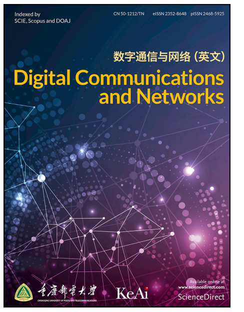
Journal Pre-proof



Building an interoperable space for smart agriculture

Ioanna Roussaki, Kevin Doolin, Antonio Skarmeta, George Routis, Juan Antonio Lopez-Morales, Ethel Claffey, Manuel Mora, Juan Antonio Martinez

PII: S2352-8648(22)00016-5

DOI: https://doi.org/10.1016/j.dcan.2022.02.004

Reference: DCAN 356

To appear in: *Digital Communications and Networks*

Received Date: 17 November 2020

Revised Date: 10 February 2022

Accepted Date: 20 February 2022

Please cite this article as: I. Roussaki, K. Doolin, A. Skarmeta, G. Routis, J.A. Lopez-Morales, E. Claffey, M. Mora, J.A. Martinez, Building an interoperable space for smart agriculture, *Digital Communications and Networks* (2022), doi: https://doi.org/10.1016/j.dcan.2022.02.004.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2022 Chongqing University of Posts and Telecommunications. Production and hosting by Elsevier B.V. on behalf of KeAi Communications Co. Ltd.

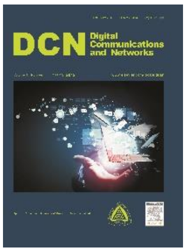
Journal Pre-proof

Digital Communications and Networks (DCN)

Available online at www.sciencedirect.com

ScienceDirect

Journalhomepage:www.keaipublishing.com/en/journals/digital-communications-and-networks



ISSN:2352-8648

Building an interoperable space for smart agriculture

Ioanna Roussaki [a,*], Kevin Doolin[b], Antonio Skarmeta[c], George Routis[a], Juan Antonio Lopez-Morales[c], Ethel Claffey[d], Manuel Mora[c], Juan Antonio Martinez[e]

[a] **Institute of Communications and Computer Systems, Athens, Greece**
[b] **Walton Institute, Waterford, Ireland**
[c] **Department of Information and Communications Engineering, University of Murcia, Murcia, Spain**
[d] **School of Business, Waterford Institute of Technology, Waterford, Ireland**
[e] **R&D Department, Odin Solutions, Murcia, Spain**

Journal Pre-proof

Abstract

The digital transformation in agriculture introduces new challenges in terms of data, knowledge and technology adoption due to critical interoperability issues, and also challenges regarding the identification of the most suitable data sources to be exploited and the information models that must be used. DEMETER (Building an Interoperable, Data-Driven, Innovative and Sustainable European Agri-Food Sector) addresses these challenges by providing an overarching solution that integrates various heterogeneous hardware and software resources (e.g., devices, networks, platforms) and enables the seamless sharing of data and knowledge throughout the agri-food chain. This paper introduces the main concepts of DEMETER and its reference architecture to address the data sharing and interoperability needs of farmers, which is validated via two rounds of 20 large-scale pilots along the DEMETER lifecycle. This paper elaborates on the two pilots carried out in region of Murcia in Spain, which target the arable crops sector and demonstrate the benefits of the deployed DEMETER reference architecture.

KEYWORDS:

Smart agriculture; Internet of Things (IoT); DEMETER; Reference architecture; Interoperability; Agricultural Information Model (AIM); Pilot validation

* Corresponding author. *E-mail address:* ioanna.roussaki@cn.ntua.gr

Journal Pre-proof

1. Introduction

Multiple European Union (EU) policies have been creating new challenges for the agriculture technology development space, and impacting the entire supply chain from food production (FOOD2030) to the bio-economy [1] through the future EU Common Agriculture Policy (CAP). In parallel, the digital single market strategy drives EU-wide requirements for "the right environment for networks and services" and "ensuring that the European economy takes full advantage of what digitization offers", and pushes for the creation of a common European data space[2].

In addition to policy pressures, the sector faces multiple technology-related challenges. While a plethora of digital technologies, such as IoT, big data, AI and robotics, are available, their capabilities in terms of gathering, understanding and using large volumes of relevant data have not been fully realized. Despite the topic having been studied for many years, farmers are yet to fully benefit from data sharing and exchange in masses.

It is without question that the use of data-based IoT technologies will form a cornerstone of the truly smart agriculture [1], with the extensive ongoing research highlighting the usage and benefits of a myriad of sensor and connectivity types in the agricultural setting [2-9]. However, it has been argued [10] that farmers need to know how to manage this new abundance of information to enable the automated decision-making in an economically, environmentally and socially aware manner. Processing the available data and enacting on its recommendations are quite labour demanding and require extended manual process executions and/or the usage of several technologies to enable remotely monitoring the farm data [11-14] and often quite advanced (big) data analytics techniques [15-18].

The motivation of this paper is to propose a technical approach that addresses the following challenges and difficulties existing in the agricultural domain. Firstly, farmers must have control of knowledge they can obtain from data relevant to their specific requirements and activities, i.e., moving from the present situation in which farmers can be overwhelmed by the shear amount of data to one in which they benefit from the insights of that data.

Next, there is the issue of protecting farmers' current investments by deploying cutting-edge technologies, particularly on legacy systems (including machinery which can be 20+ years' old). Determining the correct data sources (weather, soil quality, irrigation levels etc.), building large data sets from multiple farms, and building information models encompassing the entire agri value chain are the other critical challenges, which require the establishment of trusted data sharing mechanisms. Economic and market barriers present another challenge in a context where large players have aimed, early on, to establish themselves in dominant positions via supplier-operated technological platforms, thereby creating walled-garden models of technology deployment.

Finally, of course, a key motivation of the proposed approach is to solve the problem of interoperability and to support the adoption of technological standards to ensure compatibility, the usage of suitable well-established standards for data sharing, and communication that can allow for heterogeneous system interoperation. Currently, agricultural data consumers must interact with a multitude of systems, data models and user interfaces to access and exchange data they need to support their increasingly complex decision-making. The extended heterogeneity across the various technologies offered in this domain, which lack interoperability and cannot interact or exchange information, is a major problem that greatly reduces both the efficiency and the potential of the solutions adopted. This paper aims to present a solution addressing the aforementioned challenges. It elaborates on the related work carried out and the outcomes achieved by the DEMETER[3] project (funded within Horizon 2020) to establish a farmer-centric approach by:

- engaging farmers in the entire knowledge extraction process, and coupling the data collected by the available sensing infrastructure with the information provided by humans themselves.

[1]https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf
[2] https://ec.europa.eu/digital-single-market/en/policies/building-european-data-economy

[3] The full name of DEMETER is: "Building an Interoperable, Data-Driven, Innovative and Sustainable European Agri-Food Sector".

Journal Pre-proof

- focusing on establishing full-scale interoperability of all resources available (i.e., data, services, applications, devices, networks, platforms, and software modules), as well as interoperation across the various stakeholders engaged (e.g., farmers, advisors, agronomists, agricultural machinery manufacturers and technology providers).
- transforming the agrifood sector by building a solution based on a wealth of technologies, such as IoT, AI, earth observation and big data, and various practices and goals, e.g., co-creation, open innovation, sustainability and fairness.

In this respect, this paper aims to introduce the DEMETER reference architecture, mainly focusing on its interoperability-enabling features, and elaborate on a specific pilot use case, where this architecture has been instantiated and validated. The rest of this paper is structured as follows. Section 2 presents a brief overview of the dominating state-of-the-art smart farming initiatives that exploit advanced technologies to address several challenges, including interoperability. Section 3 introduces the main concepts and rationale based on which the DEMETER reference architecture has been designed, while Section 4 presents the architecture itself. Subsequently, Section 5 provides an overview of the pilots and pilot clusters organized and elaborates on their main technological advancements and added values as perceived by the involved stakeholders. Section 6 elaborates on a specific pilot that is currently carried out in Murcia in Spain and aims to demonstrate the advances enabled by DEMETER, focusing on the interoperability elements offered. Finally, in Section 7, the paper's conclusions are presented and an overview of the plans ahead is provided.

2. Related work

Connected systems must be compatible with each other and speak the same language in terms of protocols and encodings. This fuels innovation and provides suitable mechanisms for manufacturers to evolve their products. Noura et al. [19] made a detailed study of the most advanced solutions to facilitate interoperability between IoT-based platforms. The taxonomy of interoperability focuses on different perspectives: interoperability of networks, interoperability of devices, semantic and syntactic interoperability and interoperability of entire platforms. More specifically, farm-focused management systems are rapidly evolving and aim to improve decision-making to define the best practices in agricultural production, improve the management of natural resources, reduce production costs, increase productivity and optimise on-farm operations. A significant impediment to the process of digitising agriculture is the lack of capacity of current systems to interoperate with each other. These systems or "information islands" prevent the creation of services across different domains or platforms, as they are not able to interact and share information. Therefore, most of the data sets collected on farms are not exploited to their full extent, which prevents them from reaching their full potential.

In the literature, various initiatives aim to address interoperability and data integration challenges in the scope of agriculture [20]. Bonacin et al. [21] proposed a set of ontologies to improve agricultural data integration using semantic web-based techniques. Sahin Aydin and Aydin [22] presented an ontology-based generic data acquisition model to create data acquisition forms based on the model-view-controller design pattern for publication and use on open agricultural data platforms. Schuetz et al. [23] designed a semantic active data warehouse to support data analysis in precision agriculture, using a relational database and a Resource Description Framework (RDF) triple store. Bazzi et al. [24] proposed an Application Programming Interface (API), which can be accessed from any other application that allows HTTP communication with a server to store, integrate and manage the datasets used in agriculture-oriented applications. Furthermore, Gallinucci et al. [25] used a relational scheme and exploited geographic information to integrate heterogeneous agricultural data of different levels in detail, oriented to data analysis and Business Intelligence (BI) 2.0.

There are various other ongoing European initiatives that target, among others, a number of interoperability challenges in the agrifood sector. H2020 IoF2020 project [26] for example aims to tackle interoperability and offer portable solutions based on several IoT technologies exploited in the agrifood sector. The technologies and

Journal Pre-proof

associated standards considered by IoF2020 have been structured in several different layers, among which interoperability points have been implemented, each tackling selected interoperability challenges. In this respect, the main layers identified are: physical device layer, connectivity layer; IoT service layer; mediation layer; information management layer; application layer; security and privacy cross-cutting layer.

CYBELE (Fostering precision agriculture and livestock farming through secure access to large-scale HPC-enabled virtual industrial experimentation environment empowering scalable big data analytics) [27] is another H2020 project that focuses primarily on high performance computing and implements use cases related to interoperability in agricultural technologies. The project adopts a layered architecture consisting of modular components and ensures interoperability between these through a central focus on how data are channelled from queries, to forming simulations, and onwards to final analytical processes and data visualisation. CYBELE adopts two main mechanisms to achieve its interoperability goals. Firstly, it emphasises the exposure of functional primitives for HPC/BigData frameworks that the project integrates. Secondly, it produces a number of normative schemes and common data models (common in particular at a semantic level). It also annotates information to be communicated between components, which in turn ensures that information is harmonised, and seamless communication is established. Validation of this approach is still to be made.

Finally, the Agricultural Interoperability and Analysis System (ATLAS) H2020 project [28] focuses on the secure and dependable inter-connection of many elements of the agri supply chain, including sensor technology, machinery, and data sources. This is to be achieved by two complementary approaches. The first is architectural, taking a service-oriented approach. The second is what the project terms as the ATLAS AppEngine, which is essentially a standalone reference computing platform that allows applications to be installed and executed in situ on machinery. As is the case with CYBELE, the proposed approach remains to be validated.

However, ontologies and relational schematics are not flexible when adding new data sets and are not capable of performing data analysis to mitigate these barriers. Ngo et al. [29] introduced a continent-wide data warehouse that was designed and implemented combining Hive, MongoDB and Cassandra and the constellation schema into actual agricultural data sets. However, they did not describe how their data warehouse was built.

Nowadays, the use of spatial data helps the prediction of variables such as yield or optimal harvest date, so it is urgent to integrate and link them with other data generated by farms. Bordogna, et al. [30] proposed an architecture for managing a spatial data infrastructure for creating, managing and analysing heterogeneous geospatial data sets from multiple sources and time series on the web. Besides, Jiang et al. [31] demonstrated that there are many possibilities for integrating statistical modelling techniques and spatial-temporal data for crop management in specific locations.

The use of platforms, based on standard and open interfaces and protocols, allows the integration of different data sets, as well as interoperability with solutions from other suppliers for data exchange and exploitation. In this respect, FIWARE[4] is one of the instruments used to build solutions tackling the needs of the agri-food sector. There are several initiatives that address farm management in different policy areas, using FIWARE as a central element. For example, López-Riquelme et al. [32] exploited FIWARE over cloud services to improve the management of irrigation water. Another initiative based on FIWARE is the Smart Water Management Platform (SWAMP) presented by Kamienski et al. [33], the main objective of which is to develop innovative methods based on the IoT for the intelligent management of irrigation water. Both solutions are based on FIWARE enablers to build their architectures, but they use these generic enablers as building blocks without exploiting the interoperability property in the abroad sense.

A summary of the state-of-the-art approaches considered by the proposed solution is provided in Table 1.

Table 1. Related state-of-the-art overview

Author / initiative	Main focus of related work
Noura et al. [19]	reviewing dominant approaches that

[4] https://www.fiware.org/

Journal Pre-proof

	facilitate interoperability between IoT-based platforms, identifying taxonomies and challenges that remain open
Bahlo et al. [20]	reviewing the role of interoperable data standards in precision livestock farming
Bonacin et al. [21]	proposing a set of ontologies to improve agricultural data integration using semantic web-based techniques
Ngo et al. [29]	building a data warehouse for agricultural big data
Bordogna, et al. [30]	building a spatial data infrastructure integrating heterogeneous geospatial data and time series in agriculture settings
Sahin Aydin and Aydin [22]	delivering an ontology-based data model for open data platforms in agriculture
Schuetz et al. [23]	building an active semantic data warehouse for precision dairy farming
Bazzi et al. [24]	providing an API to enable integration of data and software in precision agriculture
Gallinucci et al. [25]	building a heterogeneous agricultural data management and analytics solution integrating business intelligence concepts
H2020 IoF2020 project [26]	establishing IoT-based solutions to address interoperability, replicability and reuse across the agrifood chain
H2020 CYBELE project [27]	building high performance computing facilities for big data management and analytics in precision agriculture
H2020 ATLAS project [28]	supporting secure interoperation of several agrifood chain elements and technologies
Besides, Jiang et al. [31]	applying spatial statistical modelling for crop yield estimation in precision farming
López-Riquelme et al. [32]	improving irrigation water management based on FIWARE over cloud services
Kamienski et al. [33]	developing IoT-based solutions for smart irrigation based on FIWARE

3. Main concepts and rationale

DEMETER's core objectives and planned results are planned to be realised through the following main architectural concepts:

- As the project is heavily user-centric and proposes a fully multiactor approach, a system which allows the needs of individual or groups of farmers to be expressed within a central framework is required. This expressed need is converted into a challenge, which then proceeds through a resolution mechanism that involves multiple stakeholders, such as the farmers themselves, and providers of technical/advisory services. The system enables pre-existing/pre-deployed technologies to be factored into the decision-making process combined with the farmers' identified goals. The system to enable this is called the Stakeholders Open Collaboration Space (SOCS). Also includes features that structure the human-centric elements of DEMETER through knowledge improvement and sharing capabilities. The DEMETER SOCS takes inspiration from the EIP Agri Social Spaces and Operational Groups, which enables cocreation through meetups, working groups, hackathons and so on, coordinated through a web platform.
- With the cocreated solution features identified, the DEMETER Agricultural Interoperability Space (AIS) takes control of its deployment. To do this, interoperability mechanisms are reused and extended at all levels (from sensors to data and to services).
- The solutions required for fully interoperable agri-tech scenarios are complex, containing multiple components, hardware, software services, and sources of data etc., so the DEMETER project centralises the fully harmonised description of all elements into what is termed as the DEMETER Enabler Hub (DEH). The DEH has two main features – firstly it provides fully harmonised descriptions that allow components to be used within the SOCS. Secondly, it enables components to be adopted in multiple deployment scenarios by

Journal Pre-proof

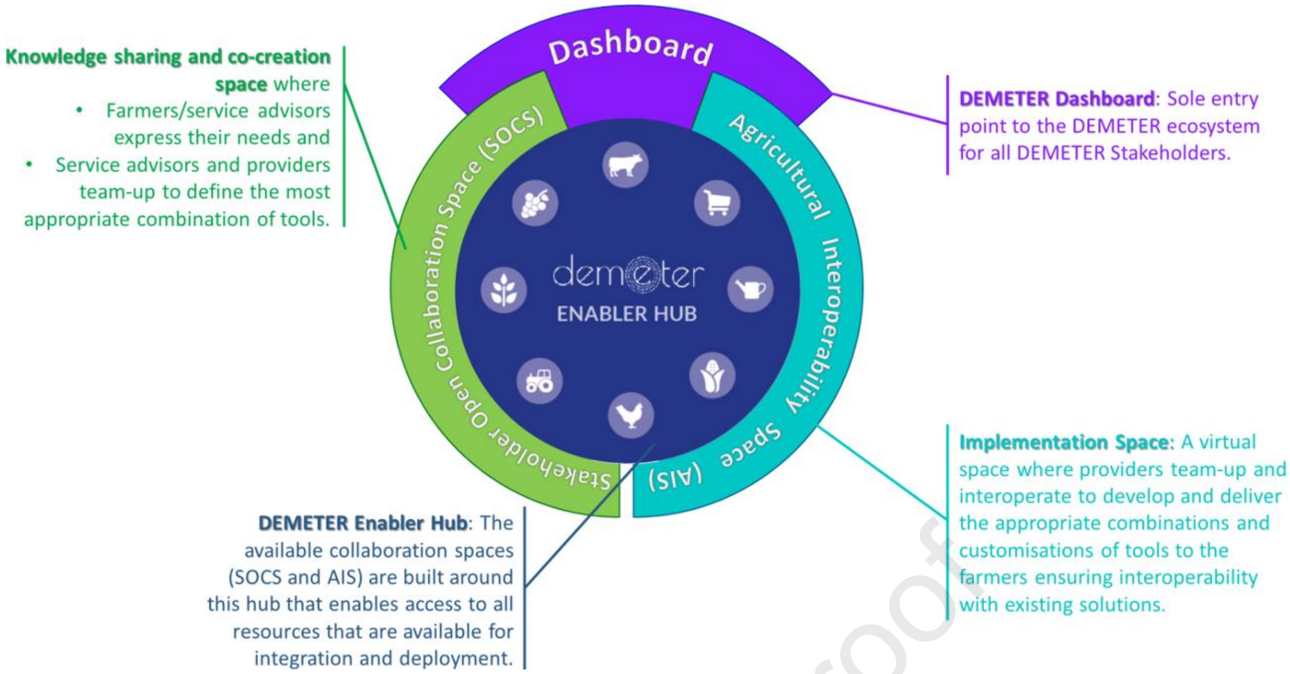


Fig. 1: Overview of the main DEMETER concepts

leveraging what are known as DEMETER-enabled interoperability mechanisms. These interoperability solutions come from standards, as well as from related initiatives such as IoF2020, DataBio (both H2020 projects).

- The final piece of the puzzle is the DEMETER dashboard, which acts as a portal to the project ecosystem for all potential stakeholders. It provides the access point for the aforementioned SOCS and AIS. In addition, the dashboard provides typical functionality such as account management, data management, etc.

Fig. 1 presents a stylised representation of these concepts. Essentially the main benefit of this approach is to provide a connection between the human-centric space (left) and the fully digital execution aspects (right). This enables DEMETER to ensure that all technical decisions / solutions are driven by human actors, and that all enabling technologies are absolutely aligned with the needs of farmers and based on combined intelligence captured through a stringent process.

The aforementioned DEMETER dashboard presents different views to the users based on the aims of their engagement with the system (e.g., to collaborate, to express their needs, to consumer resources, or to develop new applications based on the available resources), the type of user (and their associated access rights and roles), and the target for research and deployment.

Through the DEH various stakeholders (e.g., developers) can register and describe their service capabilities and resources in a semantically consistent manner which includes provision of metadata to inform the system about security, privacy and usage policies for data, or QoS metrics etc. These can in turn be searched and discovered by other interested parties. Secure communication channels between consumers and providers are established through the hub, following an identification verification process. Note the enabling technologies provided via the DEH can be developed within the DEMETER project or by external parties (such as software developers, equipment manufacturers, platform providers).

Fig. 2 illustrates a number of additional concepts that must be described prior to discussing the full DEMETER reference architecture. Firstly, there is the concept of a DEMETER-enhanced-entity. This represents any entity (hardware or software) that is registered in the DEH for external usage, and that consumes resources of other entities in the DEH, or vice versa. There are a number of rules related to provision and consumption of resources within the DEMETER ecosystem:

- Applications can consume resources;
- Services/platforms can consume and/or provide resources;
- Things (hardware) can only provide resources.

Journal Pre-proof

A number of DEMETER enablers are mandatory so as to properly support communication and interoperability at each of the DEMETER-enhanced entities in the system. These core enablers are encapsulated in the DEMETER enhancing service, accompanied by the providers and consumers discussed above. A DEMETER DEH API ensures the communication between entities and the hub. Finally, all entities and their associated access rights and policies are registered in the DEMETER registry.

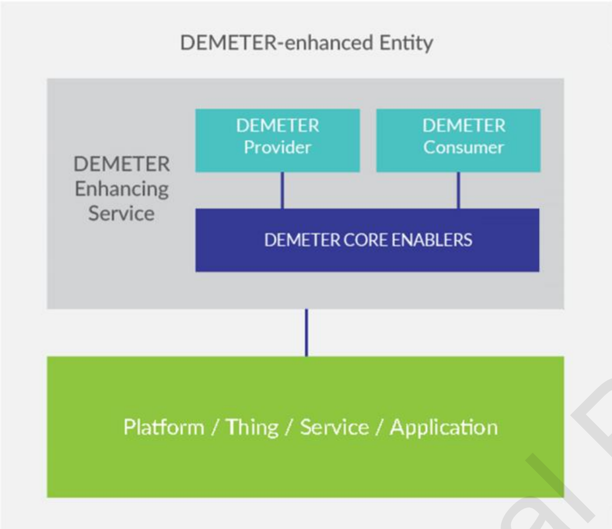


Fig. 2: DEMETER-enhanced entity: mandatory components

These variations of DEMETER-enhanced entities form a core element of the DEMETER reference architecture, which is to be elaborated in the next section.

4. The DEMETER reference architecture

Following the above presentation of the main conceptual architecture, this section presents an elevated view of the DEMETER reference architecture. A plethora of platforms and systems are deployed in a smart farming context, and this adds to the complexity of building a master system. To incorporate these and other systems (such as weather systems, satellite systems, …) is almost impossible, particularly due to the scale, variations, complexity, governance requirements and heterogeneity of the extant agri-tech sector. To counter this, DEMETER enables interoperability primarily at the data level, and includes features for scalability and data-ownership governance. This, as noted previously, is achieved through the AIS, through the extension of legacy Agricultural Knowledge Information Systems (AKISs) by enabling them to provide data to, and consume data from, cooperating systems through the exposure of new and emerging technologies and services that may be of interest. This approach presents a more realistic and viable solution in terms of potential adoption, sustainability and usability. To realise this approach, and to address the extracted requirements [34], DEMETER has specified the solution objectives as below:

- Existing AKISs must be able to provide/consume data to/from their counterparts.
- AKISs must be incentivised to share data by ensuring data integrity and exploitation, which in turn creates the potential for revenue generation.
- In order to ensure portability, scalability and rapid deployment, virtualisation containers for services must be used extensively.

The proposed architecture is presented in Fig. 3 and illustrates DEMETER's providers and consumers, which draws inspiration from the architecture model introduced by the Industrial Data Space (IDS) [35] that was further enriched by the International Data Space Association (IDSA) [36]. Beyond this architectural foundation, DEMETER's providers and consumers extend their core applications through the provision of support for AKISs to similarly provide and consume data. It is beneficial to enable the rapid deployment and decommissioning of survey services that don't necessarily require an endless feed from an AKIS. In this case the service would simply start the consumer service for an AKIS, get the required data, and stop the service. For speed, the services are packed into lightweight containers accompanied by all necessary software for independent deployment (libraries for communication, runtime environment, security/encryption, etc.).

Journal Pre-proof

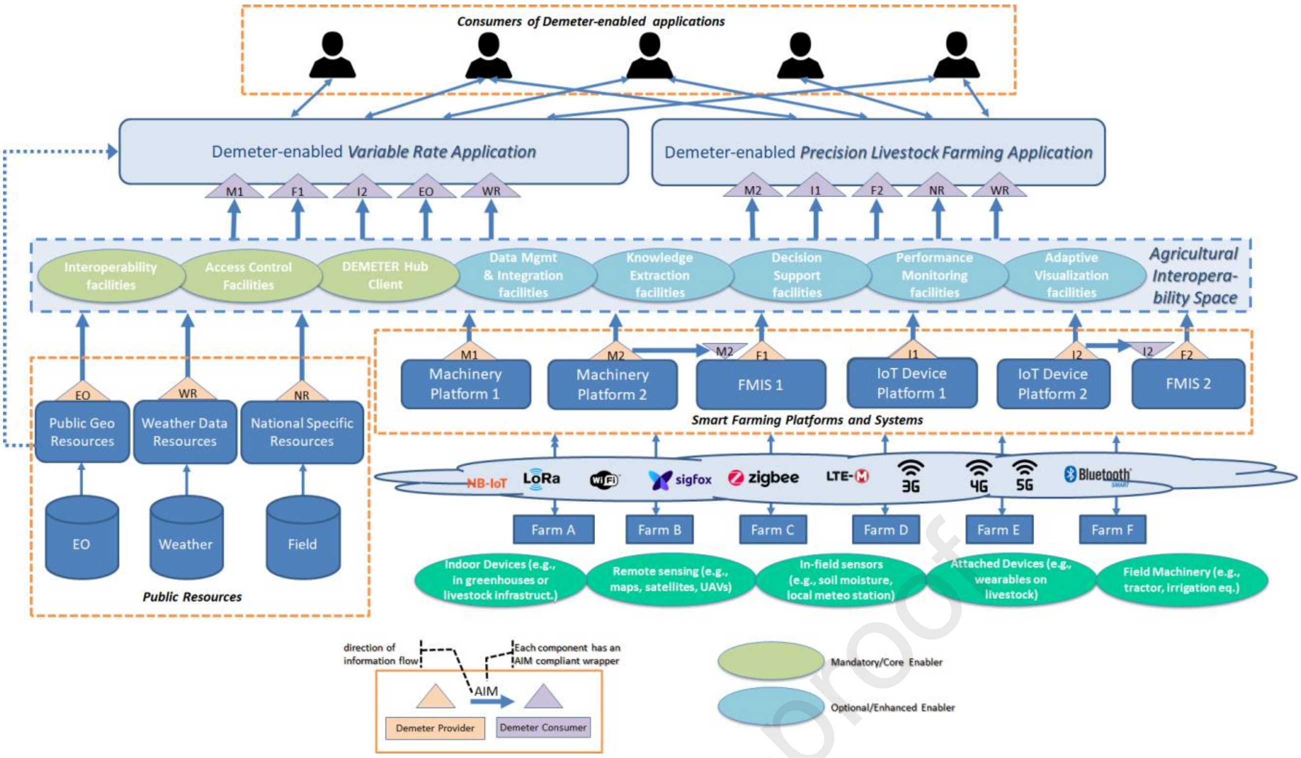


Fig. 3. High-level view of DEMETER reference architecture instantiation example

Acknowledging the criticality of interoperability at a data level, DEMETER implements a semantic data model Agricultural Information Model (AIM) [37] to support data translation, management and inference (complying with standardised solutions such as NGSI-LD[5], ADAPT[6] and Saref4Agri[7]).

The AIM common data format is adopted for DEMETER's consumers and producers to support interoperability and heterogeneous data handling, implemented with lightweight data translators and wrappers. To achieve this, each AKIS must specify its utilised data model semantics, or it must employ the AIM format to parse the returning content. The AIM extends existing ontologies and vocabularies designed for the agri-tech domain, and as such is not built from scratch.

Beyond data management and translation, DEMETER's providers and consumers must cater for security and privacy requirements in a manner that supports trustworthy deployment within AKISs' hosting environment. This is based on the principle that it is more efficient to model the processing capability rather than the data. Additionally, this provides privacy protection as data usage and sharing remain firmly in the control of the data owner. Furthermore, all services must provide user authentication and access authorisation, as is typical in deployments like this.

Following the implementation of a DEMETER-enabled application, the production version can then be discovered (by agronomists, cooperatives, agencies, farmers, etc.) via the DEMETER dashboard/DEH.

For brevity, Fig. 3 presents a sample of the platforms that can be integrated in the DEMETER reference architecture. This in effect represents a single instantiation of the architecture as deployed in a specific trial site. Apart from the platforms, the DEMETER service logic blocks can be employed by interested entities, similar to any other third-party resource.

Registered resources, accompanied with deep metadata (describing their capabilities/constraints), are available via the DEH, and ensure that apps based on the adopted technologies are best prepared to fully leverage the available resources, whilst being cognisant of the potential location-based usage restrictions.

DEMETER-enhanced entities (which represent things, platforms, services…) can have multiple instantiations as presented below:

[5] https://www.etsi.org/deliver/etsi_gs/CIM/001_099/009/01.01.01_60/gs_CIM009v010101p.pdf
[6] https://adaptframework.org/
[7] https://www.etsi.org/deliver/etsi_ts/103400_103499/10341006/01.01.01

Journal Pre-proof

Journal Pre-proof

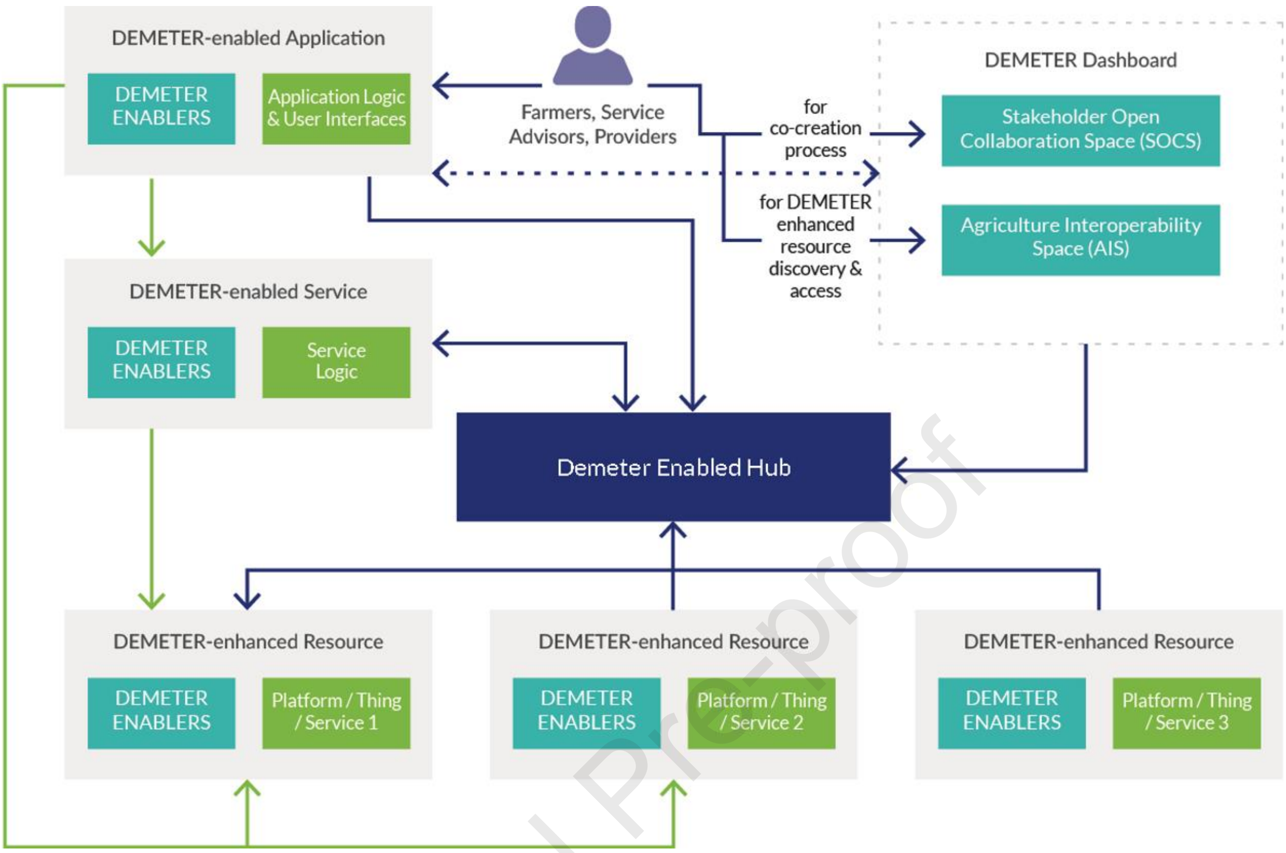


Fig. 4. Positioning and interoperation of entities (i.e., applications, services, resources) enhanced/enabled and/or made available via DEMETER

- A DEMETER-enhanced resource contains the resource (platform, thing, service) that registers its capabilities to the DEH for use by external parties. Note, a DEMETER-enabled resource can utilise other enablers within the DEH to enhance its capabilities.
- DEMETER-enabled service: This is essentially a third-party service provided by external stakeholders and integrated into the project ecosystem. It registers its service logic to the DEH to support its discoverability, and it can also discover other enablers and consumer interfaces without interoperability concerns.
- DEMETER-enabled application: The underlying logic and external UI of these applications are DEMETER-agnostic and are accessed directly by users, while the application can communicate with the DEMETER eco-system and browse the DEH to discover available resources that are compatible with and registered to DEMETER. Critically, it is possible for users to consume the functionality that the DEMETER-enabled resources expose exclusively through these applications.

Fig. 4 presents the positioning of these entities in the DEMETER ecosystem, how the stakeholder interactions are supported, and how the communication with the DEH and each other operates. Human stakeholders access the SOCS, AIS and DEMETER-enabled applications directly via the dashboard. The primary interactions among the various entities take place during the registration and discovery stages to support discoverability by interested parties. Enablers and resources identified for use are packaged with any necessary facilities for development and runtime integration. Once a discovery has happened, the DEMETER-enabled entities (resources, applications, services) can interact directly. Finally, a DEMETER provider can restrict resources to interested consumers via the hub exclusively should it wish to do so.

Journal Pre-proof

Journal Pre-proof

Table 2. Pilot cluster overview

Pilot Cluster 1 ***Sector:*** Arable Crops ***Focus:*** Water & Energy Mgmt	**Description:** The cluster focuses on an efficient integrated management of water and energy, from sources to end users to optimise both the quality and the quantity of the resources in irrigation systems applied to irrigated and arable crops. The pilots involve different technologies as IoT sensor networks or satellite imagery and advanced farming platforms.
Countries: Spain, Greece, Romania, Portugal	
1.1	**Water savings in irrigated crops:** This pilot aims to increase production while saving water and improving the automation of the irrigation zones through interoperable remote-control systems and robust management systems adapted to the conditions required by the irrigated agriculture.
1.2	**Smart energy management in irrigated & arable crops:** This pilot aims to modernize irrigation systems and design efficient networks from the energy point of view, evaluating and selecting the optimal contracting of the electricity supply, as well as implementing alternative renewable and clean energies that reduce the price of consumption.
1.3	**Optimal quality rice irrigation:** This pilot is dedicated to both rice and maize crops where the smart irrigation system is deployed and validated in order to optimise water quality control (e.g., salinity levels) and water quantity use.
1.4	**IoT corn management & decision support platform:** This pilot aims to implement an IoT corn decision support system platform for farmers to improve greenhouse gas emissions and poor water quality that adds business risks in corn production.
Pilot Cluster 2 ***Sector:*** Arable Crops ***Focus:*** Agricultural Machinery, Precision Farming	**Description:** The cluster focuses on arable crops and specifically on the usage of agricultural machinery and the establishment of precision farming. The pilots concentrate on monitoring arable crops through sensors and their documentation, while decision support systems are developed for live support of agricultural process in a secure and trusted way.
Countries: Germany, Poland, Czech Republic, Norway	
2.1	**In-service condition monitoring of agricultural machinery:** This pilot aims at demonstrating the potential application of onboard After Treatment (AT) sensors for in-service monitoring, as well as testing the legal applicability of existing sensors as an alternative to PEMS (Portable Emission Measurement Systems) while considering aspects of data management, privacy and integrity.
2.2	**Automated documentation of arable crop farming processes:** This pilot develops a DSS for live support of agricultural processes and the connected supply chains based on autonomous documentation. This includes capturing high precision data, merging with data from other farms/ machines, and deriving required documentation parameters via data analytics and knowledge management techniques.
2.3	**(Farming) Data brokerage service and Decision Support System (DSS) for farm management:** This pilot establishes a trust-based and compliant data market for agricultural enterprise data that sits between the owners and operators of agricultural data clouds and the farmers, and that includes both a technical platform and advisory services that ensure the easy adoption of data and technology by farmers.
2.4	**Benchmarking at farm level DSS:** This pilot aims at developing services to support the benchmarking on the productivity and sustainability performance of the farms, leveraging and extending the existing DSS. This involves monitoring different conditions and parameters affecting such indicators, collecting data and integrating it in a unified layer accessible by the DSS.
Pilot Cluster 3 ***Sector:*** Fruits and Vegetables ***Focus: Health*** and high-quality crops	**Description:** The cluster focuses on supporting farmers in protecting the health and the quality of production of several fruit and vegetable crops in several European countries. Two pilots are crop-oriented: olive and corn pilots focus on a pest that affects a set of tree crops and one pilot focuses on precision farming for a set of mediterranean tree crops. The pilots involve the integration of several technologies: the existing farming digital platforms, IoT sensor networks, model and decision support systems, remote sensing data, and advanced data analysis tools.
Countries: Italy, Portugal, Spain, Belgium, Serbia, Greece, Turkey	
3.1	**DSS to support olive growers:** This pilot aims to optimise irrigation and fertilization in olive orchards with integrated pest management through an on-line platform for olive farms and advisers. The proposed platform integrates software, sensors and open data sources to provide farmers and technicians a complete and efficient support for olive growing and olive oil production. The platform is tested in several farms in Italy, Greece and Turkey.

Journal Pre-proof

3.2	**Precision farming for mediterranean woody crops:** This pilot aims at promoting technology, methods and IoT solutions to optimize precision farming practices of Mediterranean woody crops (apple, olive and grape), considering small farmers' economic constraints. The proposed solutions (IoT and Ground Robots) enable a more efficient usage of inputs such as water, energy, macro-nutrients, and pesticides to increase the profits of small farmers and reduce their environmental impact.
3.3	**Pest management control on fruit fly:** This pilot aims at providing a set of tools to monitor and manage the Mediterranean fruit fly (*Ceratitis capitata*), which is a dangerous pest with a wide range of distribution and host plants. Automatic capture traps and remote sensing technologies are employed to predict and support in decision making and are tested in citrus farms in Valencia region.
3.4	**Open platform for improved crop monitoring in potato farms:** The pilot aims at integrating the Demeter project machinery data with crop- and field-specific info into WatchITgrow to analyze the interaction of parameters (yield data fertilization and protection data with satellite data, weather and soil info). Advice is provided to farmers for the optimization of field management.
Pilot Cluster 4 ***Sector:*** Livestock ***Focus:*** Animal Health, High Quality & Optimal Mgmt of Animal Products	**Description:** This cluster focuses on supporting farmers for livestock animal health and high quality in the production of animal products with farmers' dashboards with AI-based prediction and decision support for animal health and animal products. Three pilots are milk cow oriented with one focusing on AI machine learning for predictive milk production and dashboard including data flow for invoicing, settlement, accounting, bank and insurance. Two pilots focus on milk quality and animal welfare tracking through health and welfare recording protocols which is applied using various sensor technologies and digitalised records. The fourth pilot is similarly focusing on chicken health and optimal production.
Countries: Norway, Italy, Ireland, United Kingdom, Luxemburg, Serbia	
4.1	**Dairy farmers dashboard for the entire milk and meat production value chain:** This pilot focuses on a full dataflow dashboard with animal product accounting, settlement and payment, including decision support based on AI machine learning from the sensor data.
4.2	**Consumer awareness: milk quality and animal welfare tracking:** This pilot focuses on an animal welfare scoring systems with appropriate ICT tools to measure relevant parameters on a continuous, real time basis; for a well-being audit for dairy cows.
4.3	**Proactive milk quality control:** This pilot focuses on prediction models of cow welfare and health based on the analysis of streaming data from cow sensors.
4.4	**Optimal chicken farm management:** This pilot focuses on chicken sensor data and benchmarking farm efficiency across the farms through IoT devices and AI-based algorithms.
Pilot Cluster 5 ***Cross-Sectorial*** ***Focus:*** Full supply chain, Interoperability, Robotics	**Description:** The goal of this cluster is to run pilots across several sectors (fruit, vineyards, cattle, poultry) and to address both supply and demand sides of the supply chain. Such approach enables us to validate interoperability of platforms and solutions used in different sectors as well as to validate interoperability of platforms used for management of on-farm and post-farm (supply chain) activities. The complete lifecycle of a product is covered by inclusion of representatives of the recycling industry through the open call.
Countries: Serbia, Montenegro, Serbia, Georgia, Slovenia, Spain, Poland	
5.1	**Disease prediction and supply chain transparency for Orchards/vineyards:** This pilot addresses both on-farm and post-farm activities, from technical and business perspectives. Data analytics modules reason over the acquired sensor data and suitable advices given to farmers. Product passports are created for wine production and supply chain stakeholders (retailers, consumers) engaged.
5.2	**Farm of things in extensive cattle holdings:** This pilot addresses cattle farm operations, from technical and business perspectives. Knowledge extraction and fusion over the acquired sensor data is used, advisory services are provided to farmers and interaction with product passport is implemented.
5.3	**Pollination optimisation in apiculture:** This pilot addresses the apiary management from technical and business perspectives. Data analytics facilities are exploited, interaction with the product passport is implemented and suitable recommendations are provided to the farmers engaged.
5.4	**Transparent supply chain in the poultry industry:** This pilot addresses the post farm activities of a poultry farm. It validates both performance regarding technical features, as well as feasibility of business models. Product passports are created for poultry products and supply chain stakeholders (retailers, consumers).

Journal Pre-proof

Journal Pre-proof

5. Overview of the foreseen pilots

The DEMETER reference architecture and concepts introduced in the previous sections will be fully tested during the lifetime of DEMETER via 20 large scale pilots. These pilots will be used to demonstrate and evaluate how well the architecture designed addresses the user and the technical requirements in place, to validate how much the involved stakeholders benefit from the mechanisms offered by DEMETER. The 20 pilots have been classified into 5 major clusters, with each cluster deploying 4 pilots, aiming to enable the evaluation of the provided solutions across various agri-food domains in different cultural, societal and farming contexts. The 20 pilots will be conducted in two rounds. The first pilot round is currently being executed and is based on the initial release of the DEMETER enablers, hub, spaces and applications. It will complete by April 2021 and be based on the respective system and user evaluations and assessments, as well as the feedback from the multi-actor ecosystem built. Then the second pilot round will be designed and implemented. The respective evaluation findings will drive the overall DEMETER impact assessment to be delivered at the end of the project. Table 2 above presents the pilot clusters and the focus of each underlying pilot.

In the next figure, the geographic coverage of the DEMETER pilots and clusters is depicted.

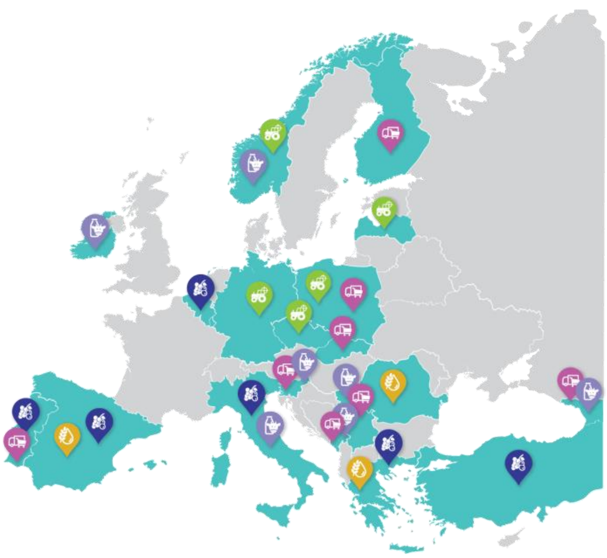


Fig. 5. DEMETER pilot coverage and distribution

6. The Murcia pilots

This section presents the details of the pilots deployed in the Murcia Region in Spain as a subset of the broader work being undertaken within the DEMETER project.

Nowadays, in irrigation communities, it is difficult to homogenize the information in a single coordination centre, therefore, limiting their organizational capacities as the joint management of all their data sets is not allowed. Also, they have installed multiple solutions that do not communicate with each other, such as Supervisory Control And Data Acquisition (SCADA) systems, different remote control systems and irrigation systems, with many sensors deployed. Nevertheless, in today's hyper-connected world, isolated solutions have no place, and interoperability is the fundamental requirement that all solutions must address to contribute to a more productive environment where information exchange is possible for a greater good.

One of the main challenges of irrigation communities is to provide a unique management system. The current technology-based solutions only partially cover their needs and limit their capabilities, as they do not allow for joint monitoring of water and energy. This makes the existing solutions monolithic and closed.

6.1. Outline

Two DEMETER pilots are carried out in the Murcia Region, namely Pilots 1.1&1.2 – water savings and smart energy management in irrigated crops & arable crops. These are the so-called Murcia Pilots that aim to increase the production of irrigated crops while saving water and energy. The pilots are deployed in a specific location of the Spanish territory thanks to the collaboration with an irrigation community: Miraflores irrigation community in the Murcia region, where Odin Solutions and the University of Murcia who are responsible for the Murcia pilots' execution, are also involved.

The Miraflores irrigation community in Jumilla, Murcia, located in the Segura river basin, comprises 1,340 ha of agricultural land, mostly devoted to woody crops, irrigated through localized irrigation. It is supplied with 3.8 hm3 per year of surface water together with 1.5 hm3 per year of regenerated water produced in the Jumilla treatment plant, generating an average of 4,025 m3/ha-y. Because the municipality has been excluded from the water supply of the Tajo-Segura transfer system,

Journal Pre-proof

the use of reclaimed water has multiple benefits, both environmentally and in direct economic terms, for agricultural activities. Within the infrastructures that form part of the community, we can highlight those in charge of the water supply: eight pumping stations with their filtering stations, seven reservoirs and 1469 hydrants.

These pilots use inputs from both soil sensors and meteorological stations, as well as satellite images, to optimize the irrigation and the SCADA systems.

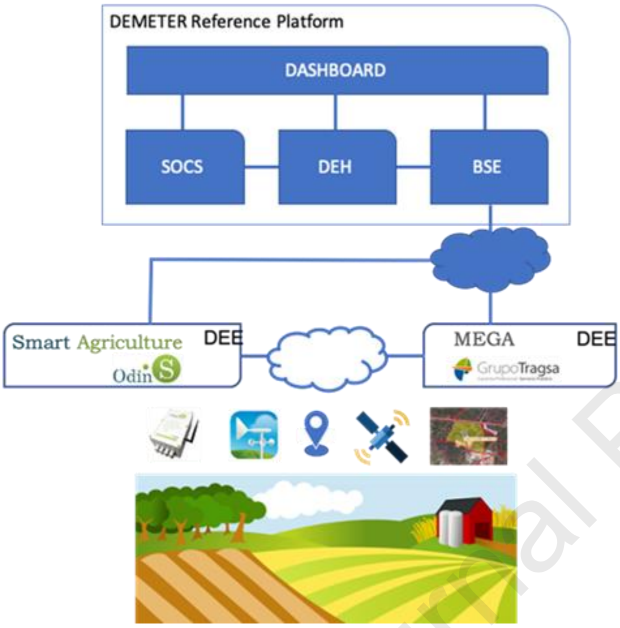


Fig. 6. Examples of pilot flow information

6.2. Use case workflow

For these pilots, the inputs considered include soil and weather information provided by soil sensors and a weather station, as well as satellite images and the different indexes they offer among others. Fig. 6 presents a general view of how this information is gathered through the different IoT platforms (smart agriculture and MEGA coordinator), tailored as DEMETER Enhanced Entities (DEEs) and integrated into the Brokerage Service Environment (BSE). Using for this purpose, specific functionalities and datasets which have been packaged as dockerized components can be searched and downloaded using the DEH.

For the case of smart agriculture, the data provided by IoT gateways follows open and standard protocols such as JSON documents over Message Queuing Telemetry Transport (MQTT). This way, the information is translated into a richer representation format by using NGSI as illustrated in Fig. 7.

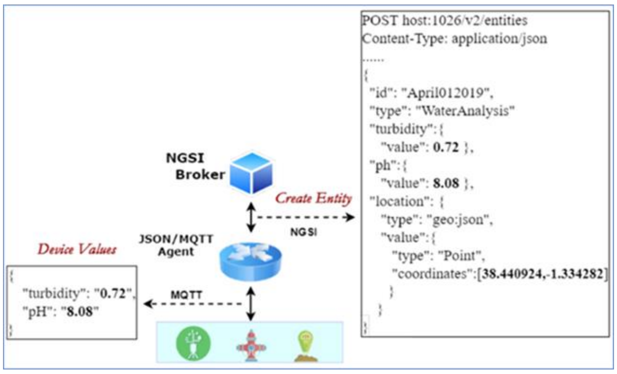


Fig. 7. IoT level information translated to NGSI

Some of the irrigation control systems used in the pilots have their own sensors that cannot be accessed directly. To access this information, ISO 21622 is used to make this information available via the MEGA platform, as indicated in Fig. 8.

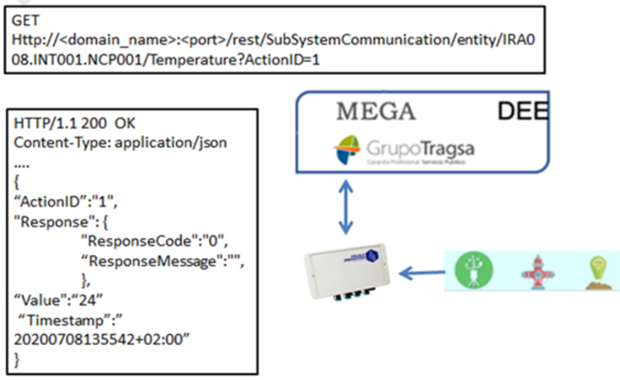


Fig. 8. Getting sensor information through MEGA

The DEMETER components downloaded from the DEH and deployed in the pilot premises allowed for the instance of the MEGA DEE, which exposes its information using the AIM format and is registered in the BSE so that it could be available to all interested stakeholders. This information is also presented to the users using the DEMETER dashboard. This way, the information obtained by MEGA DEE can be shared with other platforms. This process is made in a secure manner, based on the DEMETER authorisation enablers to ensure that only legitimate users with the right permissions access the corresponding information.

Journal Pre-proof

6.3 Used data

The Murcia pilots aim primarily at the optimisation of water and energy resources for arable crops. Therefore, the data collected and exploited include:

- Geospatial data: location, Geographical Information System for Agricultural Parcels (SigPac), EGNSS (GPS/EGNOS/Galileo).
- Satellite imagery: Copernicus Sentinel 2.
- Climate data: air temperature/ humidity, wind speed/direction, solar radiation and rain.
- Soil data: temperature, salinity, humidity, conductivity, soil water tension, soil water content, soil water height.
- Water data: hydrants (water flow and water consumption).
- Farm data: historical farm statistics, farm crop data.

Additionally, the Murcia pilots manage other general information related to users and companies such as username/password, personal or company details, etc. This information is modelled based on the AIM of DEMETER [37]. Below, in Listing 1, we detail the concepts more related to the agricultural domain.

```
"@context": {
   …
   "Plot":
"http://foodie-cloud.com/model/foodie#Plot",
   …
   "CropSpecies" :
"http://foodie-cloud.com/model/foodie#CropSpecies",
   …
   "creationDateTime" : {
      "@id" : "http://foodie-
cloud.com/model/foodie#creationDateTime",
      "@type": "xsd:dateTime"
   },
   "cropSpecies" : {
      "@id" :
"http://foodie-cloud.com/model/foodie#cropSpecies",
      "@type": "@id"
   },
   "originType" : {
      "@id" :
"http://foodie-cloud.com/model/foodie#originType",
      "@type": "@id"
```

Listing 1. Representation of agronomic concepts

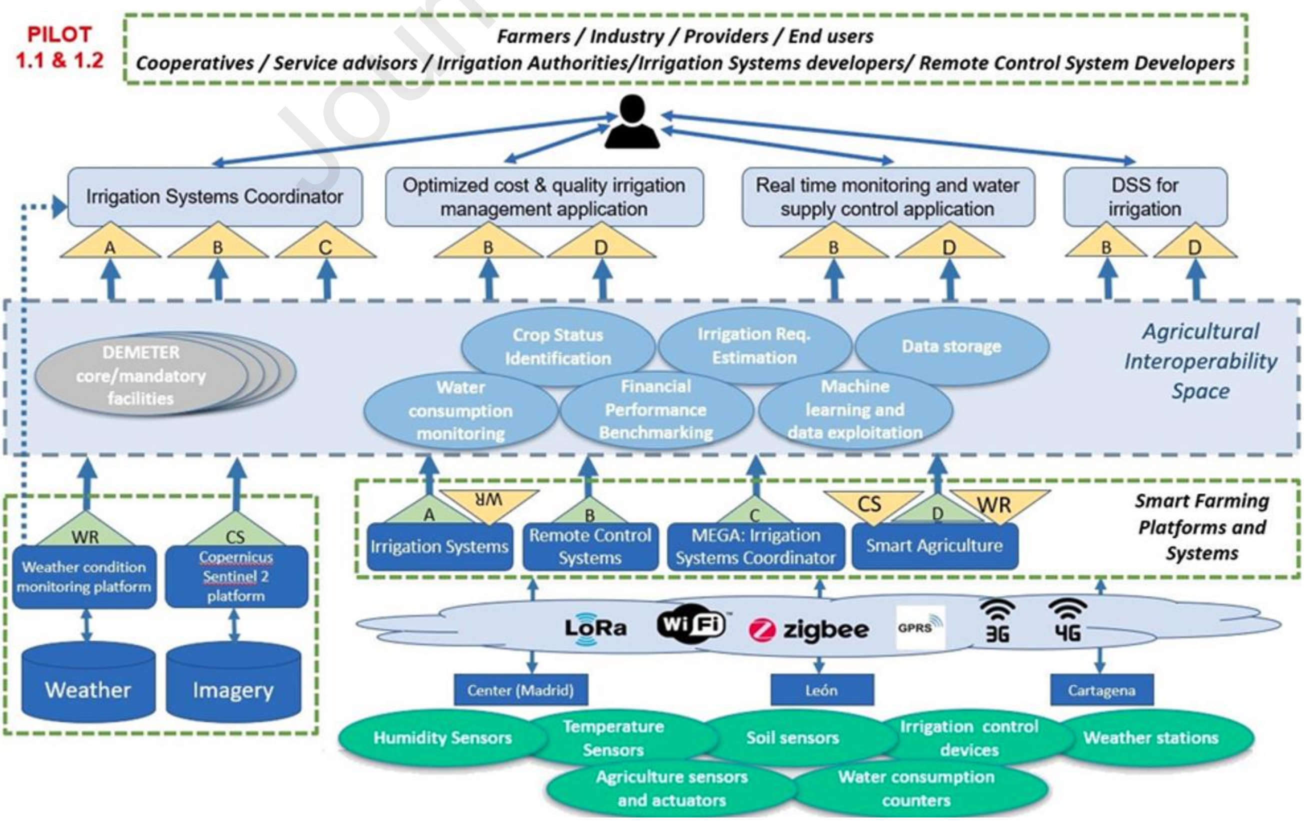


Fig. 9. DEMETER reference architecture instantiation for the Murcia pilots

Journal Pre-proof

These concepts have been mapped to AIM thanks to the reuse of standardized ontologies and dominant solutions related to the representation of agriculture features, crops, alerts, properties and systems.

6.4. System extensions and applications

This section elaborates on how the Murcia pilots are integrated in DEMETER, elaborating on the specific DEMETER enablers used, and the necessary customization of SW/HW external to DEMETER, applications, interfaces, as well as the customization of the DEMETER enablers needed.

Fig. 9 presents the instantiation of the reference architecture as deployed for the Murcia pilots. The figure illustrates the mapping of the DEMETER architecture to the pilot, the delivery of applications through the DEH and the composition of such applications from DEMETER-enabled entities, data and services. The raw resources (e.g., various types of devices) are presented at the bottom. They are connected through the appropriate communication protocols (LoRa, WiFi, etc.) to existing Farm Management Information Systems (FMIS) or IoT device platforms. These pilots integrate:

- <u>Irrigation systems:</u> deployed across the farms engaged in the Murcia pilots.
- <u>Remote control systems:</u> outdoor high performance dataloggers and controller devices for remote control and monitoring (i.e. IPEX12, IPEX16).
- <u>MEGA:</u> Irrigation systems coordinator that manages, through different web services (i.e., SOAP, REST), the connections between all the management irrigation systems that implement ISO 21622.
- <u>Smart agriculture:</u> a web-based platform based on standards and open protocols (i.e., NGSI, MQTT) that has specific modules for the integration with IoT devices, data exploitation and map-based interfaces.

To make them compatible with DEMETER and to use their data and facilities, they are paired with an appropriate entity (DEMETER enabler) that will provide an AIM compliant wrapper. The central part of the figure above conforms the DEH through which all these entities are offered. On the left, we find the DEMETER mandatory entities (grey) to be used by the optional ones (blue) needed by this pilot, where we can find:

- <u>Data storage:</u> A component having all the functionality related with database storage management.
- <u>Crop status identification:</u> This component estimates the crop status with data fusion by using parametric and machine learning techniques with different inputs (i.e., weather stations, IoT devices, imagery, etc.).
- <u>Water consumption monitoring:</u> This component monitors real time water consumption of the irrigation system with the information from the remote controllers.
- <u>Irrigation requirement estimation:</u> This component estimates the crop's irrigation needs with data fusion using parametric and machine learning techniques with different inputs (i.e. weather stations, IoT devices, imagery, etc.).
- <u>Machine learning and data exploitation:</u> This component offers machine learning and parametric techniques to be used for data exploitation, predictions and input for the decision support system.

These enablers offered by the DEH are used to compose the DEMETER enabled applications for the business solutions of the pilot, which are presented at the top of the figure:

- Irrigation systems coordinator.
- Optimized cost & quality irrigation management application.
- Real-time monitoring and water supply control application.
- DSS for irrigation.

7. Conclusions and future plans

This paper highlights the importance of developing a system that can enable interoperability across multiple heterogeneous systems, which has been noted as a critical requirement for technology development not only in the agricultural sectors. Stakeholders wishing to enter the agri tech domain, also the existing providers, need to factor the direction that the scientific, political and development community is taking in this regard, particularly to avoid walled-garden technology

Journal Pre-proof

Journal Pre-proof

approaches which take choices and power away from the farmers. Across the globe, putting the end-user/farmer in better control is becoming an almost mandated requirement (considering the revised EU Common Agricultural Policy for example). Apart from the socioeconomic aspects that this presents, technological standpoint initiatives, such as the Common European Agricultural Data Space, are gaining traction. Moreover, developments such as DEMETER are playing heavily into this field, and future developments must take this into account.

This paper proposes a reference architecture that addresses two main challenges in the agricultural domain: the lack of interoperability across a multitude of related software and hardware technologies available to farmers and agronomists, as well as the insufficient protection of farmers' interests; and the lack of suitable farmer support, including their not being able to control the usage of their data and respective knowledge generated, or to co-create integrated technology offerings suitable for their needs and compatible to their current investments. In this respect, it presents an interoperable space for smart agriculture that has been introduced by the DEMETER project. Instead of creating a new master system to integrate other platforms, DEMETER proposes an overarching approach that allows the integration of heterogeneous technologies, platforms and systems. To do so, DEMETER builds its reference architecture based on three main concepts: a Stakeholders Open Collaboration Space (SOCS) for resolving the farmers' needs to convert these needs into challenges, which are later addressed through a multi-actor co-creation process; an AIS providing all interoperability mechanisms for deploying the solution suitable to address the farmer's needs and the DEMETER Enabler Hub (DEH) that provides the components, services and devices accessible for deployment; and a dashboard with the purpose of presenting user friendly interfaces to understand and access all available resources.

The DEMETER reference architecture extends the model specified by IDSA by considering the support of AKIS, allowing for publication and consumption of information. Data interoperability is also a cornerstone aspect in DEMETER, which is tackled by the so-called AIM semantic data model by adopting well-known and standardised solutions. This reference architecture is foreseen to be validated via two rounds of 20 large scale pilots grouped in 5 clusters, the first of which addresses the arable crops domain.

The Murcia pilots of DEMETER belong to this first cluster and their first round is now being executed. The reference architecture has been deployed to both Murcia pilots to allow for the integration of heterogeneous data sources, as well as enhancing and supporting the decision-making process, mainly for communities of irrigators, also for distinct types of agricultural facilities. Based on open interfaces, it allows increased interoperability in the level of communication between administrative services, the IoT devices and the controllers they interact with. DEMETER-enablers make it possible to integrate the controllers and the sensors from other manufacturers, and allow for the establishment of a singular access point for all information. By doing so, techniques applicable to the agricultural sector can be significantly improved, and this in turn enables sustainably higher social, economic and environmental yields. Additionally, the range of services offered by the system can be expanded as a result of the achieved interoperability.

On the one hand, from a technical point of view, the homogenisation of the operation of agricultural exploitation systems has been achieved through the use of communications and data transmission standards, the integration of heterogeneous data sources, and the use of information models to harmonise specific data that does not have any linkage. The use of an information model creates a knowledge base for sharing/exposing data reliably among the managers of the irrigation communities, as well as for obtaining performance indicators and supporting farmers' decision making. On the other hand, from an agricultural point of view, tasks that affect the efficiency of production have been optimised, such as the control of the quality of the reclaimed water, the generation of alerts to improve crop development (frost, water stress or pests) or efficient use of pumping.

The evaluation findings of the first round of the 20 large scale pilots carried out will be processed and properly considered to drive the revising of the DEMETER reference architecture. The revised architecture will be validated via the second round of pilots and offer full scale semantic, syntactic and

Journal Pre-proof

technical interoperability for a larger set of existing models, devices, protocols, services, applications, platforms and systems. Moreover, additional features, such as personalised decision support and advisory services tailored to the farmers' needs are to be supported. This includes establishing an agricultural solution / business benchmarking system, which targets productivity and sustainability performance of farms, agricultural services/technologies/practices, based on farming community specific Key Performance Indicators (KPIs). Eventually, DEMETER aims to demonstrate the impact of digital innovations across multiple sectors at national and international levels and to successfully promote its outcomes to the agrifood market.

Nevertheless, there are certain limitations in the work presented in this paper and challenges that are not yet addressed sufficiently. This study is part of an ongoing complex EU project, where technologies are developed in conjunction with multiple partners with different priorities, and is still in quite an experimental phase. Therefore, bringing together such a large number of partners with the often competing technology offerings and different exploitation expectations, and addressing multiple agricultural scenarios within a singular system create a limitation in terms of the generalizability and applicability of results to particular agricultural sectors. However, it must be noted that the strategy for doing so is to demonstrate the relevance of the overall technical architecture across multiple domains. As another limitation, the proposed approach competes with very large-scale industrial players across the globe that are developing focused technologies in parallel in a rapidly expanding technical landscape. Therefore, there is no guarantee that the proposed approach will be the one that is eventually standardized and manages to dominate the agricultural domain. Finally, the presented solution is yet to be validated and verified in fully operational environments that include thousands of real end-users. This is to be fulfilled in the second round of the DEMETER pilots planned for execution in 2022, which not only aim to demonstrate the efficiency of the proposed solutions, but are also expected to reduce the aforementioned limitations as the real-world value and pertinency of the DEMETER approach achieve end-user validation.

Acknowledgements

This paper is based on work carried out under the H2020 DEMETER project (Grant Agreement No 857202) that is funded by the European Commission under H2020-EU.2.1.1 (DT-ICT-08-2019).

References

[1] Brewster, C., Roussaki, I., Kalatzis, N., Doolin, K., Ellis, K., 2017. IoT in agriculture: Designing a Europe-wide large-scale pilot. IEEE Communications magazine, 55(9), p. 26-33.

[2] Sanjeevi, P., Prasanna, S., Siva Kumar, B., Gunasekaran, G., Alagiri, I. and Vijay Anand, R., 2020. Precision agriculture and farming using Internet of Things based on wireless sensor network. Transactions on Emerging Telecommunications Technologies, 31(12), p.e3978.

[3] Boursianis, A.D., Papadopoulou, M.S., Diamantoulakis, P., Liopa-Tsakalidi, A., Barouchas, P., Salahas, G., Karagiannidis, G., Wan, S. and Goudos, S.K., 2020. Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: a comprehensive review. Internet of Things, p.100187.

[4] Bayrakdar, M.E., 2020. Energy-efficient technique for monitoring of agricultural areas with terrestrial wireless sensor networks. Journal of Circuits, Systems and Computers, 29(09), p. 1-17.

[5] Bacco, M., Barsocchi, P., Ferro, E., Gotta, A. and Ruggeri, M., 2019. The digitisation of agriculture: a survey of research activities on smart farming. Array, 3, p.100009.

[6] Islam, N., Rashid, M.M., Pasandideh, F., Ray, B., Moore, S. and Kadel, R., 2021. A review of applications and communication technologies for Internet of Things (IoT) and Unmanned Aerial Vehicle (UAV) based sustainable smart farming. Sustainability, 13(4), p.1821.

[7] Mekonnen, Y., Namuduri, S., Burton, L., Sarwat, A. and Bhansali, S., 2019. Machine learning techniques in wireless sensor network based precision agriculture. Journal of the Electrochemical Society, 167(3), p.037522.

[8] Feng, X., Yan, F. and Liu, X., 2019. Study of wireless communication technologies on Internet of Things for precision agriculture. Wireless Personal Communications, 108(3), pp.1785-1802.

[9] Bayrakdar, M.E., 2020. Enhancing sensor network sustainability with fuzzy logic based node placement approach for agricultural monitoring. Computers and Electronics in Agriculture, 174, p. 1-10.

[10] Sørensen, C., Pesonen, L., Bochtis, D., Vougioukas, S., Suomi, P., 2011. Functional requirements for a future farm management information system, Computers and Electronics in Agriculture 76(2), p. 266-276.

Journal Pre-proof

Journal Pre-proof

[11] Doshi, J., Patel, T. and kumar Bharti, S., 2019. Smart Farming using IoT, a solution for optimally monitoring farming conditions. Procedia Computer Science, 160, pp.746-751.

[12] Bayrakdar, M.E., 2020. Employing sensor network based opportunistic spectrum utilization for agricultural monitoring. Sustainable Computing: Informatics and Systems, 27, p.1-10.

[13] Triantafyllou, A., Sarigiannidis, P. and Bibi, S., 2019. Precision agriculture: A remote sensing monitoring system architecture. Information, 10(11), p.348.

[14] AshifuddinMondal, M. and Rehena, Z., 2018, January. Iot based intelligent agriculture field monitoring system. In 2018 8th International Conference on Cloud Computing, Data Science & Engineering (Confluence) (pp. 625-629). IEEE.

[15] Ouafiq, E.M., Elrharras, A., Mehdary, A., Chehri, A., Saadane, R. and Wahbi, M., 2021. IoT in smart farming analytics, big data based architecture. In Human Centred Intelligent Systems, pp. 269-279. Springer, Singapore.

[16] Iaksch, J., Fernandes, E. and Borsato, M., 2021. Digitalization and Big data in smart farming–a review. Journal of Management Analytics, 8(2), pp.333-349.

[17] Wolfert, S., Cor Verdouw, L.G., Bogaardt, M.J., 2017. Big Data in Smart Farming – A review. Agricultural Systems, 153, pp. 69-80.

[18] Evstatiev, B.I. and Gabrovska-Evstatieva, K.G., 2021. A review on the methods for big data analysis in agriculture. In IOP Conference Series: Materials Science and Engineering (Vol. 1032, No. 1, p. 012053). IOP Publishing.

[19] Noura, M., Atiquzzaman, M., Gaedke, M., 2019. Interoperability in Internet of Things: Taxonomies and Open Challenges. Mobile Network Applications, 24, p. 796–809.

[20] Bahlo, C., Dahlhaus, P., Thompson, H., & Trotter, M., 2019. The role of interoperable data standards in precision livestock farming in extensive livestock systems: A review. Computers and Electronics in Agriculture, 156, 459-466.

[21] Bonacin, R., Nabuco, O. F., Junior, I. P., 2016. Ontology models of the impacts of agriculture and climate changes on water resources: Scenarios on interoperability and information recovery. Future Generation Computer Systems, 54, p. 423-434.

[22] Sahin Aydin, Mehmet N. Aydin, 2020. Ontology-based data acquisition model development for agricultural open data platforms and implementation of OWL2MVC tool. Computers and Electronics in Agriculture, 175, p. 105589.

[23] Schuetz, C. G., Schausberger, S., Schrefl, M., 2018. Building an active semantic data warehouse for precision dairy farming. Journal of Organizational Computing and Electronic Commerce, 28(2), p. 122-141.

[24] Bazzi, C. L., Jasse, E. P., Graziano M., Paulo S., Michelon, G. K., de Souza, E. G., Schenatto, K., Sobjak, R. 2019. AgDataBox API – Integration of data and software in precision agriculture. SoftwareX, 10, p. 100327.

[25] Gallinucci, E., Golfarelli, M., Rizzi, S., 2019. A hybrid architecture for tactical and strategic precision agriculture. The 21st International Conference on DaWak, LNCS-Springer, 11708, p. 13-23.

[26] IoF2020, 2019. Reference Architecture for Interoperability, Replicability and Reuse. Available online: https://www.iof2020.eu/open-call/d3.3-iof2020-reference-architecture.pdf (accessed on September 10th, 2020).

[27] Perakis, K., Lampathaki, F., Nikas, K., Georgiou, Y., Marko, O., Maselyne J., 2020. CYBELE – Fostering precision agriculture & livestock farming through secure access to large-scale HPC enabled virtual industrial experimentation environments fostering scalable big data analytics, Computer Networks journal, 168(26), 107035.

[28] ATLAS, 2020. Deliverable D3.2 Service Architecture Specification. Available online: https://www.atlas-h2020.eu/wp-content/uploads/2020/06/ATLAS-D3.2-Service-Architecture-Specification.pdf (accessed on September 10th, 2020).

[29] Ngo, V. M., Le-Khac, N. A., Kechadi, M. T., 2019. Designing and implementing data warehouse for agricultural big data. 8th International Big Data, Springer-LNCS, 11514, p. 1–17.

[30] Bordogna, G., Kliment, T., Frigerio, L., Brivio, P.A., Crema, A., Stroppiana, D., Boschetti, M., Sterlacchini, S. A., 2016. Spatial Data Infrastructure Integrating Multisource Heterogeneous Geospatial Data and Time Series: A Study Case in Agriculture. ISPRS International Journal of Geo-Information, 5(5), p.73.

[31] Jiang, G., Grafton, M., Pearson, D., Bretherton, M., Holmes, A., 2019. Integration of Precision Farming Data and Spatial Statistical Modelling to Interpret Field-Scale Maize Productivity. Agriculture, 9(11), p.237.

[32] López-Riquelme, J. A., Pavón-Pulido, N., Navarro-Hellín, H., Soto-Valles, F., Torres-Sánchez, R., 2017. A software architecture based on FIWARE cloud for Precision Agriculture. Agricultural water management, 183, p.123-135.

[33] Kamienski, C., Soininen, J. P., Taumberger, M., Fernandes, S., Toscano, A., Cinotti, T. S., Neto, A. T., 2018. "Swamp: an iot-based smart water management platform for precision irrigation in agriculture." 2018 Global Internet of Things Summit (GIoTS), Bilbao, Spain.

[34] Roussaki, I., et al., 2020. D3.1 DEMETER Reference Architecture (Release 1). H2020 DEMETER project, Available Online: https://h2020-demeter.eu/wp-content/uploads/2020/10/D3.1-DEMETER-reference-architecture_v1.0.pdf (accessed on September 10th, 2020).

[35] Otto, B., Steinbuß, S., Teuscher, A., Lohmann, S. et al. 2019. IDS

Journal Pre-proof

Journal Pre-proof

Reference Architecture Model Version 3.0, International Data Spaces Association, Available Online: https://www.internationaldataspaces.org/publications/reference-architecture-model-3-0/ (accessed on September 10th, 2020).

[36] Bader, S., et al. 2020. The International Data Spaces Information Model – an Ontology for Sovereign Exchange of Digital Content. 19th International Semantic Web Conference (ISWC 2020), virtual conference, November 2020.

[37] Palma, R., et al., 2021. Agricultural Information Model, Chapter accepted for publication in the Springer "ICT for Agri" Book.
Journal Pre-proof

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Journal Pre-proof