issues. It is necessary the appropriate mechanisms to be enforced ensuring access control and compliance with legal regulations.

Table 3. Combination of tecnologies towards VRA implementation, benefits for farmers, and for CAP monitoring.

Combination of Technologies	**Benefits for the farmers**	**Benefits for CAP Monitoring & Evaluation**	**Example case studies**
Remote sensing for scanning the field/canopy of plants Field zoning algorithms	Optimised use of inputs (agrochemicals, seed, fuel) Reduced environmental impact	Farm level digital evidences of applied inputs (PPPs, seeds, fuel) Increased transparency of applied practices useful for food	NIVA Use Case 4b: "Machine data" [34] IoF2020 Use Case: "Farm machine interoperability"[35] DEMETER: In-Service Condition Monitoring of

[32] https://www.augmenta.ag/product
[33] https://quantifarm.eu/
[34] https://www.niva4cap.eu/uploads/USE%20CASE%20PROGRESS/NIVA_UC_progress_for_webpage_UC4b_31Mar2021.pdf
[35] https://www.iof2020.eu/use-case-catalogue/arable/farm-machine-interoperability

Variable Rate Application sprayers Satellite navigation systems	Reduced cost for farmers Automated documentation of activities	retailers/processor s	Agricultural Machinery[36]

Key Challenges – Open Issues
Data modelling
Data Interoperability (semantic and syntactic)
Quality of recorded data
Cost and ease of use. Compliance with non-modern machinery
Privacy protection & compliance with regulations

[36] https://h2020-demeter.eu/pilots-overview/pilot-cluster-two/automated-documentation-of-arable-crop-farming-processes/

4.2 Farm level data monitoring through agricultural decision support systems

According to FAO (2021), smart farming ICT systems can be divided into three main categories: farm management information systems (FMIS), precision agriculture (PA) systems, and agricultural automation and robotics. In the analysis conducted in MEF4CAP's D2.1 (Kalatzis et al., 2021) on agriculture related technologies and their potential to contribute to CAP monitoring, FMISs were considered as one of the most valuable but not yet enough exploited technologies. Sørensen et al. (2010) define the FMIS as a computer assisted system for collecting, processing, storing, and disseminating data in the form needed to carry out a farm's operations and functions. FMISs are usually offering, the functionality related with the digital recording of agricultural activities (also called "Farmer's Calendar", "Farm Log", "Field book") that demonstrates the potential to contain various relevant to CAP monitoring information (e.g. use of pesticides, irrigation, fertilizers, harvested yields).

FMISs when combined with emerging technologies and data sources like IoT and Remote Sensing can offer predictive insights in farming operations and drive real-time operational decisions (Wolfert et al., 2017). This functionality is also associated with the term Agricultural Decision Support Systems (ADSS). In general, Decision Support Systems are software services designed to assist humans in making more effective decisions. In the field of agriculture, different stakeholders such as farmers, advisors and policymakers use software tools that support 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 aiming to provide a holistic approach to assist farmers with optimising inputs e.g. fertilisers, pesticides, water, and fuel (Paustian and Theuvsen, 2017).

ADSSs have already reached the required level of maturity (TRL8-9) and are offered as commercial solutions significantly contributing in applying more optimized agricultural practices and on the same time generating the necessary digital evidences for transparent agricultural practices. An indicative but not exhaustive list of FMIS providers in EU that have achieved to reach a significant number of farmers and cultivated land is presented in table 4.

Table 4. An indicative list of FMISs providers in EU

Provider	FMIS solution/product	Link
ABACO	ABACO Farmer	https://www.abacofarmer.com/
Farmnet365	Farmnet365	https://www.365farmnet.com/en/
Neuropublic	Gaiasense	https://www.gaiasense.gr/en/gaiasense-smart-farming
Hispatec	ERPagro	https://www.erpagro.com/

Horta	Grano.net; granoduro.net; orzobirra.net; mais.net; girasole.net; pomodoro.net; legumi.net; vite.net; uva.net; olivo.net	https://www.horta-srl.it/
Seges	SEGES Crop Manager	https://cropmanager.dk/
Smag	Smag FARMER / Smag EXPERT	www.smag.tech
DACOM	Crop Recording, Cloudfarm, Irrigation Management	https://www.dacom.nl/
Agricolus	Agricolus Easy, Agricolus Observa, Agricolus Plus	https://www.agricolus.com/en/
eAgronom	eAgronom Farm management system	https://eagronom.com/en/manager/

A continuously updated inventory of FMISs along with their respective characteristics, including TRL, market availability, targeted cultivations and details of offered services is provided by the SMART-AKIS platform, available here: https://smart-akis.com/SFCPPortal/#/app-h/technologies. The SMART-AKIS platform supports queries based on various criteria while a snapshot of the replied outcomes is illustrated in figure 4.

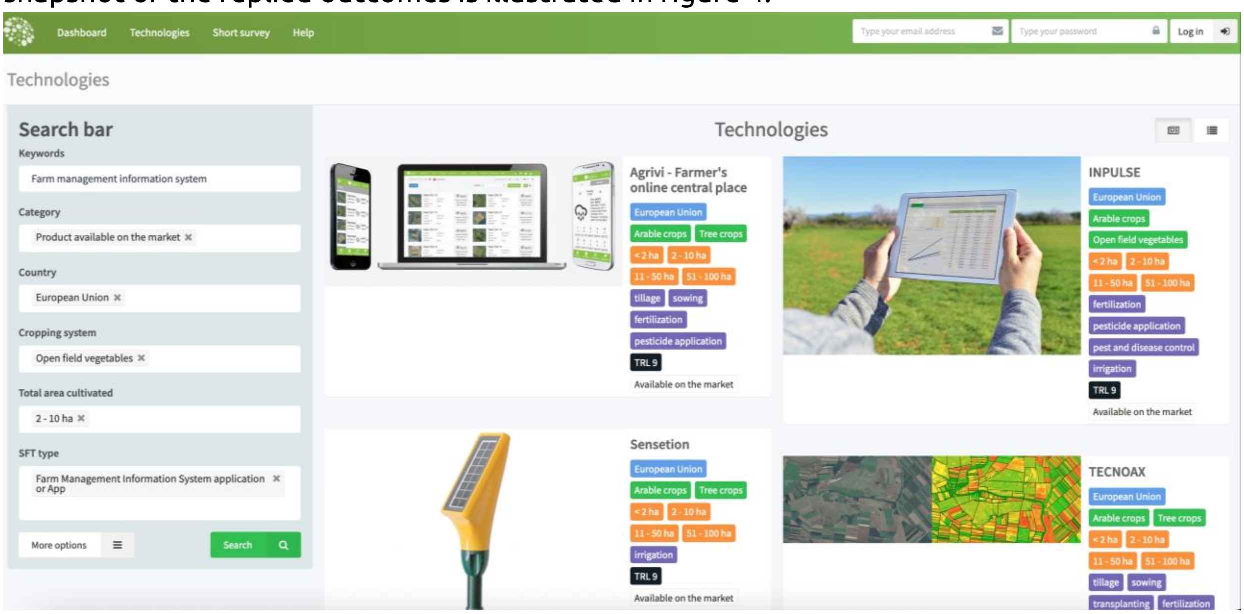

Figure 10. The SMART-AKIS dashboard presenting a list of FMISs

One of the key benefits that FMISs combined with ADSSs are providing is that the applied cultivation activities are not only based on farmers' empirical experience but are also guided by additional data-driven evidences. A typical FMIS utilises a range of diverse data types and technologies in order to provide specific recommendations for key agricultural activities like pest management, fertilisation and irrigation. An extensive list of potential data sources that FMISs can integrate is provided figure 5.

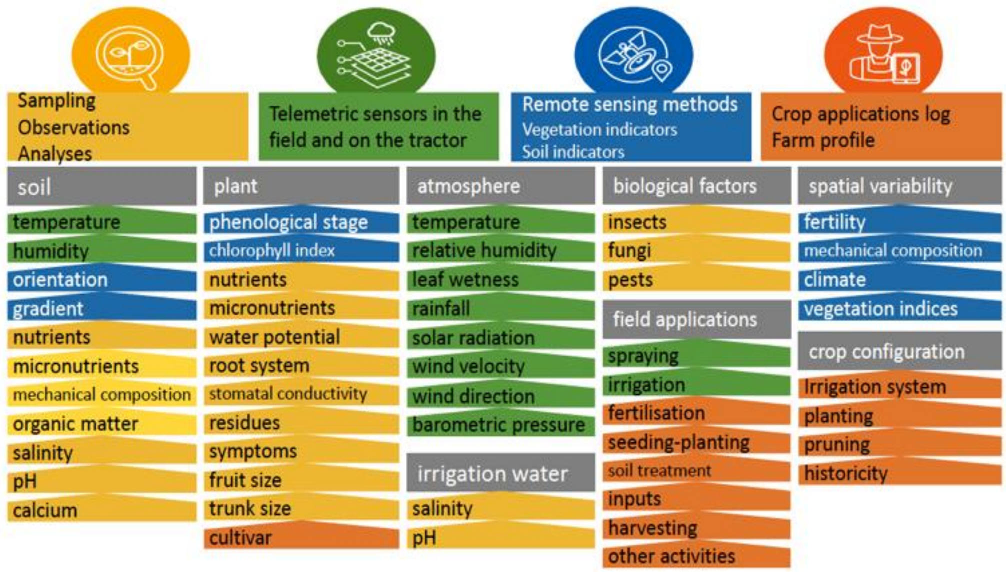

Figure 11. List of potential information sources exploited by FMISs (Adamides et al., 2020)

It should be noted that the sources able to provide data to a FMIS are not static. Continuous developments on sensing technologies are making available new type of sensors or can improve the endurance, reliability and accuracy of existing ones. FMISs must be considered as dynamic systems able to connect and incorporate new information items. In addition, information sources and sensors are dynamically installed and uninstalled depending on the cultivation needs. For example, in some cases soil sensors are deployed during the summer time when there is the need for implementing a data-driven irrigation schedule. Soil sensors can then be uninstalled during winter where there is no need for irrigation or during harvesting process in order to protect sensing devices from spoilage. It should be noted that in some cases these operations are realized by trained technicians and not by individual farmers or agronomists.

As it is analysed in Adamides et al. (2020), a typical information cycle implemented by FMISs is that data from various sources are collected to a central data repository where they are stored, processed, combined, and converted into facts based on knowledge extraction techniques. Among the core objectives of the FMISs is the close-to-real-time monitoring of the conditions of the cultivation and the generation of farming advices. In many cases the process of generating a farming advice is based on a predefined logic coded as computer algorithms but in many cases also requires the intervention of human experts (e.g., agronomists). The generated advice can also be escorted with selected agro-environmental measurements that will help the farmer to comprehend the underlying mechanisms that contributed in the specification of the advice. Often the advice and escorting data evidences are mediated through web-based applications. It should be noted that the role of the advisor/expert remains significant once the generated advice needs to be confirmed (by both the advisor and the farmer) and the respective farmer's cultivation practices need to be supported during their implementation. Feedback related to the actually applied farming practice, as a response to the advice, is necessary to be returned to the FMIS to be further analyzed and incorporated, supporting the generation of future advice. It is a common practice for FMISs that the provided recommendations/advice and the respective applied cultivation activities to be registered as entries to the farmers' digital farm book. Figure 6 provides a screenshot of a FMIS dashboard (provided by DACOM37) where data from various heterogeneous sources – including photos-about a selected parcel are visualized in a user-friendly way. More detailed examples of farm book records maintained by an FMIS are presented in Annex.

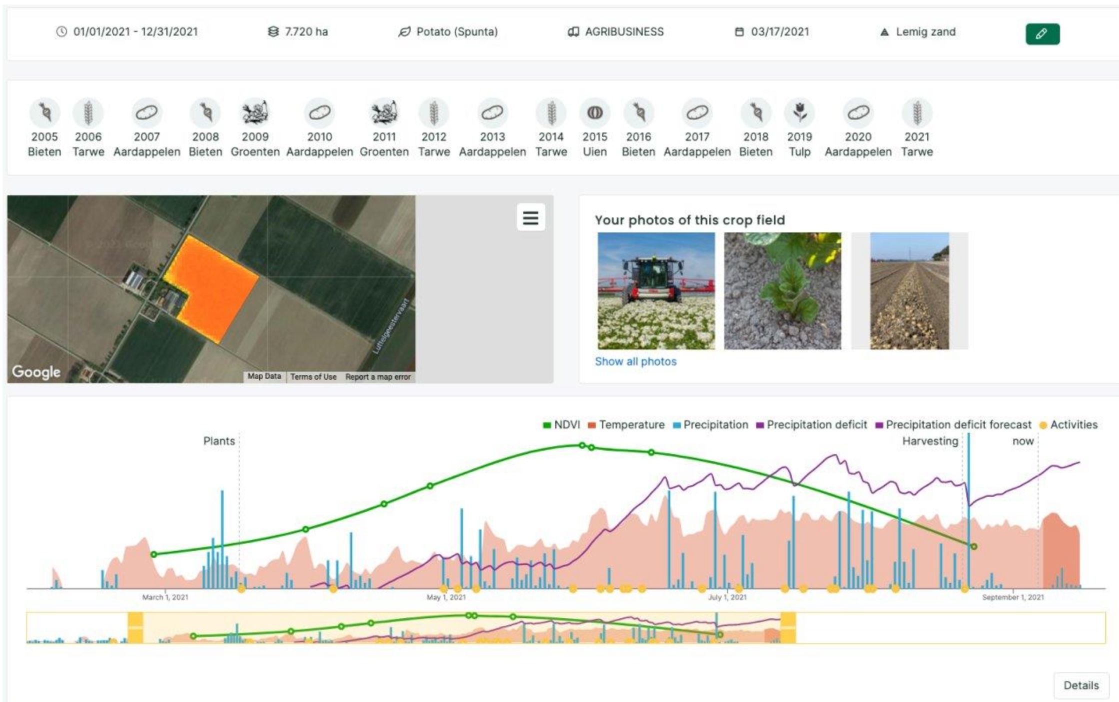

Figure 12. A view of the DACOM's "Crop recording" software visualising farm data evidences from various sources[38]

4.2.1 Pest management advice

With regards to pest management among the most important environmental parameters involved in defining potential risk infestations is the combination of temperature and relative humidity. During their lifecycle, pests and insects require a specific amount of heat to develop from one stage to another. In many cases, the accumulation of degree days that is required to complete the development of an organism is specific and countable (Leiminger et al., 2012). Crop disease infection models are coded as algorithms and utilised as decision support systems in order to provide information on the probability of occurrence of the disease and to provide recommendations on the optimum time of application of crop protection products. An

[37] https://www.dacom.nl
[38] https://www.dacom.nl/en/products/crop-recording/#

additional important parameter is the phenological stage given that there are specific growth stages that plants are more sensitive to specific threats. Figure 7 illustrates a visual representation of collected environmental recordings along with the calculated disease (e.g. leaf curl) infestation risk index.

Figure 13. Visualisation of pest infestation risk index along with related data from sensors[39].

Combining these data, the FMIS can generate a pest management advice which will be mediated to the farmer. The advice usually corresponds to pesticides application (e.g. spray) and also defines the active substances that the phytochemical should contain, the optimal dose and the optimal date to be applied. It is a common practice that the computer-generated advice is also filtered by an agronomist with good knowledge of the area and the cultivation type in order to proceed with the necessary adjustments prior to the final approval and mediation to the farmer. In addition, selected environmental recordings as data evidences and explanations may escort the advice. The farmer will either accept the advice and proceed with the implementation of the plant protection recommendation or will reject it. It is necessary for the sound operation of the plant protection process that the information about the action that took place at the field to be provided as feedback to the system. The actual type of chemicals utilised, the dose and time of implementation need to be provided and recorded. There are many reasons for the actual action to diverge from the recommendation. For example, a sudden change on the weather conditions e.g. strong winds or rain, unavailability of spraying equipment, other urgent activities for the farmer may postpone the implementation of the recommendation. The recording of the implemented actions is necessary to be registered within the FMIS in order to design the future plant protection strategy. It should be noted that even if the crop protection strategy is based on a FMIS system, there can be still actions (e.g. spraying of chemicals) that are not associated with a FMIS recommendation and were realised based on farmers'/agronomists' observations and decisions. Again, it is considered as a best practice to register these actions with the FMIS.

[39] https://www.gaiasense.gr/en/gaiasense-smart-farming

Concluding, a FMIS that incorporates plant protection operations will maintain a digital calendar of the applied type of plant protection products (chemicals), the active substance that is included, date, dose and means of application. In many cases a pest management advice that is based on (agro-environmental) data collected from the field will also be associated with the various plant protection operations.

4.2.2 Irrigation advice

The key parameters that can be monitored by mature technological means and can contribute on irrigation optimization strategies are the following (Adamides et al., 2020):

- **Environmental conditions:** Solar radiation, precipitation, relative humidity, wind speed, temperature, and soil moisture. Based on these data, it is feasible to calculate the amount of the plant's moisture loss due to the "evapotranspiration[40]" phenomenon.
- **Aquatic state of the plant:** Leaf water potential and stomatal conductance that are recorded with the use of sophisticated equipment.
- **Recordings of irrigation:** Time and quantity of irrigation water utilized.
- **Other parcel details:** Irrigation system, planting distances, crop variety, mechanical soil composition, etc.
- **Type of plant and current phenological growth stage:** Different plants have different needs. During the lifecycle of a plant (growth stage) there are different needs for water.

A rational water management strategy is based on the determination of the optimal irrigation time and amount of irrigation. Determining the irrigation time is achieved by introducing critical water scarcity values derived from the time-gradient analysis of the soil moisture profile along the active root and hydrodynamic parameters of the plants. For this purpose, precise knowledge of the spatial distribution of the active bedrock is required in conjunction with the continuous recording of soil moisture. Irrigation management with soil water sensors is based on maintaining soil water between upper limit (wetter value) and lower limit (drier value)—permitting unrestricted availability of water. In many cases, the optimal irrigation dose is determined as the sum of daily water absorption values from the crop after the last irrigation.

The FMISs that incorporates irrigation advisory services usually maintain a digital calendar of irrigation actions including date, irrigation dose and means of application. In many cases the irrigation action will be associated with an irrigation advice which is based on (agro-environmental) data collected from field sensors.

4.2.3 Fertilisation advice

Developing a fertilisation strategy is an important part of a holistic agronomic plan. Fertilisation needs to be effective; this means that nutrients uptake by the crop needs to be enhanced, nutrients addition needs to be balanced and ecologically sensible, while the respective cost has to be affordable for the producer. A fertilization advisory service aims to

[40] https://www.usgs.gov/special-topics/water-science-school/science/evapotranspiration-and-water-cycle

provide directions for applying organic and inorganic fertiliser rates based on a calculated nutrient balance. There are various stand-alone software tools or tools integrated within a FMIS (Snauwaert et al., 2017) that aim to match the amount of nutrients applied to the conditions/needs of the land such as soil type, crop demand, and available soil nutrients. These tools are generally based on crop nutrient requirements for the desired yield under the given environmental circumstances. Some of these tools account for the nutrient content of organic fertilisers and establish the ratio to mineral fertilisers to fully satisfy crop needs, and consider the time lapse between the application and the assimilation of nutrients by crops. In many cases, the fertilization advisory services are generally considering soil sampling and chemical analysis in order to identify the current soil type and the availability of nutrients.

One key aspect of the nutrient planning is the determination of the nutrient efficiency (especially nitrogen) that can vary according to the soil type, weather conditions, application rate, application techniques, and characteristics of the organic and mineral fertilisers used. Besides soil sample analysis conducted in lab, some additional parameters that can be scanned through the use of proximal soil sensors (Rossel et al, 2011) are electric conductivity (EC), pH and the content of organic matter. This is a good basis for estimation of the local texture allowing the application of nutrients through VRA technologies (analysed in section 4.1). Eventually a map can be set up for each parameter which serves as a basis for site specific advice, which can be read in the form of a task card into GPS-controlled machinery.

In a similar manner with pesticides and irrigation FMISs are feasible to maintain a record of the fertilization actions (including date, dose, product name of applied fertilisers, and main substances included) along with the details of the advice that justified the fertilization action.

4.2.4 Sharing of FMIS logs

The FMIS based data-driven advisory services described in previous sections have an additional benefit besides the support for applying optimized farming practices. FMISs have the necessary data management mechanisms for maintaining and sharing extensive records of the applied farming practices along with the data evidences that dictated their implementation. The benefit of having all farming information in one place is that facilitates the automated generation and exporting of reports with selected partners.

There are already cases where food processing factories are requiring as a prerequisite the provision of detailed logs with farming practices along with the purchased harvested yields. Going a step further there is also the requirement from some food processors that the farmers are utilizing data-driven agricultural decision support services besides the digital recording of farming actions. For example, this is the case for the farmers across EU that have contracts with Barilla41 food processing company. The farmers are utilizing -among others- the

[41] https://www.barillagroup.com/media/filer_public/9f/d7/9fd7c845-06da-4a94-a024-6a44f5d12f94/barilla_gygp2021_en.pdf

Granoduro.net42 FMIS and farm advisory service in order to both optimize the applied farming practices but also to provide track records of all crop interventions, enabling the compliance with various regulation schemes.

FMIS generated logs have also been integrated in certification of good agricultural practices auditing procedures. A widely accepted food safety certificate is the GLOBALG.A.P.43 offering more than 40 standards for 3 scopes: Crops, Livestock, and Aquaculture. The "GLOBALG.A.P. - Fruit & Vegetables Standard"44 covers all stages of production, from pre-harvest activities such as soil management and plant protection product application to post-harvest produce handling, packing and storing. The certificate aims to ensure traceability & transparency from the farm to the market shelf while a secure online certification database is offered in order for everyone to validate producers' certificates using a unique certificate number. The auditing process for the Fruit & Vegetables Standard45 includes the evaluation of applied practices on "SOIL MANAGEMENT AND CONSERVATION", "FERTILISER APPLICATION", "WATER MANAGEMENT", "INTEGRATED PEST MANAGEMENT", and the use of "PLANT PROTECTION PRODUCTS". Various FMISs (e.g. DACOM, gaiasense, eAgronom) are already providing report extraction functionality tailored to the needs of the certification audit process. The report creation process allows the creation of predefined reports (e.g. list of pesticides interventions) in the form of standardized file formats e.g. pdf, xls, csv).

As a final note many FMISs provide functionalities for programmatically sharing selected data sets. These FMISs are offering Application Programming Interfaces (API) that allow authorized service consumers to issue criteria-based queries (range of date, parcel, type of farming activities). Currently, this type of services is utilized among predefined partners (e.g. farmers having contract with agronomists) with the use of software components in order for all entities to have easier access to raw data recordings.

4.2.5 FMIS data logs as a source for CAP monitoring and evaluation

Given that FMIS data logs are already utilised for certification and traceability purposes, the research community evaluates their use also for monitoring and evaluation in the context of CAP. The NIVA project realises a number of experimental use cases evaluating pathways for the digitisation of Integrated Administration and Control Systems and CAP implementation in general. The Use Case 1c (UC1c), entitled "Farmer Performance" focuses on the exploitation of FMISs as a source of information for CAP monitoring purposes. A short description of UC1c follows (Manolarakis et al., 2021):

"In order to design effective policy measures, data is needed to evaluate farmers' impact on environment, climate and sustainability (farmer performance). Valuable source of such data is

[42] https://www.horta-srl.it/en/granoduro-net/
[43] https://www.globalgap.org
[44] https://www.globalgap.org/uk_en/for-producers/globalg.a.p./integrated-farm-assurance-ifa/crops/FV/
[45] https://www.globalgap.org/export/sites/default/.content/.galleries/Documents_for_Mailings/170704_GG_Implementation.pdf

IACS. However, although IACS already contains a lot of data, there are still data gaps which must be filled by getting additional data about farming activities from other sources. Valuable source of information about farming activities is FMIS, type of (commercial or non-commercial) software used by farmers to manage farm data. By exchanging bi-directionally data between IACS and FMIS-type of applications, agricultural activities data collected in a farm will become an additional input for monitoring farmer performance.

Data exchange between IACS and FMIS-type of applications provides an opportunity to reduce administrative burden for farmers (data already existing in the FMIS can be shared with IACS and vice versa), also PA can use such exchange of data to support farmers' compliance with regulatory requirements. Entering data manually and/or manual import/export of data files is time consuming, risky and therefore automatic system to system exchange of data is desirable solution (less administrative burden). Objective of the NIVA use case UC1c is to enhance assessment of farmer performance in the context of CAP post-2020, combining IACS and FMIS data."

The use case is essentially implementing the necessary software modules that facilitate data sharing among a commercial FMIS and the appropriate Paying Agency (PA). The prototype technical solution of bi-directional data exchange is tested among the NIVA project partners: a) the Estonian Agricultural Registers and Information Board (ARIB), i.e. the Estonian PA and b) and a small set of farmers utilising the eAgronom[46] FMIS software. The eAgronom is typical FMIS offering functionalities as these described in the previous sections:

- Agronomical planning – crop rotation, inventory, task maps, and financial analysis;
- Personnel management – tracking working hours, giving work orders;
- Artificial Intelligence based alerts and suggestions – AI crop planner, business appraisals, task timing;
- Integrated soil and air sensors;
- Normalized Difference Vegetation Index (NDVI) calculation;
- Consultation – agribusiness consultancy services.

In general, eAgronom supports mainly grain producers in Estonia, Latvia, Lithuania, Poland, etc. offering a software as a service (SaaS) platform while interaction with farmers is realised with desktop and mobile applications.

For the needs of this use case a data exchange protocol is implemented based on the "eCROP47" standard proposed by the UN/CEFACT for electronic exchange of crop cultivation data along the supply chain. The overall development and testing of this use case is still ongoing and the developed data sharing modules are available here: https://gitlab.com/nivaeu/uc1c-public-api.

[46] https://eagronom.com/en/
[47] https://unece.org/fileadmin/DAM/cefact/brs/BRS_eCROP_v1.pdf

Although the execution of this use case is still in progress there are already various useful outcomes that are summarised in the following section along with the overall conclusions on utilising FMISs for CAP monitoring and evaluation purposes.

4.2.6 Conclusions on CAP monitoring and evaluation via FMIS data logs

FMISs demonstrate the potential for supporting the farmer on optimizing farming practices and generate extensive logs that can act as farm level data sources for the need of CAP monitoring and evaluation. Some of the key issues/challenges towards a large-scale realization of such a monitoring approach are reported hereafter:

FMIS as farms e-gateway: Among the various agricultural technologies utilised in a farm FMISs have the potential to act as a centralized repository providing the necessary data management and communication facilities. Raw data collected from various sensors, devices and services (e.g. VRA) need to be combined and processed in order to have a meaningful format which will be useful for the farmer but also for monitoring purposes. FMISs are usually deployed as cloud services on systems with adequate computational and networking resources. Thus, it is feasible to implement the necessary data translation processes, to enforce access control policies, and to share data logs in a controlled manner acting as an e-gateway for the farm with the rest of the digital world. However, until today FMISs are mainly designed to operate as a tool with the main purpose of supporting the farmer in executing farming activities and not as a communication tool, thus data sharing and communication features are currently limited. As it was presented in previous sections some FMISs provide already data sharing mechanisms but in most of the cases these approaches are fragmented, custom based, with limited integration with well-established user management and access control protocols (e.g. OAuth). In general, FMIS software providers will be interested in establishing technical readiness for data exchange only when their customers (farmers) request such functionality.

Semantic Interoperability: Currently there are many FMIS providers following different approaches on formatting the respective data logs. Harmonising the semantics of relevant information (e.g. crop types, agricultural operation types, active substance type and commercial name of phyto-chemicas) is crucial towards the utilization of FMIS data for CAP monitoring and evaluation. As it was evident by the analysis in MEF4CAP – D2.1 (Kalatzis et al., 2021. MEF4CAP – D2.1) the overall ecosystem is highly fragmented without having yet a dominant and efficient data harmonisation approach. In some cases, standardised agricultural data models (e.g. eCrop) are already published and in use in various EU countries but these standards are not adequate to model all the required information aspects. In addition, there are parallel data modelling standards currently in development for the agricultural sector (e.g. SAREF-AGRI[48], DEMETER-AIM[49], eCrop) something that imposes the need for cross standard interoperability mechanisms.

[48] https://saref.etsi.org/saref4agri/v1.1.2/
[49] http://agroportal.lirmm.fr/ontologies/DEMETER-AIM

Accuracy of FMIS data logs: Although FMISs are offering the necessary mechanisms for storing various farm activity data items there are still many issues regarding the validity and accuracy of these entries. In most of the cases data import is a manual process which is prone to intentional and unintentional errors. In many cases, farmers are still not well familiar with the use of such systems and often it is not among their first priorities to proceed with the timely and accurate completion of the implemented farming activities within the digital farm calendar. Integration of various sensing technologies can act as supporting evidences on the various farm calendar entries which will increase the accuracy of the recorded entries. For example, recordings from flowmeters can provide evidences on the applied volumes of irrigation but this also increases the overall integration complexity of the various technical means that operate on a farm level. An innovative approach that can also be utilized for data validity verification can be realized through the farm's benchmarking and comparison with outcomes from other similar farms in the area[50]. This approach may allow the identification of farms with exceptional performance compared with the regional average outcomes.

Farmers' acceptance and data sharing: A key use towards the utilization of FMIS for monitoring and evaluation purposes is farmers' acceptance and consent on sharing their data. A thorough analysis on futures of farm data sharing practices is presented in (Burg, et. al, 2020) where the various shortcomings and farmers concerns are presented. One of the key findings that is also evident in Manolarakis, et al. (2021) is that farmers will be reluctant to trust the overall process and share FMIS data referring to their applied practices if these data collections act as evidences for penalties. On the contrary there should be clear incentives and benefits encouraging the sharing of data.

Table 5. Agricultural Decision Support Systems and CAP M&E.

Combination of Technologies	Benefits for the farmers	Benefits for CAP Monitoring & Evaluation	Case studies
Earth Observation data IoT sensors Decision models Data analytics	Optimised used of inputs (plant protection products, fertilisers, irrigation, fuel) Reduced environmental impact/better farm performance Reduced cost for farmers	Evidences for monitoring of applied irrigation/ pesticides /fertilisers on a field level. Crop type identification	H2020 Demeter PILOT 2.4 Benchmarking at Farm Level Decision Support System[51] H2020 NIVA - Use Case 1c (UC1c), entitled "Farmer Performance"[52]

[50] https://h2020-demeter.eu/pilots-overview/pilot-cluster-two/benchmarking-at-farm-level-decision-support-system/
[51] https://h2020-demeter.eu/pilots-overview/pilot-cluster-two/benchmarking-at-farm-level-decision-support-system/
[52] https://gitlab.com/nivaeu/uc1c-public-api

	Automated documentation of activities		
Key Challenges – Open Issues			
Data harmonisation and data Interoperability (semantic and syntactic)			
Quality of recorded data			
Cost and ease of use of the DSS technologies.			
Famers Privacy protection			
Acceptance and ease of use of the various technologies.			

4.3 Pasture management

Pasture management is the key to profitable dairy and animal production in grazing-based systems, however it's only very recently that digital technology has been used to assist and address management problems (Shalloo et al., 2021). Pasture management and technology can be separated into systems that stay within the farm, such as tools for measuring grass yields (e.g. digital plate meters) and paddock/feed management systems (grass wedge, rotation planners etc.) into which the data is fed. This technology improves data collection efficiency for the farmer but the data is siloed on the farm.

The other type of approach is external provision of pasture management services – delivered through the internet/cloud, is new and currently under development, but does offer the opportunity for centralised data collection across many farms. The provision of services in pasture management cover services in 4.1, 4.2 and 4.3.

4.3.1 Earth Observation (EO) services

There are now a number of companies that provide specialised EO PA data for the grassland farmer- some of these services have developed from crop-based approaches and some developed from first principal for grassland management. Many of the crop derived systems are mainly based on NDVI variability maps. These have some utility in rangeland systems but little in paddock based and they have only a small possible role in CAP data provision (identification of farming activity). Those services developed with the grassland farmer in mind, provide actual data in yield of grass and will populate feed planners and grass wedges for the farmer client. Increasingly these systems are looking at DSS for farmers in terms of fertiliser planning and monitoring of fodder quality.

They offer mapping services, NDVI time series and biomass estimation (DM/Ha). The biomass estimation is produced through machine learning algorithms often including a gap filling process for cloudy days- either through standard growth curve adjustment or the use of SAR data[53] for those systems exploiting Copernicus sentinel data. The Biomass estimates can then be incorporated into standard paddock management of feed management models (such as a feed wedge).

Table 6. Examples of Grassland Focused EO derived PA services – adapted from Green et al. 2021.

Name	Service	Notes
Pasture.io	Map, NDVI, Biomass, Wedge	High resolution high frequency optical mapping. Grass wedge needs reliable data input from farmer. NZ but offers service in EU. https://Pasture.io
LIC SPACE	Map, NDVI,Biomass, Wedge	Optical gap fills using predicted pasture growth https://www.lic.co.nz/products-and-services/space/
Pasture From Space	NDVI	Focus on Range Management http://www.pasturesfromspace.csiro.au/
Anuland- Fieldsense	Biomass, Map, IoT, DSS	Primarily uses proprietary sensors on farm to produce outputs- uses EO as back ground annuland.ie
FarmMote	Map, NDVI, Wedge, IoT	Augments EO with in-field sensors it calls “motes” Home | Farmote Systems
EDENPA	NDVI, Map, Biomass	Australia rageland service Home - Eden Precision Agriculture (edenpa.com.au)
Cibolabs	NDVI, Biomass, Map	Australia Pasture | Australia | Cibolabs
PastureMap	Map	Sensor/farmer input focussed but uses EO as background image. Focussed on rangelands in US Home - PastureMap Grazing Management & Livestock Software

[53] https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar

4.3.2 PastureBase Ireland

PastureBase Ireland (Hanrahan et al., 2017) is an example of a centralised pasture management database – turning farmer provided information (growth rates etc.) into actionable data for the farmer- grass wedge, growth forecasts etc. Farmers record paddock level growth rates once a week (by the chosen approach – often by visual inspection only, but other approaches are used). Other data, such as soil test results, livestock numbers and fertiliser use allow for a full profile of each paddock to be created creating feed wedges, rotation plans, yield curves etc.

The use of GIS maps is expanding within the service and client now receive forecasts of grass growth based on the MOST model developed within Teagasc. Data is available at different aggregated levels to the research community (as part of the T&C contract for farmers signing up).

Farmers can record information on fertilizer application and slurry application generating reports at paddock level. Reports on soil test and weather conditions are entreated automatically on request giving summaries on soil fertility. A Nitrogen Use Efficiency Calculator has been added.

Many of the functions are available on a mobile app – that can work "offline" in areas of low cellular coverage- updating the database automatically when in coverage. This is important, as recently a survey of farmer's attitudes to adoption of digital technology found that connectivity issues and availability of broadband was the main barrier (55%) identified by the farmers. (Skillnet, 2019).

The list of data captured by farmers include:

- Farm Paddock map (this is more detailed than the Parcel Map produced for LPIS)
- Regular Grass covers (measures of grass biomass in each paddock)
- Event recording – date on which paddocks are grazed or cut for silage
- Milk Sales data
- Fertiliser application rates and date
- Reseeding dates
- Soil Test Results

Information Calculated for Farmer include:

- Feed Wedge
- Rotation Planner
- Grass Budget
- Feed Budget

- Annual Tonnage of Grass produced
- Weather reports

Figure 14. A snapshot of the PastureBase Interface

4.3.3 Pasture management services and CAP monitoring and evaluation

Most of the services outlined here are privately contracted between farmer and provider. Both parties would understand the value of the data and the value proposition is two way-the reference data the farmer provides improves the quality of the service overall and the more farmers involved the better the accuracy of the service, and thus the offering to new entrants.

In both EO provided PA services and cloud-based management systems need farmer provided data. This data is not verified and as such can be challenged. The EO systems provide little more than evidence of farming and have issues with cloud cover (excepting those exploiting sentinel 1) for provision of event monitoring services (dates of mowing, spraying, establishment of green cover etc.).

Systems like PastureBase rely entirely on farmer engagement – those farmers that use the full functionality of the system would be providing data that almost completely characterises the main inputs of the grass /paddock-based farm system (animals, fertilizer, time) – recording events such as reseeding, liming, open and closing paddocks for grazing, silage harvest. The terms and conditions of this free service include access to anonymised farm data for research purposes and the use of aggregated data for regional statistical purposes.

However, the percentage of farmers who engage with the systems to this extent is small (and the number of farmers who use digital paddock management is a small percentage of the whole 3,881 farmers in 2021, from potential population of 120,000). The key to improving engagement is to provide new tools (grass growth forecasts) and new ways to interact (mobile collection app). As this service and others like it are entirely voluntary and self-selecting the use of data form these services may not be appropriate for population level statistics – and hence CAP monitoring and evaluation – until a certain penetration is achieved. These services are adopted by larger commercial enterprises and thus may reflect the performance of the major source for farm output if not the whole farm population.

To understand and characterise grass-based farming at national and farm level, data from EO provision and Digital Paddock management serves need to be combined with official databases such as AIM (Animal Identification and Movement), FADN and LPIS. The EO data can provide an independent measure of grass utilisation and management. On farm recording in paddock management FIMS such as PastureBase records inputs such as nutrients on wider population than is captured in FADN and includes timing of events.

However private or voluntary recording is dependent entirely on trust between farmer and operator. The use of such data as a replacement for existing farm level monitoring and compliance checks may be acceptable to individual farmers as a way to reduce administrative burden on principle of prior consent. The widespread harvesting of such data to provide statistics on compliance on a national level (essentially national compliance monitoring) will need to be done in an open manner.

As a final note, one of the major issues with grassland and pasture EO based services is in the Mediterranean context, where these have much lower biomass cover than in Northern Europe, hence difficult to discriminate through remote sensing technologies.

Table 7. Combination of EO and field level data for pasture management

Combination of Technologies	**Benefits for the farmers**	**Benefits for CAP Monitoring & Evaluation**	**Case studies**
Earth Observation data IoT sensors Digital calendar of pasture management Data analytics	Optimised use of pastures Automated budget reporting (grass, feed) Reduced environmental impact.	Automatic creation of paddock level management reports National level compliance statistics	PastureBase is an ongoing project.
Key Challenges – Open Issues			
Data harmonisation and data Interoperability (semantic and syntactic)			
Quality of recorded data			

Cost and ease of use of the DSS technologies.
Acceptance and ease of use of the various technologies
Performance of the technology for countries with lower biomass

5. Conclusions

Among the objectives of the MEF4CAP project is to evaluate the use of agricultural technologies that provide a potential benefit for data capturing and data processing in support of future CAP monitoring and evaluation objectives. This deliverable (D2.2) describes exemplar, real-world cases of agricultural technologies utilisation that are concurrently serving two objectives:

a) The implementation of good and sustainable agricultural practices that provide clear benefits for the farmers and for the environment.

b) The provision of ground truth evidences of the applied agricultural practices that can potentially be utilised for the monitoring and evaluation of agricultural related policies (CAP).

The example use cases presented focused on the use of agricultural machinery and the implementation of Variable Rate Application for agrochemicals, the use of decision support systems in the context of FMIS for inputs optimisation and Earth Observation assisted pasture monitoring.

The respective benefits and challenges for each of these use cases along with the respective conclusions are presented within each subsection. It is clear that currently multiple sources of agricultural data now exist and there is clear potential for data aggregation and the additional value this can bring for data users, be they policy maker, farmers or consumers. A number of pilot projects have already begun to explore this potential with useful findings.

This deliverable will be utilised as input for the work to be conducted in WP6 - “Synthesis and road map”. In deliverable “D6.2 Synthesis Report and roadmap” additional aspects on the use of ICT agricultural technologies in the context of farming practices optimisation and CAP M&E will be considered including user acceptance, privacy protection, and cost of investment.

An overall outcome that is also identified in the AIOTI (https://aioti.eu/) report entitled “IoT and digital technologies for monitoring of the new CAP” is that the new technological solutions should not end up being seen as a form of surveillance. It is crucial to ensure that the new monitoring systems based on data will not be introduced to penalise farmer more easily for non-compliance, but rather to inform and guide them on their performance connected to the CAP rules and objectives as well as providing them a better decision making with less bureaucracy. There is an opportunity to increase trust and reduce costs for all stakeholders by improving transparency and access to information of common interest such as databases of soil maps, water maps, etc. In general, the recommendation can be summarised as "create substantial benefits and incentives for the farmer through smarter regulation, simplification, higher tolerances, smaller penalties and more guidance and correction, adding value for all stakeholders".

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Annex

Examples of records registered in Farm Book as part of a Farm Management Information System. The following farm book samples correspond to real entries registered within the "gaiasense[54]" smart farming solution referring to potato crops.

a) Growth Stages

Start Date	End Date	Growth-Stage
20/4/2020	21/4/2020	Planting of tuber seed or "potato seed"
24/5/2020	27/5/2020	Stems growing towards soil surface, formation of scale leaves in the axils of which stolons will develop later
1/6/2020	15/6/2020	Emergence: stems break through soil surface
16/6/2020	20/6/2020	4th-6th basal side shoot visible (> 5 cm)
20/6/2020	21/6/2020	Crop cover complete: about 90% of plants meet between rows / First individual buds (1–2 mm) of first inflorescence visible (main stem) / Tuber initiation: swelling of first stolon tips to twice the diameter of subtending stolon
21/6/2020	1/7/2020	First flower petals of first inflorescence visible / First open flowers in population

b) Fertilisation applications

Start Date	End Date	Type	Application method	Commercial Name	Dose	Unit
17/3/2020	17/3/2020	basal fertilisation	Broadcasting	Macro Speed Gren 25%MgO + 50%SO3	266	kg/hectare
4/4/2020	4/4/2020	basal fertilisation	Broadcasting	Wapno Nordkalk (Organic manure)	2600	kg/hectare
9/4/2020	9/4/2020	basal fertilisation	Broadcasting	Mega DAP 18-46	96	kg/hectare
18/4/2020	21/4/2020	basal fertilisation	Broadcasting	RSM (26%)	558	kg/hectare

c) Pesticides applications

[54] https://www.gaiasense.gr/en/gaiasense-smart-farming

Start Date	End Date	Commercial Name	Active Substance	Dose	Unit
18/4/2020	21/4/2020	MONCUT 46 SC	flutolanil 460g/lt	513	mL
21/5/2020	21/5/2020	Round-up FL-360	glyphosate 360 g/l	2	L
21/5/2020	21/5/2020	Boa 360 CS	clomazone 360 g/l	0.16	L
21/5/2020	21/5/2020	Bandur 600 SC	aclonifen 600 g/l	2	L
21/5/2020	21/5/2020	Citation 70 WG	metribuzin 700 g/kg	0.45	kg
21/5/2020	21/5/2020	Stomp 400 SC	pendimethalin 400 g/l	4	L
21/5/2020	21/5/2020	Tuberon 70 WG	metribuzin 700 g/kg	0.46	kg

d) Examples of crop photos at various stages and metadata (including geotagged info)




Image Filename	Location	Gyroscopic	Parcel Id	Manufacturer/ OS	Device OS	Date & Time
Vkol_01.07.2020.jpeg	25.269230615119, 40.962504122927	x: 0.77332854270935 , y: 0.028375301510095, z: -0.387714922428131	Parcel 123	Samsung	Android	15/9/2020 10:37:16 AM
Vkol_02.08.2020.jpeg	25.269230615119, 40.962504122927	x: 0.77332854270935 , y: 0.028375301510095, z: -0.387714922428131	Parcel 123	Samsung	Android	25/9/2020 10:37:16 AM

Vkol_08.07.2020.jpeg	25.272085408258, 40.9634093694705	x: 0.77332854270935 , y: 0.028375301510095, z: -0.387714922428131	Parcel 123	Samsung	Android	10/10/2020 10:37:16 AM
Vkol_15.07.2020.jpeg	25.272085408258, 40.9634093694705	x: 0.773328542709350, y: 0.028375301510095, z: -0.387714922428131	Parcel 123	Samsung	Android	20/10/2020 10:37:16 AM

