INTERNET OF THINGS

IoT in Agriculture: Designing a Europe-Wide Large-Scale Pilot

Christopher Brewster, Ioanna Roussaki, Nikos Kalatzis, Kevin Doolin, and Keith Ellis

The technologies associated with the Internet of Things have great potential for application in the domain of food and agriculture, especially in view of the societal and environmental challenges faced by this sector. From farm to fork, IoT technologies could transform the sector, contributing to food safety, and the reduction of agricultural inputs and food waste.

ABSTRACT

The technologies associated with the Internet of Things have great potential for application in the domain of food and agriculture, especially in view of the societal and environmental challenges faced by this sector. From farm to fork, IoT technologies could transform the sector, contributing to food safety, and the reduction of agricultural inputs and food waste. A major step toward greater uptake of these technologies will be the execution of IoT-based large-scale pilots (LSPs) in the entire supply chain. This article outlines the challenges and constraints that an LSP deployment of IoT in this domain must consider. Sectoral and technological challenges are described in order to identify a set of technological and agrifood requirements. An architecture based on a system of systems approach is briefly presented, the importance of addressing the interoperability challenges faced by this sector is highlighted, and we elaborate on requirements for new business models, security, privacy, and data governance. A description of the technologies and solutions involved in designing pilots for four agrifood domains (dairy, fruit, arable, meat and vegetable supply chain) is eventually provided. In conclusion, it is noted that for IoT to be successful in this domain, a significant change of culture is needed.

INTRODUCTION

The Internet of Things (IoT) provides a unique opportunity for technology to transform many industries [1, 2], including the food and agriculture sector. The agrifood sector has a rather low level of uptake of information and communications technology (ICT) and a relatively high cost of data capture [3]. The stack of technologies in IoT [4] includes sensors, actuators, drones, navigation systems, cloud-based data services, and analytics delivering a variety of decision support tools, and could significantly change this sector. In Europe, large-scale deployments, or pilots (LSPs), of IoT in the context of H2020 [5] will be funded by the European Commission. This article provides an overview of the potential role that IoT can play in the agrifood sector from the perspective of designing and specifying such an IoT-based LSP, thus enabling the readers to understand the associated opportunities, constraints, and requirements of the sector that IoT can address.

In the agrifood sector, IoT technologies appear under labels such as "precision agriculture" or "smart farming." A typical example is the use of GPS to control tractors (auto-guidance of machinery) to ensure precise coverage of a field, whether ploughing, planting, or engaging in some other activity. The gradual instrumentation of all stages of the agrifood sector leads to a wealth of new data-driven services. These can provide the farmer with advice as to where to spray or apply fertilizers, when to inseminate a dairy herd, and when to capture data required by regulatory or certification bodies. Data-driven services could help the logistics and supply chain by enabling optimal route planning, facilitating recalls in food crisis scenarios, or more generally improving stock taking and ordering processes [6]. Supermarket checkout counter data and loyalty cards can integrate well with various IoT eco-system elements. While the majority of these technologies and services exist, they are only deployed in a few instances.

The European Research and Innovation agenda includes deployment of IoT through integration of these technologies across the value chain and their operation on a large scale to respond to real needs of public authorities, citizens, and business [7]. Designing and executing such LSPs will reveal potential shortcomings in the technologies and help promote IoT in agriculture. This article elaborates on the design of an LSP that aims to address several major challenges of the agrifood sector via the exploitation of IoT technologies and their adoption by all stakeholders in the food supply chain.

IOT CHALLENGES AND CONSTRAINTS FOR THE AGRIFOOD SECTOR

The uptake of IoT in agriculture faces considerable challenges, but there are also specific drivers. ICT and corresponding data driven services have penetrated in large-scale industrial farming, especially in North America, and supermarkets in most developed countries. There are many areas, even in highly developed countries, where there has been little or no uptake of IoT. The main issues affecting the uptake of IoT in the agrifood sector in Europe are elaborated on hereafter.

SECTORAL ISSUES

Heterogeneity of the sector: There are a great variety of different types of actors in the food system ranging from very large (supermarkets, seed

Digital Object Identifier:
10.1109/MCOM.2017.1600528

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and inputs suppliers, commodity traders) to very small (artisanal cheese makers, microbreweries, roadside fruit and vegetable sellers). Consequently, no single solution, whether technological, business model, or regulatory, will fit or accommodate the needs of all. Vineyards in Hungary need quite different solutions from arable farmers in North America. In the EU, for example, precision agriculture practices in arable farming have been widely adopted by large farmers in Central and Northern Europe, in order to increase production and enhance quality. However, in Southern Europe, the latest economic pressure in agriculture, the high farm segmentation and dispersion, as well as the increasing water scarcity requires the exploitation of precision irrigation techniques mainly for minimizing the usage of resources [3].

Farm sizes and capital investment costs: Larger more capital-intensive farms are much more receptive to the uptake of IoT technology, and also are recipients of such technology as part of the continuous investment in new equipment (e.g., tractors and farm equipment). Existing leading smart farming industrial solutions have either been designed for large farms, for example, MyJohnDeere (JohnDeere™), or operate only in limited geographical spaces, for example, FieldView (The Climate Corporation™) and Encirca (DuPont™), which offer services mainly in the United States and Canada. 365FarmNet is adapting the cost and type of offered services to the size of the holding, but its market penetration is still limited to Central Europe. The challenge is making IoT offerings sufficiently attractive to small-scale farmers with limited investment available for new technology and significant fears of data misuse.

Business models and business confidentiality: Appropriate business models are needed with the requisite level of confidentiality and control over data for which farmers are asking, but allowing farms and other agrifood actors to monetize the data they are producing. This is an area of contention, with large players like John Deere seeking to exploit the data captured by the machines they provide, and farmers resisting this as yet another loss of control and loss of value. The American Farm Bureau Federation has been leading a fight for farmers there to retain control and ownership of their data and recently set up the Agricultural Data Coalition.

User and societal acceptance: Education and training aspects are necessary to help end users understand the use and applicability of these new technologies. According to [8], 71 percent of EU farm managers were still operating on the basis of practical experience until recently, believing that they do not need such enhancements for their daily jobs and do not have time to learn. The adoption of smart technologies will undoubtedly be challenging for non-technologically literate persons. However, there are already education and training initiatives running across Europe aiming to disseminate IoT culture among youngsters and all stakeholders in the food chain.

TECHNOLOGICAL ISSUES

Lack of interoperability: Common building blocks, data protocols, and standards are needed for billions of devices to interoperate, and there are various appropriate standards in the agrifood domain in an attempt to reach an overall consensus in this area. Such standards exist for semantics and data modeling (e.g., AgroRDF, AgroVOC, agroXML), agri-machinery (e.g., ISOBUS), weather data (e.g., SWEET), for the supply chain (EPCIS from GS1), e-commerce retail stores (e.g., Good Relations and Schema.org), and numerous initiatives; for example, the IEEE Standards Association's IoT Related Standards; the International Telecommunication Union's (ITU's) IoT Global Standards Initiative; Onem2m, Open Interconnect Consortium; the AllSeen Alliance; and the IPSO Alliance). However, standards such as ISOBUS have not adapted to the pace of change, and most new machinery has proprietary connectivity with machinery of the same manufacturer. This leads to "vendor lock-in" and further resistance from farmers. Major initiatives are underway from both the Agricultural Electronics Foundation and AgGateway to overcome interoperability barriers. The challenge here is not the lack of standards, but the emergence of too many standards.

Lack of connectivity: A key challenge in many locations for the further development of IoT in agriculture is the lack of connectivity, that is, poor third/fourth generation (3G/4G) coverage (in spite of the much trumpeted wish to move to 5G). Low power wide area (LPWA) technologies like LoRa and SIGFOX provide a real opportunity to overcome such limitations [9], but they do not handle large datasets (e.g., originating from satellite imagery).

Data processing power: This may appear surprising, but the ability to access large-scale processing power at reasonable cost to solve complex calculations (e.g., traveling salesman type planning of field traversal) remains a challenge for small to medium farmers. The absence of data processing services significantly hinders IoT.

Lack of clear data governance: Regulations and legal frameworks are only slowly catching up with the current technological realities. Control and ownership of farm data is still contentious (as noted above). Large companies may want to conceive of themselves as "data companies" and fight initiatives to leave control of data in the hands of farmers and other primary actors.

Data security and privacy: Distinct from governance issues are the issues of security and data privacy. In a European Commission/International Data Corporation (EC/IDC) analysis of the EU demand for cloud computing services and barriers to uptake, the top five concerns among respondents directly or indirectly relate to security or privacy. This is indicative of the wider importance of such matters for IoT adoption in smartagri [7].

Despite these issues, there is a growing community of either technically literate young farmers, or hi-tech professionals and tech-enthusiasts with a strong interest in the agrifood domain. This has led to a proliferation of startups, hackathons, and many different initiatives which are gradually making the application of data science, sensors, and technology in general to agrifood an attractive and exciting prospect. The U.S.-based Food + tech Connect website is an excellent source of examples, but there are equally many such initiatives in Europe and East Asia.

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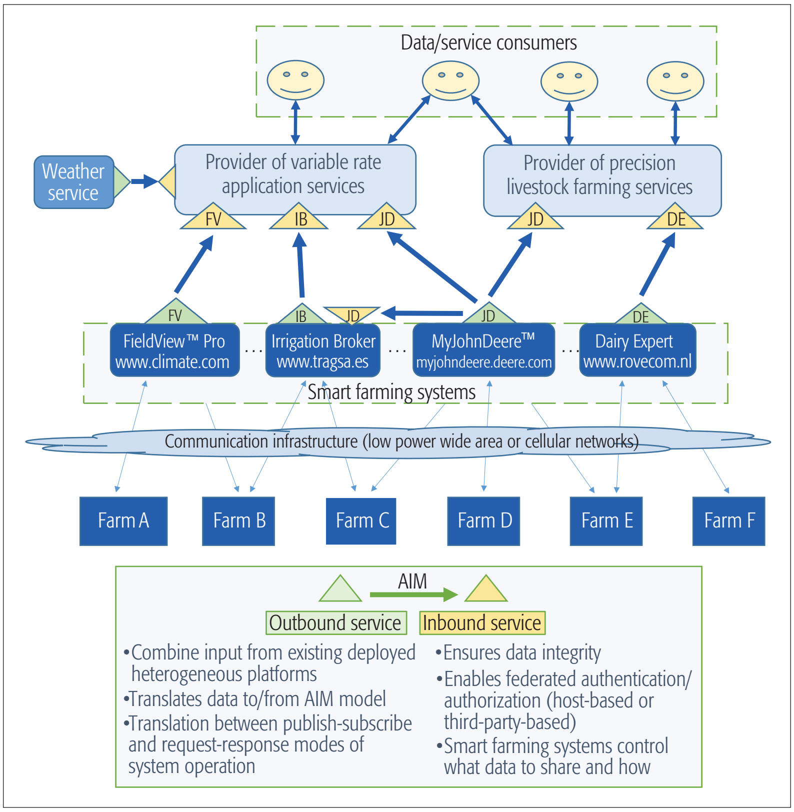


Figure 1. A system-of-systems architectural approach to an IoT-based large-scale pilot in agriculture.

In addition to tacking the sectoral and technological issues above, the LSPs need to address several objectives specific to the agrifood sector in order to convince users of the usefulness of IoT technologies in agriculture. These include the following:

- Lower production costs and increase yield quality/quantity.
- Increase productivity and animal health/welfare.
- Enable monitoring and control of plant/animal products during the entire life cycle for food traceability and increased food awareness for consumers.
- Reduce use of water and other natural resources, and improve soil quality.
- Minimize the ecological footprint and environmental impact of agricultural practice, and adapt crop management to requirements of climate change.
- Facilitate and enhance food safety/security.
- Ensure that certification schemes (e.g., organic) are effective and fraud-free across the entire food supply chain.
- Develop or enable business models adapted for an IoT ecosystem, and create new business and cooperation opportunities.

OVERALL ARCHITECTURE

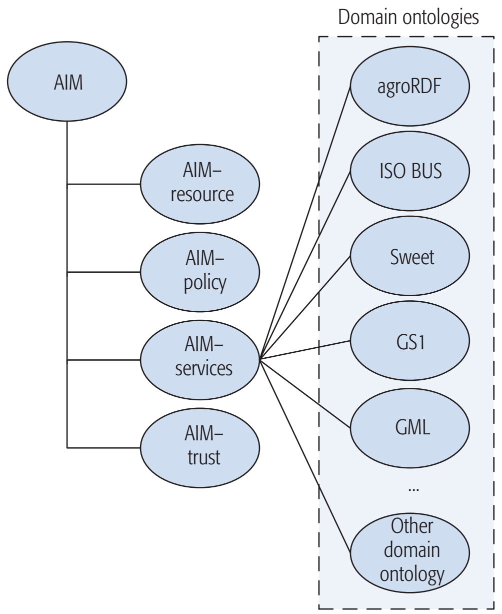
There is a variety of "precision agriculture" systems and platforms already deployed, employing many different communication, sensing, and data processing technologies. Analysis of the challenges indicate that the approach of building a new master system to incorporate others may not be feasible for an LSP due to potential scalability (e.g., maintaining state in a pub/sub approach) and governance (e.g., access to agricultural data) issues. Therefore, a system-of-systems (SoS) approach is proposed. This enables existing agriculture knowledge information systems (AKISs) to continue operating, but also allows those systems to make available and consume data from cooperating systems within the SoS. Additionally, the SoS can expose newer technologies and services that may be of interest to cooperating AKISs. This is more realistic and viable in terms of usability, market adoption, and sustainability. In order to realize this approach, the following two core functional requirements need to be fulfilled by the proposed solution:

1. Allow existing AKISs to offer their data to and consume data from their counterparts.
2. Extensive use of virtualization containers for services should be made to ensure rapid deployment once required

The proposed architecture (Fig. 1) consists of an inbound and an outbound service that support AKISs to expose and consume data, respectively. Rapid deployment is highly beneficial for survey services that might not require a continuous feed from a particular AKIS. Such a service would deploy and start an inbound service for that particular AKIS, gather necessary information, and then stop the service. The service will be packaged into a lightweight container along with all the software necessary to support self-contained deployment of the service (runtime environment, libraries for supported communication protocols, encryption techniques, etc.).

As data interoperability is of critical importance, the proposed solution provides the necessary data translation mechanisms combining the use of a semantic data model (Agriculture Information Model — AIM) along with the respective data translation/management/inference mechanisms adopting OMA Next Generation Sensors Initiative (NGSI) functional network application programming interfaces (APIs). In order to enable interoperability of heterogeneous data handling approaches, the inbound-outbound services, deployed on various AKISs, translate and exchange data based on the AIM common data format with the utilization of lightweight data wrappers/translators. For this conversion to be feasible, each AKIS needs to provide the specifications of the utilized data model-semantics, or it should parse returning content in AIM format. The AIM is not built *ab initio*, but incorporates and extends existing ontologies and vocabularies already available for this domain (e.g., agroRDF, GACS, EPCIS).

Inbound-outbound services maintain the necessary mechanisms for satisfying data security and privacy concerns (cf. below). They need to be trusted to be deployed and hosted by the AKIS on their own cyber-premises (i.e., hosting environments). This is an inherent data privacy protection feature as the owner of the data maintains the control/decision of which data are allowed to be shared with other entities. The services need to provide privacy and security functionalities, including user authentication and access authorization.



- The OWL encoded AIM ontology is defined by a hierarchy of different ontologies. On the highest level basic concepts and properties are defined that are re-used and specialized in the subjacent ontologies.
- The AIM-resource ontology describes any provisionable, controllable, and/or measurable entity.
- The AIM-Policy ontology defines the rules governing the utilization of data with respect to authorization, data access rights, and business model.
- The AIM-Trust ontology defines all aspects for representing the trustworthiness of data sources.
- The AIM-services ontology describes data derived from existing entities/platforms/AKIS in the relevant application areas. The ontology incorporates existing ontologies that are already widely utilized (e.g., de facto standards) for respective domains. Ontology mapping/matching mechanisms are necessary to translate data to these ontologies.

Figure 2. The Agricultural Information Model (AIM) structure.

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ADDRESSING INTEROPERABILITY ASPECTS

Interoperability is a core issue for IoT in the agricultural domain [10]. For a viable ecosystem to develop, a hardware provider from country A should be able to offer services to farmers in country B using software from country C. Probably the most coordinated domain-specific effort in this direction is AgGateway, an association of agriculture and agtech companies started in the United States but expanding globally. Technical interoperability is not discussed below, as the protocols and infrastructure required are not specific to the agrifood sector, but are rather addressed by domain agnostic groups like the Open Channel Foundation (OCF) with initiatives such as the Alliance for the Internet of Things Innovation (AIOTI), set up to support dialogue among the various actors in Europe.

SYNTACTIC INTEROPERABILITY

In spite of the widespread adoption of XML and more recently JSON as standard syntaxes for data sharing, because of the wide variety of legacy systems it is often expedient to export in simple formats such as comma separated variables (CSV). Electronic data interchange (EDI), specifically EDIFACT, despite its expense and complexity, still plays a significant role in some agrifood sectors, mostly for invoices and similar types of messaging. Thus, a key requirement here is that all systems provide export facilities or API access that return standard formats, typically XML or JSON, and where possible legacy systems are provided with appropriate interchange gateways.

SEMANTIC INTEROPERABILITY

There are two types of semantic standards for data sharing relevant here. There are standards for on-farm operations (e.g., ISOBUS, AgroXML) and standards for data exchange across the supply chain (e.g., GS1 EPCIS, EDIFACT). For precision farming and IoT in the supply chain, there is no shortage of standards, but rather a lack of universal uptake. One of the most successful examples is the creation of unique identifiers for bovine animals in the EU, which has been gradually extended to other dairy animals. The United Nations and Global Standards One (GS1) have an initiative to offer global location numbers (GLNs) to small-scale farmers around the world, so-called blue numbers, for participation in supply chains. In the supply chain, the GS1 EPCIS standard (for barcodes and RFID) has established itself as the dominant standard, but while the core standard is agreed, slow progress has been made to incorporate additional information concerning production methods or other characteristics. There are many different standards in existence for the description of agricultural products including AGROVOC from the Food and Agriculture Organization (FAO), CBV from GS1, the NALT thesaurus, or the CAB Thesaurus, among others. While the GACS initiative is a step in the right direction, this largely is an outcome of "research data" rather than precision farming or supply chain requirements.

The proposed approach is to use semantic technology building on existing standards, extending where appropriate, and ensuring appropriate mappings so as to produce an integrated AIM (Fig. 2), as mentioned in the previous section. This fits with the ambitions of AgGateway in their SPADE and ADAPT projects for integration of data from agricultural machinery for farm management information systems. In Fig. 3, a proposal for SoS-based integrated information management from farm to fork is shown that supports syntactic and semantic interoperability, handling data collected from different sensors/devices/platforms and modeled with various local ontologies/schemas. The system considers the data governance/ownership/privacy policies, and if the necessary rights are in place, it supports agri-data fusion and exchange of data across formats.

Most IoT architectures assume all data is written to one blackboard, and all services have access to all data. This is not realistic from a business perspective, as most actors will refuse to participate. Architectures are needed that ensure each farmer controls the data from their own farm and can determine who has access and for which service.

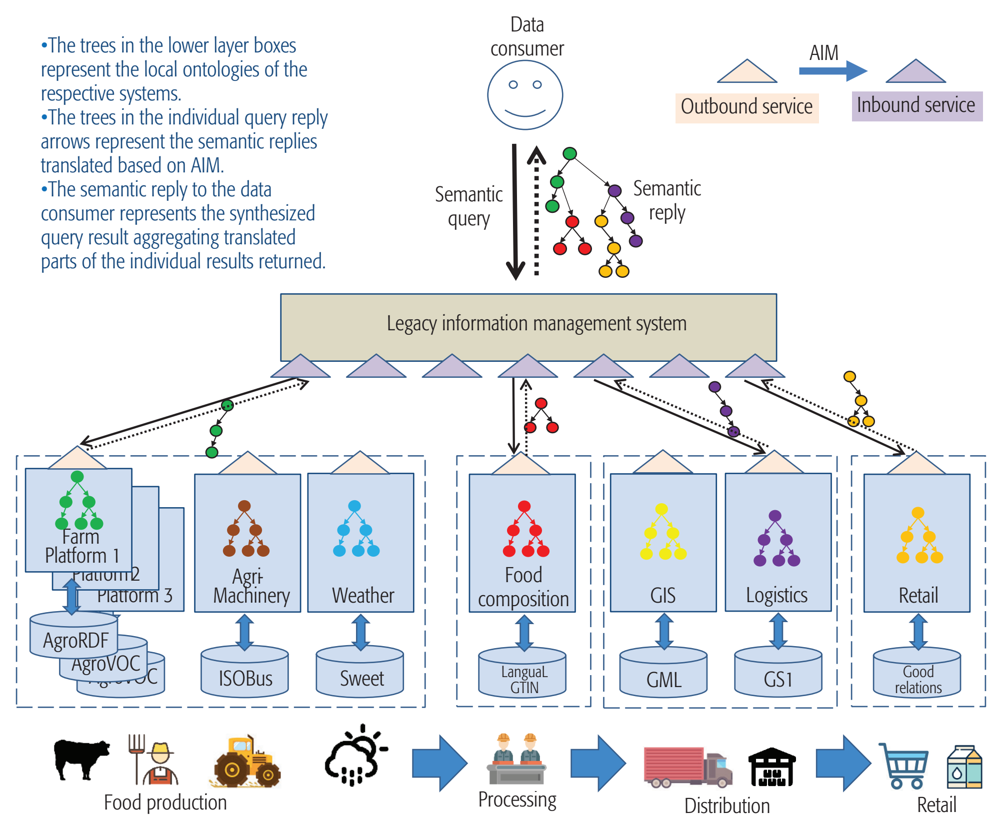
- The trees in the lower layer boxes represent the local ontologies of the respective systems.
- The trees in the individual query reply arrows represent the semantic replies translated based on AIM.
- The semantic reply to the data consumer represents the synthesized query result aggregating translated parts of the individual results returned.

Figure 3. A farm-to-fork management information system ensuring data interoperability.

OTHER CRITICAL ASPECTS FOR PILOT SPECIFICATION

NEW BUSINESS MODELS

The food chain is quickly turning into a food-and-data chain [11]. Although there have been a great many data-driven startups in the agrifood domain in the last few years, the sector is being reshaped by large corporations. DuPont, Monsanto, and John Deere have acquired various data focused startups. As the dominating stakeholders are now creating powerful positions for themselves, there may be no incentive to enable radical, transformative changes, and recent developments will not truly make use of the affordances offered by smart technologies, or explore how to reconnect parties in the supply chain in entirely new ways. The future of farming involves engaged farmers becoming active prosumers of agri-data, rather than passive consumers of data analyzed by other parties. Thus, a new connected collaborative agriculture" (CCA) farming model is needed, focused on the farmer as the primary producer of agricultural data. We envision the emergence of a data cooperative where all data collected along the supply chain will be made available via a community platform, mirroring the open data movement. This is the basis for enabling the creation of new business models that will be of financial, environmental, and social significance for all entities in the food production value chain [8]. One way is by connecting to other industries such as pharmaceutical companies, insurance companies, and consumer groups.

The core business model will be built around the components applicable for IoT general business models regarding digital products [12]. These components are: physical freemium, digital add-on, digital lock-in, product as point of sales, object self-service, remote usage, and condition monitoring, while the new "sensor as a service" business model pattern emerges. This core business model will be adapted to the various use cases and will be vertically complemented by data brokerage, as well as linked data components.

SECURITY AND PRIVACY

In spite of the emergence of different cross-world initiatives in recent years — the International Electronics Recycling Congress (IERC), ITU Telecommunication Standardization Sector (ITU-T) Study Group 20 (SG20), the IEEE IoT Initiative, and the Internet Protocol Security Option (IPSO) Alliance are just some of them — there is a lack of a unified vision on security and privacy considerations in the IoT paradigm. Requirements for the agrifood domain include data confidentiality and authentication, access control within the IoT network, privacy and trust among users and things, and the enforcement of security and privacy policies [13]. To be able to carry out IoT-based LSPs in the agrifood domain, an efficient lightweight authentication, authorization, and access control solution for smart agriculture needs to be employed, building on best practices [14], but controlling data at the data model level. The success of IoT services could be threatened if privacy by design or data minimization principles are not supported.

DATA GOVERNANCE AND OWNERSHIP

The proposed approach is to ensure that the architecture facilitates complete control of data by the primary data generator (i.e., the farmer, the transportation company, the aggregator, etc.). This would provide the participant in an IoT ecosystem with a sense of control, and thus also both conform to the privacy requirements of the European Data Protection Regulation (EDPR) and enable farmers to treat data as a potential source of income. As farmers have generally lost out in recent years due to developments in the agrifood supply chain, control of data and the ability to see this as an income stream are important incentives for participation in the IoT ecosystem.

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LARGE-SCALE PILOTS

An LSP aims to evaluate the usability and usefulness of IoT technologies in agriculture, and four pilot domains are proposed here. We describe the main focus, the respective technical challenges addressed, the IoT technologies used, as well as the agrifood applications provided. The last subsection provides a set of metrics for the evaluation of the proposed pilots in a quantifiable manner. In Fig. 4, various representative applications of the four selected pilot domains are illustrated.

DAIRY PILOT

Main focus: Demonstrating end-to-end *integration of heterogeneous data sources* throughout the value chain and *advanced decision making* for farm operations.

IoT HW/SW include: Devices/sensors for *position/location and activity monitoring of individual animals* (e.g., GPS trackers, proximity tags, neck/leg transmitters with accelerometer, rumen pH sensing) and environmental sensors (temperature, humidity, sound, gas sensors). Communication technologies include *IoT communication protocols*, such as Constrained Application Protocol (CoAP), message queueing telemetry transport (MQTT), and Advanced Message Queuing Protocol (AMQP); AND LPWA (LoRA, SigFox) or cellular networks (EDGE, HSPA, LTE, 5G). Platforms/systems and components include IoT-enabling (e.g., FIWARE Generic Enablers, components from FInish, FRACTALS, IoT6, iCore) and agri domain specific platforms (e.g., FIspace, 365FarmNet, AgroIT, Ermes, Agrocycle, Rovecom Dairy Expert). Analytics can provide advice to dairy farmers regarding animal/herd behavior (e.g., collar-based analytics, disease and pregnancy detection), and dairy quality (e.g., milk composition, quality, and quantity).

FRUIT PILOT

Main focus: Demonstrating *interoperability of IoT systems* and support for advanced learning/reasoning/prediction over several farm-related elements.

IoT HW/SW include: devices/sensors for *air/soil/water monitoring* (e.g., evapotranspiration, water content, stem water potential, stem psychrometer sensors, CO_2 gas, IR and VIS absorbance and temperature, water nitrates and conductivity, humidity, radiation, nutrient levels, pH, cation-exchange capacity, and salinity), sun intensity, wind (direction/speed), and meteorological stations networks. *Agri-machinery monitoring* (e.g., sensors monitoring via the ISOBUS, temperature, pressure, electronic noses, product barcodes readers, RFID sensors, irrigation systems controlling solenoid valves and hydrometers, fertigation actuators, autonomous solar units). *Plant/fruit monitoring* (e.g., berry growth rate; sap-flow meter, dendrometer, drone and satellite imagery data for, e.g., fruit maturation, vegetation decay, quality forecast), crop and post-harvest monitoring (irrigation, pest, and quality alarms); biophysical (LAI, fPAR, etc.), and biochemical indicators (chlorophyll estimations allow recommendation of corrective actions, e.g., fertilization, directing and commanding variable rate production technologies). Communication technologies are similar to those in the Dairy pilot. Platforms/systems and components are also similar to those in the Dairy pilot. Forecast models are: disease/pest prevention, soil condition and quality analysis/estimation, crop management, and harvest period estimation. Also included are recommendations and control of variable rate production technologies based on indicators and crops current status, irrigation related recommendations, and machinery control, as well as vehicle tracking systems (e.g., V-Track AutoID middleware).

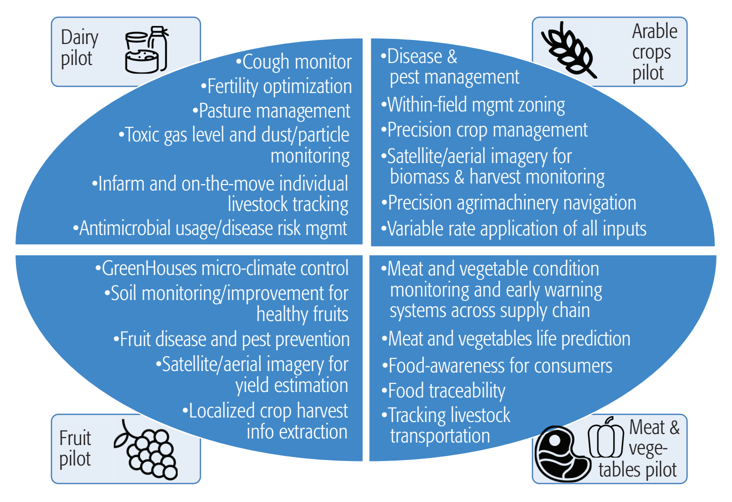

Figure 4. Applications in the various pilot domains.

ARABLE CROPS PILOT

Main focus: Demonstrating *integration of fixed IoT systems with machinery IoT infrastructure, collective decision making, and cross-country interoperability*.

IoT HW/SW used: devices/sensors include *air/soil/water monitoring* (similar to Fruit), including conventional micro-meteorological stations; soil sensors, and proximal and remote crop sensors (NDVI, near-infra-red spectroscopy, hyperspectral images); sensors for water supply, soil water; leaf wetness and nutrients sensors; delivery points, hydrant remote controls, pumping stations, raft sensors, and cameras; and irrigation systems with hydrometers). *Agri-machinery monitoring* (e.g., RTK-DGPS for precise vehicle guidance, onboard sensors, VIS-NIR spectrometer), historic satellite soil and crop variability data, sound-based pest detection, pheromone traps). Communication technologies are similar to those in the Dairy pilot. Platforms/systems and components are similar to those in the Dairy pilot. Crop factor and NDVI-based irrigation systems (both need formula and equations specifically adapted to farms, crops, and parcels using remote sensing, for example, MegaBroker (Tragsa, bb-smartworx). IoT technologies on farm machinery, farm management system (FMS) (e.g., MyJohnDeere by John Deere). Decision support systems to improve crops yield forecasting and to optimize the harvesting strategy. Yield forecasting systems (soil, crop cover, and grain quality data acquired with spectrometers, on-line grain selection system, other sensors and meteorological stations) (e.g., 365FarmNet™, OnFarm™, MyCrop, Yield Prophet).

Domain	Key performance indicators
Business & sustainability	• Jobs# created by the pilot involved parties • Innovative business models# identified by the pilots • Companies# implementing new industrial/business processes after the pilot execution • Farmers/producers# profiting by granting access to the data collected on their farms after the pilot execution • Partnership projects# created by pilot involved parties based on learning from pilot activities • Local/rural businesses# involved in pilots with cross-border companies • Local businesses# willing to expand their business beyond borders • Pilot-involved parties# willing to continue exploiting the pilot deployment • Pilot sites# that will continue using the piloted deployments • Amount of additional investments committed pilot end-users during the project oriented to reinforce their IoT-based capabilities • Agri-Industry adoption of pilot approach over 5 years
End-user side	• Adherence to Privacy-by-design across pilot components and applications • Achievement of agreed, credible security format • Rating of user acceptance per pilot through qualitative and quantitative means • Qualitative analysis of user perception of privacy and security, vulnerability issues throughout the project.
Standardization	• Standards# used across pilot deployments • Companies# adopting open platforms / standards within the pilots • Partners# contributions to (pre)-standardization activities • Standardisation committees# contributed to • Waste reduction, traceability best practice adoption • EPCIS standards# uptake
Scale and more	• Pilot sites# • Services/applications# deployed at pilot sites • Applications# deployed on top of open platforms • Demand side actors# participating in the requirement definition phase • Individual users# of applications deployed on top of open platforms • Proprietary solutions integrated against open platforms/solutions across pilots • Inclusive and with participation levels recorded • Datasets# aggregated by the pilots

Table 1. Key performance indicators across the domains of the large scale pilots.

MEAT AND VEGETABLES PILOT

Main focus: Demonstrating *interlinking of IoT systems of various stakeholders* across the entire food supply chain, *element monitoring and tracing* across all supply chain phases, and *security and privacy* of information collected.

IoT HW/SW used: For Meat, very similar to the Dairy Pilot, for Vegetables very similar to Fruit. Additional devices/sensors include RFID readers (FEIG/DTE), RFID tags (HID Global); slaughterhouse recordings (monitoring information regarding the kill time/origin of animal and safety compliance), sensors for recording the movement of vehicles. Environmental sensors for farms and trucks (temperature, humidity, luminosity, CO_2, noise, and ammonia), weight/load cells, cooling actuators (transport and shop shelve). Communication technologies similar to the Dairy pilot, plus vehicle-to-infrastructure, vehicle-to-vehicle, IoT/machine-to-machine communication protocols (technologies used for V2X communications include DSRC, cellular, RFID, IEEE 802.11). Platforms/systems and components similar to the Dairy pilot, plus livestock logistics, decision support systems for complying with legal regulations of animal welfare (e.g., Connecterra, QIfresh, VirtualVet), and fusion systems (i.e., fusion of sensor information for measurement of several parameters that are later integrated into products, e.g., farmsoft). Track & trace platforms for meat from farm to fork (e.g., fTrace and other EPCIS-based systems). Vehicle tracking systems (as above).

PILOT PERFORMANCE EVALUATION

The pilots proposed above need to be measured against well defined, quantifiable key performance indicators. Table 1 introduces an indicative set of such indicators.

CONCLUSIONS

This article aims to guide industry stakeholders and researchers who have undertaken the task to build large-scale pilots in agriculture that are heavily based on IoT technologies. The IoT-related challenges and constraints for the agrifood sector are described together with the core objectives of IoT-based LSPs. A system-of-systems architectural approach is proposed, with an emphasis on the interoperability aspects which are critical for the uptake of IoT technologies in the agrifood sector. The Agricultural Information Model approach is proposed to address semantic interoperability, and a farm-to-fork management information system solution ensuring data interoperability is outlined. There remain many challenges including the need for new business models, security and privacy, and data governance and ownership solutions, as they are critical for executing IoT-based LSPs in agrifood. Finally, a detailed account is presented of the most appropriate IoT technologies and agrifood applications to be used, as well as the main key performance indicators to which one can refer to evaluate the performance of the proposed LSPs in a quantifiable manner. The execution of such LSPs will undoubtedly promote the usage of IoT in agriculture, thus optimizing various operations in the entire food supply chain resulting in reduced effort and costs for the producers, and higher food quality and safety, as well as extended food awareness for the consumer. Nonetheless, the main barrier that needs to be overcome before IoT is extensively exploited by the stakeholders across the food supply chain is the change of culture that is needed to appreciate the advantages and opportunities provided by IoT technologies.

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