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A practical approach to cross-agri-domain interoperability and integration

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***Abstract*— In this paper we describe the process for making sensors and IoT devices interoperable with existing agri-solutions, and to federate data and services between two agricultural smart platforms, more precisely the AFarCloud and DEMETER solutions. This approach is in line with EU data-driven strategy and GAIA-X's federation strategy. Finally, we present the use case where this process has been tested and validated, i.e. Kotipelto farm, a dairy farm located in Ylivieska (Finland).**

Keywords—semantic interoperability, smart agriculture, data and services federation

I. INTRODUCTION

Smart agriculture is a domain where there is a huge heterogeneity of sensors, devices, actuators, vehicles and systems exchanging information among them, using a variety of data protocols, in different smart farming use cases. Soil and environmental data collected by sensors and image data collected by drones allow farmers to take decisions to optimise and increase soil quality and productivity, early detect plant diseases and improve sustainability by reducing fertilisers and herbicides, emissions and soil compaction. Wearables on animals allow monitoring livestock welfare, activity and behaviour patterns such as in-heat or calving detection.

The semantic interoperability among all these entities is critical in order to develop decision-making tools for the farmer based on the exploitation of all the data collected. In addition, there does not exist a unique and standard smart agriculture platform that supports the aggregation, storage, analysis and visualisation of all this information. Different solutions for disparate purposes are available in the market, so providing interoperability mechanisms among them will allow farmers to increase the volume of data and services that they can benefit from. E.g. IRRINET [1] is an IT irrigation system (web service based) aiming to advise farmers on efficient water management; AgroLife [2] is a web-oriented software application for automated management of agricultural production processes and all types of land; the AFarCloud [3] platform supports near real-time monitoring of crops and livestock, and management of missions with drones, UGVs (Unmanned Ground Vehicle) and ISOBUS tractors; the DEMETER [4] platform builds upon a number of related state-of-the-art agri-solutions to extract new knowledge to improve farmers' decision making and ease the evolution of these solutions.

In this paper we provide mechanisms and tools to foster cross-agri-domain interoperability and integration, and a practical example customised to AFarCloud and DEMETER smart farming platforms. By fostering interoperability between these two platforms, we demonstrate how their communities can exchange information and services for mutually beneficial collaboration. This work is the result of the research being carried out in the project H2020-DEMETER.

II. BACKGROUND

A. Interoperability

Interoperability is the ability of two or more components or systems to exchange information and to understand and use the information that has been exchanged.

ISO/IEC 21823-1:2019 [5] defines five levels of interoperability. The lowest level, Transport Interoperability, is about setting the communication infrastructure that allows sending data from an origin to a destination, even when the two entities are connected to different networks. Besides, this interoperability level is in charge of managing the data quality of service (QoS) requirements including data delivery (best-effort delivery vs reliable delivery), timeliness, ordering, durability, lifespan and fault tolerance.

The second level, Syntactic Interoperability, is about reading the information. It manages the exchange of data in a common data format and protocol so that formats of the exchanged information can be understood. However, at this level we cannot guarantee that the meaning of the information is correctly understood.

The third level, Semantic Interoperability, is achieved when all entities attribute the same meaning to the information exchanged. To do so, metadata and shared information models (ontologies) are used.

The fourth layer, Behavioural Interoperability, tries to align and integrate business processes so that the actual result of the exchange achieves the expected outcome.

Finally, the last layer, Legal or Policy Interoperability, is about ensuring that organisations operating under different legal frameworks, policies and strategies are able to exchange information and work together.

B. AFarCloud

The AFarCloud (Aggregate FARming in the CLOUD) platform is the result of an ECSEL JU project that aims to provide a distributed platform for precision and autonomous farming that allows the integration and cooperation of agriculture Cyber Physical Systems in real-time in order to increase efficiency, productivity, animal health, food quality and reduce agricultural labour costs. The project is aimed at early adopter farmers and rural professionals which require the management of crops and livestock information in real-

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time. The platform offers a GUI for farm management that supports monitoring and decision-making based on Big Data and real time data mining techniques. The main features offered by this platform are the support for near real-time monitoring of crops and livestock; algorithms and definition of prescription maps for precision farming; and automation of agricultural tasks by the management of UAVs (Unmanned Aerial Vehicle) and UGVs. By combining these technologies, farmers can automate targeted key interventions, such as defining prescription maps that determine the exact amount and location to apply fertiliser or measuring the NDVI (Normalized Difference Vegetation Index) of crops.

C. DEMETER

The main goal of the project DEMETER (Building an Interoperable, Data-Driven, Innovative and Sustainable European Agri-Food Sector) is to contribute to the digital transformation of Europe's agri-food sector through the rapid adoption of advanced IoT (Internet of Things) technologies, data science and smart farming, in order to empower farmers and farmer cooperatives to use their existing platforms and machinery to extract new knowledge for decision making, and to ease the acquisition, evolution and updating of these platforms, machinery and sensors. Its goal is to increase performance in multiple aspects of farming operations, as well as to assure the viability and sustainability of the sector in the long term. The project focuses on interoperability as the main digital enabler, extending its coverage through data, services, platforms, M2M (machine-to-machine) communication and artificial intelligence. Besides, it provides tools to facilitate the connection among all actors in the agri-food chain: not only among farmers, but also among advisors and suppliers of ICT solutions and machinery.

III. INTEROPERABILITY MECHANISMS

In this paper we present mechanisms for making sensors and IoT devices interoperable with existing agri-solutions and to federate data and services between two agricultural smart platforms, i.e. AFarCloud and DEMETER.

A. Sensors, IoT Devices and Vehicle Telemetry Integration

As mentioned before, the potential of smart agriculture is based on the exploitation of heterogeneous data coming from sensors, IoT devices and vehicles. One of the problems a farmer needs to face when buying a new device or vehicle is how to make it interoperable with the existing solutions deployed in the farm, i.e. how to read and understand the data coming from the device or vehicle in order to store it in the farm repositories in the appropriate format.

The data harvesting process consists of four steps, as can be seen in Fig. 1.

First, the data needs to be fetched. In the case of sensors, measurements are usually transmitted using MQTT (Message Queuing Telemetry Transport) protocol, which provides syntactic interoperability. MQTT is a publish/subscribe communication protocol standardised by ISO (ISO / IEC PRF 20922). It is light weight, open, simple, and designed so as to be easy to implement. These characteristics make it ideal for use in IoT context where a small code footprint is required, network bandwidth is at a premium, and low energy consumption is highly desirable.

Second, data preparation includes cleaning and validation of the data (e.g. checking that the measured values are inside ranges) and quality checks because sensor data can be contaminated with various sources of errors (e.g. in the case of machinery data, sources of errors can be measurement location, field geometry, speed changes, or sensor deficiencies [6]).

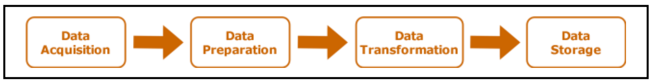


Fig. 1. Data harvesting process

Third, data are transformed to a common information model and metadata can be added to enrich the information. After this step, data are ready to be stored.

To guarantee semantic interoperability, data should be annotated by means of an ontology which describes the concepts and relationships among terms in the domain, making it possible to unambiguously interpret the meaning of the information exchanged. In DEMETER, the Agriculture Information Model (AIM) [7] has been defined as the common vocabulary providing the basis for semantic interoperability across smart farming solutions.

Hence, the measurements published using MQTT need to be transformed to the AIM model. The AIM model is based on the SSN (Semantic Sensor Network) and SOSA (Sensor, Observation, Sample and Actuator) ontologies for modelling sensors, actuators, devices and observations (i.e. sensor measurements).

In the case of AFarCloud, observations are published in JSON format describing the observed property, the EPOCH observation timestamp and its value, which are the same concepts that are used in the AIM and SSN/SOSA models. However, AFarCloud extends these models by defining a taxonomy of the most common types of sensors and observations used in agriculture. Static information related to the sensor such as its location, accuracy, units of measurement and valid range of the observation values, are not sent in every message in order to reduce battery consumption. The AFarCloud information model is available at [8] and an example JSON containing the static information related to a sensor ("sensorData" label) and the observations published via MQTT ("multiVariableObservationData" label) can be found at [9]. In addition, AFarCloud provides a model to represent missions for unmanned robotic vehicles. Examples of missions of interest to agriculture include supervision of areas by collaborative UAVs, collection of sensor observations by UAV or UAV, or generation of NDVI maps from UAV imagery. Finally, AFarCloud also provides a model for animals and dairy farms.

Therefore, we need mechanisms to automatically transform these JSON data compliant with the AFarCloud information model into the AIM. One approach can be to define a JavaScript file that reads the JSON message and performs the transformation. This approach is followed in open source tools such as Piveau Consus [10], [11]. A second approach is to write a mapping file with key-value pairs that define how the source fields should be mapped to destination fields. This solution was used in SynchroniCity H2020 project to convert several file types (e.g. CSV, Json, GeoJson) to the different Data Models in JSON format defined both by the project and by FIWARE [12]. Both of these two approaches are useful, although not standard-based, when the destination format is a plain format like JSON or XML. However, when the destination format is a graph-based syntax like RDF, Turtle or JSON-LD a third approach is recommended. In this case, using a generic mapping language such as RML (RDF Mapping Language) [13] provides more flexibility. RML is a mapping language defined to express customised mapping rules from heterogeneous data structures and serialisations to the RDF data model.

```
rr:subjectMap [
  rr:class afc:AfarcloudSensors,afc:SoilSensor;
  rr:template
"urn:afc:AS03:cropsManagement:RISE:{sensorData.resourceType}:{sensorData.resourceId}"
];
```

Fig. 2. RML mapping to create a sensor instance in AIM

```
{ "@id":"urn:afc:AS03:cropsManagement:RISE:soil:0100",
  "type":["SoilSensor","AfarcloudSensors"] }
```

Fig. 3. Resource describing the sensor in AIM

As AIM is an ontology model and RML is a W3C recommendation that supports multiple data source types (database, CSV file, JSON and XML), in this paper we suggest using this third approach.

Hence, to transform the observations formatted using AFarCloud's data model, we will use the RML mapping file in [14] and will obtain the data formatted in JSON-LD according to the AIM [15]. Excerpts of RML mappings for sensor and observation instances are shown in Fig. 2 and Fig. 5, respectively. The resulting RDF graph contains several resources. First, there is a resource which represents the sensor that made the measurement, in our example it is a soil sensor, as shown in Fig. 3.

Next, for each variable that this sensor can measure, the graph contains a resource of type "Observation". This resource has five properties (as shown in Fig. 6): (1) the feature of interest which is a GPS coordinate where the sensor is physically located ("hasFeatureOfInterest"); (2) the property "hasResult" that points to an object of type "QuantityValue" where the numeric value and the units of the measurement are defined; (3) a reference to the sensor that made the measurement ("madeBySensor"); (4) the type of observed property of the given measurement ("observedProperty"); and (5) the timestamp when the measurement was made ("resultTime").

A data transformation enabler from AFarCloud's information model into the AIM is available for download as a docker image in [16].

The benefit of this approach is that by using online transformations of data, it is possible to easily integrate the device (i.e. sensor, wearable, machinery, etc.) into any agri-solution independently of the information model used by the agri-solution. Besides, one same device can publish data to more than one agri-solution in real-time, as shown in Fig. 4.

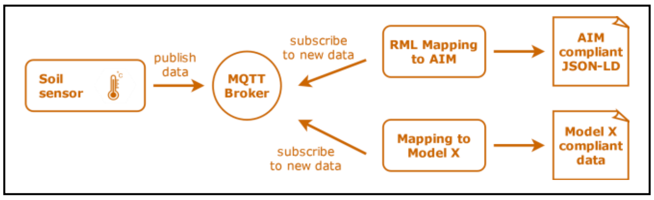


Fig. 4. Sensor publishing data into one or more agri-solutions

B. *Federation of Smart Agriculture Platforms*

Making a device semantically interoperable by being able to publish data compliant to various information models, is extremely useful, especially considering the European data strategy [17] that aims to make the EU a leader in a data-driven society.

```
rr:subjectMap [
  rr:class sosa:Observation;
  rr:template "urn:afc:observation:{observedProperty}:{resultTime}"];
rr:predicateObjectMap [
  rr:predicateMap [rr:constant sosa:observedProperty];
  rr:objectMap [
    rr:termType rr:IRI;
    rr:template "http://www.w3id.org/afarcloud/{observedProperty}" ]
];
rr:predicateObjectMap [
  rr:predicateMap [rr:constant sosa:resultTime];
  rr:objectMap [
    rr:datatype  xsd:dateTime;
    rml:reference "resultTime";]
];
rr:predicateObjectMap [
  rr:predicateMap [rr:constant sosa:hasResult];
  rr:objectMap [
    rr:termType rr:IRI;
    rr:template "urn:afc:observation:{observedProperty}:{resultTime}:q1"
  ]
];
rr:predicateObjectMap [
  rr:predicateMap [rr:constant sosa:hasFeatureOfInterest];
  rr:objectMap [
    #rr:termType rr:IRI;
    #rr:template "urn:{$.sensorData.latitude}"
    rr:parentTriplesMap <#Feature>;
    rr:joinCondition [
      rr:child "resultTime";
      rr:parent "sensorData.resultTime";
    ];
  ]
];
rr:predicateObjectMap [
 rr:predicateMap[rr:constant sosa:madeBySensor];
  rr:objectMap [
    rr:parentTriplesMap <#sensor>;
    rr:joinCondition [
      rr:child "resultTime";
      rr:parent "sensorData.resultTime";
    ];
 ]
];
```

Fig. 5. RML mapping to create an observation instance

```
{ "@id":"urn:afc:AS03:cropsManagement:RISE:soil:0100:battery-
1583311439683",

    "type":"Observation",

    "hasFeatureOfInterest":"http://www.w3id.org/
afarcloud/poi?lat=57.9202195&amp;long=16.4001396",

    "hasResult":urn:afc:AS03:cropsManagement:RISE:soil:0100: battery-
1583311439683/q1",

    "madeBySensor":"urn:afc:AS03:cropsManagement: RISE:soil:0100",

    "observedProperty":"http://www.w3id.org/ afarcloud/battery",

    "resultTime":"2018-01-01T12:36:12Z" }
```

Fig. 6. Resource describing an observation in AIM

However, to obtain the full potential of existing agri-solutions, we need to find mechanisms to federate and make not only devices, but also the whole platforms, interoperable. The purpose of federation is to enable and facilitate interoperability and portability, not only of resources, but also of services, so that both data and services can be shared between two platforms. Interoperability among platforms will provide numerous benefits such as new market opportunities, availability of cross-domain services, and the feasibility of a major cooperation among platforms to offer better solutions to consumers and users. A federation strategy is being led in Europe in Gaia-X [18], a project where representatives from business, politics, and science are working together, to create a federated and secure data infrastructure. This infrastructure will provide an open, transparent and secure digital ecosystem, where data and services can be made available, collated and shared in an environment of trust.

Our solution addresses data federation by means of the *Data Preparation & Integration Enabler* [19]. This enabler includes an MQTT connector to the data streaming in AFarCloud, that is able to acquire the observations published by sensors, IoT devices and vehicles' telemetry. It then performs the four steps of the harvesting process explained in the previous chapter (see Fig. 1) and can store the data in a triplestore repository. Similarly, data from DEMETER's Enhanced Entities could be harvested and transformed from the AIM to AFarCloud's data model and stored in AFarCloud's repositories.

In order to federate and share services between the two communities, each of the platforms provides a software component and a catalogue where services can be discovered and invoked. In the case of AFarCloud, this DSS Framework [20],[21] offers a common interface for all algorithms independently of the location of the algorithm (deployed in cloud repositories or in the partner's premises), the functionality covered by the algorithm, the data it uses internally or the programming language in which the algorithm was coded. This common interface is based on a standard REST API using HTTP and JSON as formats for information exchange. The result of the algorithm can then be either shown graphically, integrated into another component or stored in a database.

In addition, the AFarCloud DSS Framework includes an Algorithm Manager which manages the interaction of the user with the DSS. This component handles the configuration of the algorithms and the start/stop actions. Besides, it stores the list of algorithms that are available in each farm, their status (running or stopped) and their endpoint (i.e. URL and port where the algorithm is accessible through APIs). Any user can call the "*/list*" method to discover available services and then use the "*/start*" method to obtain the result of the DSS. Using this common interface, it is really easy to share services between communities.

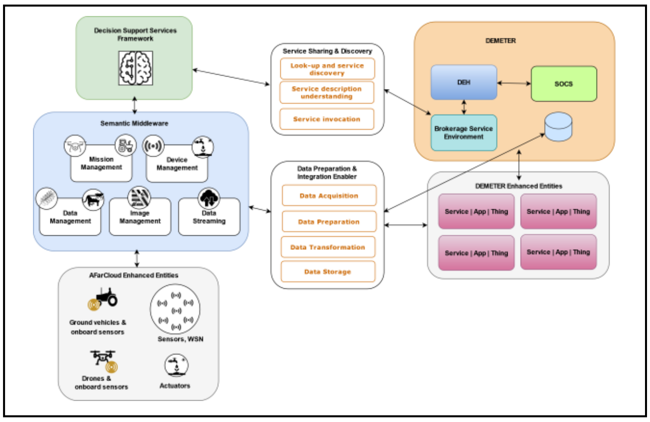


Fig. 7. Federation of AFarCloud and DEMETER resources and services

On the other hand, DEMETER provides the Brokerage Service Environment (BSE) component, which facilitates the registration, discovery, and provisioning of a service through a RESTful interface. The BSE is built on top of Consul [22] which is a service mesh solution providing a full featured control plane with service discovery, configuration, and segmentation functionality. Services are annotated with metadata to facilitate discovery and functional interoperability. Using the REST API, services can be easily discovered and queried through the BSE.

The data and services federation approach are displayed in Fig. 7.

Both AFarCloud and DEMETER use their own vocabularies to describe services, but for future developments, and in order to ease interoperability and be compliant with GAIA-X federation strategy, we recommend service providers to describe and annotate services using GAIA-X's Self-Description schemas[23], as it promises to be the EU standard in the coming years. A GAIA-X Self-Description describes properties and claims of an asset according to the GAIA-X core ontology [24], which contains the concepts and relationships needed to model an efficient, competitive, secure and trustworthy federation of data infrastructure and service providers. Self-descriptions can be easily defined using a GUI wizard [25].

IV. USE CASE VALIDATION

The interoperability between DEMETER and AFarCloud has been tested at Kotipelto farm, a dairy farm located in Ylivieska (Finland). The feeding of these animals is based entirely on TMR (Total mixed ration). The aim of feeding a TMR diet is that each cow can consume the required level of nutrients in each mouthful. A cow's ration should include good quality forages, a balance of grain and protein, vitamins and minerals. In this respect, it is important to control the nutrients in the grass to be used as fodder for the cows. Harvesting fields at optimal time is challenging. During growth, the nutritional properties of the grass reach the optimum level, and it must then be harvested before it starts to lose its quality.

To solve this problem, the farm is using an AFarCloud compliant monitoring solution. This solution is based on an ecosystem of soil sensors deployed in the fields and an innovative grass growth monitoring device developed in that project. On the one hand, soil sensors measure the properties of the land in which the grass has been planted, e.g. amount of water held in soil, amount of minerals, temperature, etc. These soil sensors can be LoRA-based or short-range sensors that lack of internet connection. In the latter case, their observations are collected by means of UGVs deployed in agricultural missions. On the other hand, the grass growth monitoring device is intended to measure the D-value, an indicator of the digestibility of the pasture, closely related to its nutrition level. After analysing all these data, the AFarCloud platform offers the farmer an estimate of the precise moment to harvest the grass.

The farmer, as a user of the AFarCloud platform, can benefit from the solutions provided by DEMETER. One of the strengths of the project is its suite of DSSs (Decision Support System) that aim to help farmers in the decision-making process. DSSs provide a data visualisation module based on Knowage [26], an open source solution for analytics and business intelligence, which displays an intuitive interpretation of information to users. Among these DSS, the following can be of interest to enhance the AFarCloud platform:

Plant Yield Estimation DSS: this DSS predicts crop yield based on NDVI maps and allows training and fine-tuning a crop yield model at parcel level given some NDVI maps. Similarly, AFarCloud provides image processing algorithms that can calculate NDVI maps based on autonomous flight missions carried out by UAVs on a field (see Fig. 8), where the UAVs' waypoints are automatically calculated by the AFarCloud platform to cover the region taking photos at the appropriate intervals and height. Thanks to the possibility of integrating these data in DEMETER, the farmer can make use of the plant performance estimation algorithm.

Variable Rate DSS: variable rate technology is a tool that allows farmers to apply fertiliser, water, chemicals and seeds at different rates across a field. This DSS generates a variable rate task map in AIM format for a given parcel, based on NDVI maps. As in the previous case, the farmer can use the NDVI maps obtained through AFarCloud to make use of this algorithm.

Field Operation DSS: this DSS provides information about tractors and drivers, e.g. distance travelled, vehicle average speed or driver behaviour. As input data, the component receives data in the AIM format about tractor location, speed, braking and fuel consumption. Likewise, AFarCloud supports the definition of prescription maps for ISOBUS tractors, and the storage of tractor telemetry data while those missions are in progress.

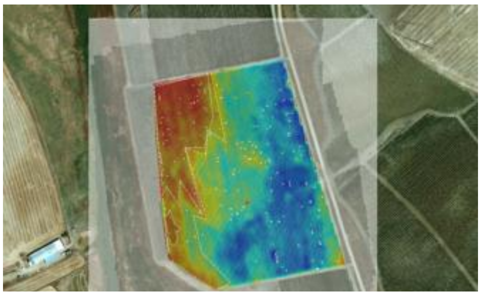
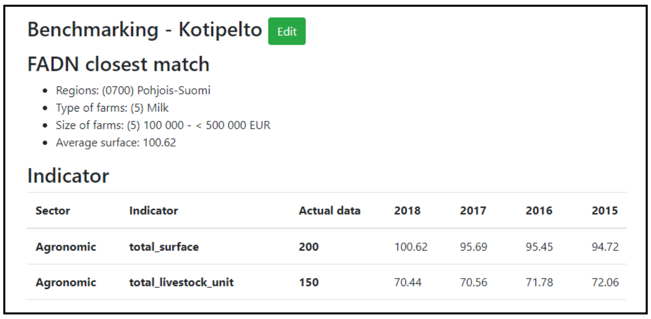


Fig. 8. NDVI map based on autonomous flight missions

Thanks to the *Data Transformation Enabler* interoperability solution, these data can be converted into the AIM-compliant data, offering the possibility of seamlessly integrating this DSS into the AFarCloud solution.



Benchmarking - Kotipelto

FADN closest match

- Regions: (0700) Pohjois-Suomi
- Type of farms: (5) Milk
- Size of farms: (5) 100 000 - < 500 000 EUR
- Average surface: 100.62

Indicator

Sector	Indicator	Actual data	2018	2017	2016	2015
Agronomic	**total_surface**	**200**	100.62	95.69	95.45	94.72
Agronomic	**total_livestock_unit**	**150**	70.44	70.56	71.78	72.06

Fig. 9. Kotipelto farm comparison with neighbouring dairy farms

Crop Nitrogen Balance Model DSS: this DSS estimates crop nitrogen requirements and provides scheduling for fertilisation. As input data, it receives crop locations, field properties, meteorological data and NDVI maps. In our use case, these first two data types are provided by the AFarCloud-compliant sensors. These data are integrated in real time into the project ecosystem through the *Data Preparation & Integration Enabler* interoperability solution. On the other hand, meteorological data have been aggregated by integrating data provided by a Finnish weather station near Kotipelto. Finally, the farmer can obtain NDVI maps through AFarCloud. As a result of the input data analysis performed by this DSS, the farmer can obtain cartographic plans and differentiated fertilisation recommendations on the same plot to reach higher yields.

Farm Benchmarking and Performance Indicator DSSs: this set of DDSs aim to provide end-users with tools to assess the productivity and sustainability of the practices adopted, as well as the effectiveness of the digital solutions developed. Thanks to these DSSs, farmers can compare their farm with other farms, from different points of view: (1) economic farm comparison, exploiting data from the FADN (Farm Accountancy Data Network) which monitors farms' income and business activities (see Fig. 9); (2) neighbouring benchmarking, comparing a group of farms with similar environmental conditions and type of farming; and (3) technology benchmarking, assessing the impact of a specific technology.

V. CONCLUSIONS

The authors of this paper have been able to provide a solution for the interoperability of DEMETER and AFarCloud platforms. This solution has been validated in a farm that takes advantage of the monitoring tools provided by the AFarCloud platform, and which also participates in the DEMETER project demonstrators.

By making the ecosystems of both platforms interoperable, the two communities can mutually benefit in a variety of ways. On the one hand, thanks to DEMETER, the AFarCloud community can access and benefit from a wider range of targeted data analysis tools and decision-making services. Besides, some of these DSSs address objectives that are also of interest to AFarCloud, such as *Plant Yield Estimation* and *Crop Nitrogen Balance Model*, for crop monitoring, *Variable Rate* and *Field Operation*, both related to the monitoring of machinery operation, and *Farm*

Benchmarking. Farmers who are already using AFarCloud, can visualise this information in an intuitive way, thanks to the visualisation tools, based on Knowage, which present the information in an easily understandable way for the end user.

On the other hand, DEMETER could also benefit from being interoperable with AFarCloud, and from some of the services offered by this project: (1) AFarCloud offers a DSS to manage the irrigation needs of vineyards [27] that could be of interest to DEMETER demonstrators focusing on precision farming for Mediterranean woody crops; (2) DEMETER could also extend its services portfolio with the mission planning and monitoring services for unmanned vehicles provided by AFarCloud, which include automatic path planning calculation and the continuous supervision of the mission progress and the vehicles' feedback (i.e. location and vehicle status).

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