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Internet of Food and Farm 2020

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"Surprise: Agriculture is doing more with IoT Innovation than most other industries" Jahangir Mohammed [1]

4.1 Global Food Production – Setting the Scene

Agriculture is of vital importance to feed Europe in a healthy way, while Europe has also an important role in feeding the world. It is a large sector with a big social and economic impact, e.g.:

- 43% of the EU's land area is being farmed [2];
- The food and drink industry is the largest manufacturing sector in the EU, representing 15% of EU manufacturing sector turnover [3];
- Agri-food logistics has 27% share in the EU road transport [4];
- Agri-food exports contribute to more than 7% to total EU exports in goods [5];
- Europe is the largest exporter of agri-food products in the world, EU28 exports reached €122 billion in 2014 [5].

At the same time, the agri-food domain has to face very critical challenges, in particular:

- Food security is a major issue, which will become even more urgent and critical in the next decades due to the expected increase of the world population and the growing economic wealth of emerging economies.
- In the meantime, we have already exceeded the carrying capacity of planet Earth with the current way of agricultural production. Further

globalization, climate change, a shift from a fuel-based towards a bio-based economy, and competing claims on land, fresh water and labour will complicate the challenge to feed the world without further polluting or overuse (Figure 4.1).

Figure 4.1 demonstrates the perpendicular paradigm shift needed. The right-bound dashed line indicates the current trend of an increasing food demand and the associated ecological footprint that is needed. Currently we are already at the point in which this footprint is already too large (two times our planet's carrying capacity). Our challenge will be: more than doubling of the agri-food production while at the same time at least halving our ecological footprint (Source: Wageningen UR).

- Increasing consumer concerns about food safety by the continuing sequence of food calamities, which have required massive product recalls, sometimes even on a European scale. Recent examples include the horsemeat scandal [6] and the E. coli outbreak [7].
- Agri-food supply chains are characterised by complex network structures where many small and medium enterprises (farms and parts of the processing industry) trade with huge multinationals in the input and retail sector. At this, agri-food products are often considered as commodities with cost-leadership as the dominant marketing strategy, resulting in low profit margins.

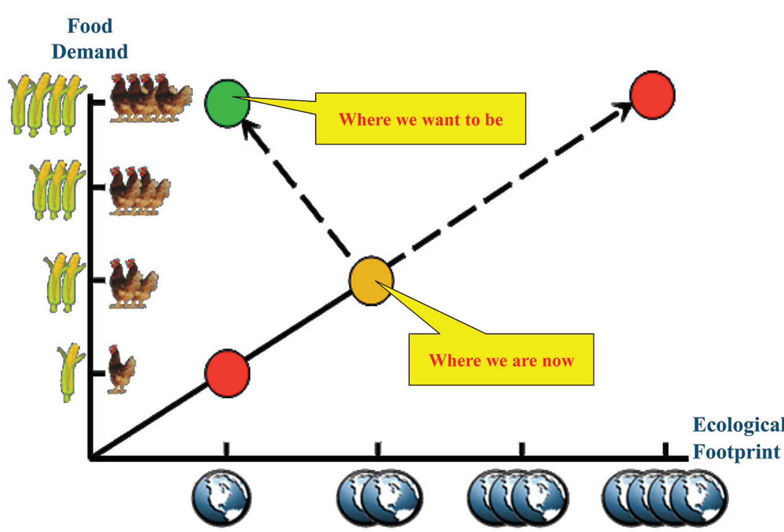

Figure 4.1 Food demand vs ecological footprint.

- Sustainable food chains are becoming 'license to deliver': roughly one-third of food produced for human consumption is lost or wasted globally [8] and food products account for an important part of the emissions produced by the transportation sector. The society does no longer accept the extremely high waste of food and the big CO2 footprint of food products.
- Growing attention for impact of food on health: consumers and society are increasingly aware that there is a strong relation between food consumption and so-called diseases of civilization, including obesity and food allergies.

Automation and mechatronics has enabled huge steps forward in in production efficiency, quality improvements and sustainability. For example, global crop yield increased by 77% between 1961–2007 [9] and the total greenhouse gas emissions of the primary production has been reduced by 23.8% in the period 1990–2012 [10]. The improvements are mainly accomplished by non-Internet technologies, such as mechanisation of field operations, breeding new varieties, and more environment-friendly cultivation techniques. Yet, the sector has to drastically increase productivity to feed the growing world population and to satisfy their changing food demands. This must be accomplished while at the same time agriculture is facing huge challenges in dealing with climate change, becoming more resource efficient, improving livestock conditions (animal welfare) and creating a circular economy, reducing waste, guarantying food safety and contributing to a healthy lifestyle of consumers.

The Internet of Things (IoT) is very promising for realizing new levels of control [11–13]. It is expected to be a powerful driver that will transform farming and food into smart webs of connected objects that are context-sensitive and can be identified, sensed and controlled remotely [14]. As such, we believe that IoT will be a real game changer in agriculture and the overall food chain that drastically improves productivity and sustainability, because it allows for [15]:

- Better sensing and monitoring of production, including farm resource use, crop development, animal behaviour and food processing;
- Better understanding of the specific farming conditions, such as weather and environmental conditions, animal welfare, emergence of pests, weeds and diseases, and creation of knowledge about appropriate management actions;
- More sophisticated and remote control of farm, processing and logistics operations by actuators and robots, e.g. precise application of pesticides

and fertilizers, robots for automatic weeding, or remote control of ambient conditions during transportation;
- Improving food quality monitoring and traceability by remotely controlling the location and conditions of shipments and products;
- Increasing consumer awareness of sustainability and health issues by personalised nutrition, wearables and domotics.

This situation is offering excellent opportunities for both the farm and food sector itself as well as for IoT providers.

4.2 Smart Farming and Food: Where We Are Right Now

The industrialisation of agriculture has expanded a lot in the previous decades. Farms and food companies are developing towards high-tech factories that are increasingly characterised by large-scale production and intensive use of technology. At the same time, those new IoT potentials are enabling new business models that were before impossible to realise. For example, the numerous startups that are following a basic trend to realise solutions that are offering fresh produce as well as to realise a very short supply chain from supplier to end-consumer [16], even leaving out steps of classical food chains. Collaboration of business partners is becoming more dynamic, competition for acquiring high quality produce at larger profit margin is increasing and delivery of information is rather a prerequisite for the realisation of innovative business models. Subsequently, data-rich management practices enabled by the IoT are of crucial importance for realising new levels of control resulting in a new jump in productivity and sustainability [17]. Some important advances in various domains (see Figure 4.2) pave the way for this breakthrough.

Precision Agriculture and Smart Farming

Precision Agriculture is about the very precise monitoring, control and treatment of animals, crops or m^2 of land in order to manage spatial and temporal variability of soil, crop and animal factors. In the previous decade so-called precision agriculture techniques have been introduced successfully [18]. For example, using satellite data, tractors can be very precisely located and steered making it possible to increase labour productivity especially for bigger machines: a 24 meter broad spraying machine requires advanced guidance equipment in order to avoid overlap and instability of spraying booms. By precise application of pesticides and fertilizers efficiency is increased, simultaneously reducing pollution. Another example from livestock

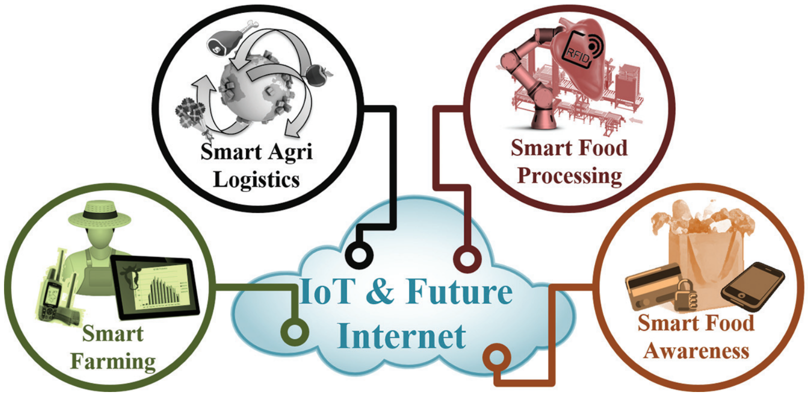

Figure 4.2 The various smart agri-food domains are increasingly integrated by the IoT and Future Internet technologies.

production is where RFID technology makes it possible for the amount of concentrate feed to be based on measured milk production for each individual cow. However, Precision Agriculture is adopted only by innovative farmers and the intelligent usage of precision farming data is still rather limited. At this, integration, ease of use and affordability are crucial bottlenecks [19]. Moreover, there are a lot of opportunities for the use of new sensors in the field and stables.

Smart Farming goes beyond the concept of Precision Agriculture by basing management tasks not only on location but also on data, enhanced by context- and situation awareness, triggered by real-time events. Real-time assisting reconfiguration features are required to carry out agile actions, especially in cases of suddenly changed operational conditions or other circumstances (e.g. weather or disease alert). These features typically include intelligent assistance in implementation, maintenance and use of the technology.

Figure 4.3 summarizes the concept of smart farming along the management cycle as a cyber-physical system. In this picture, it is already suggested that robots can play an important role in control, but it can also be expected that the role of humans in analysis and planning is further taken over by machines so that the cyber-physical cycle becomes fully autonomous. Of course, humans will still be involved in the whole process but probably at a much higher level of intelligence.

This role of farming robots is recognized in the forecasted supplies of service robots. It is expected that agriculture will be at the second place

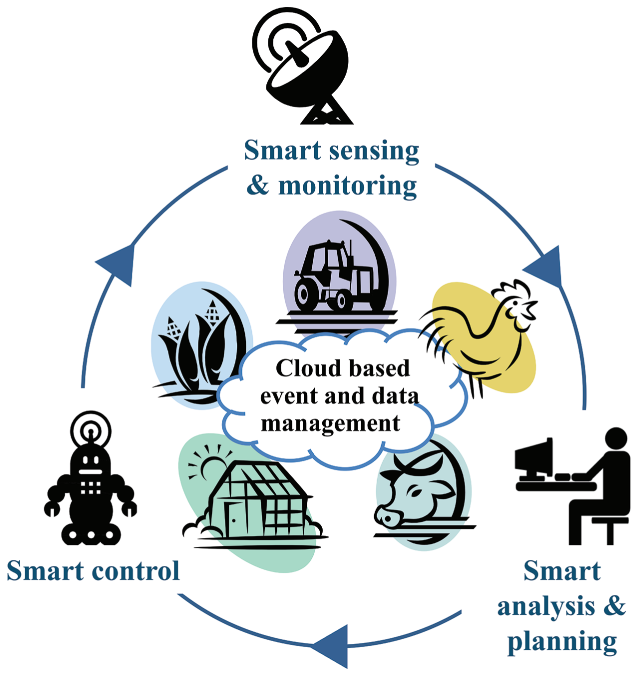

Figure 4.3 The cyber-physical management cycle of smart farming enhanced by cloud-based event and data management [21].

for demanding new service robots for professional use in the period of 2015–2018 [20]. This trend of an increased availability of high-tech devices will also facilitate to realise synergetic effects for IoT powered solutions, while different agri-food innovation fields can be considered as innovation drivers.

Smart Logistics: Food Traceability, Safety and Quality

Handling of food imposes the dimension of perishability upon all agri-food chain steps when planning and managing transport and storage. Logistic decisions need to be based on the underlying fact that quality characteristics are changing over time and due to environmental conditions. Unique identification of individual food items is rather complicated in terms of labelling, costs in relation to its value and real-world handling of food in cases, pallets and shipments. Therefore, produce and related packaging units are aggregated for being able to properly manage logistics, while virtualisation of shipments and its items, cases and pallets directly facilitates forwarding and storage.

The IoT provides sophisticated solutions for tracking and tracing as well as for remote management of shipments and products from production to the end-consumer. Figure 4.4 illustrates that such solutions allow supply chain actors to monitor, control, plan and optimize business processes remotely and in real-time through the Internet, based on virtual objects instead of observation on-site.

Food companies are obliged by law to trace products back to their origin and to track the ongoing location of products. This has forced companies worldwide to implement coordinated traceability systems along the food supply chain. However, food traceability is currently still often achieved by conventional systems, focusing on a single company or a specific part of the supply chain and using too basic technologies, e.g. product labelling, Electronic Data Interchange (EDI), email, paper trails [22]. Due to cost-benefit considerations, available RFID applications focus on container or pallet level, while single items are identified by barcodes. In most existing systems, traceability data are passed from one partner to the next one, while each partner records the supplier and customer of specific products ('one step forward

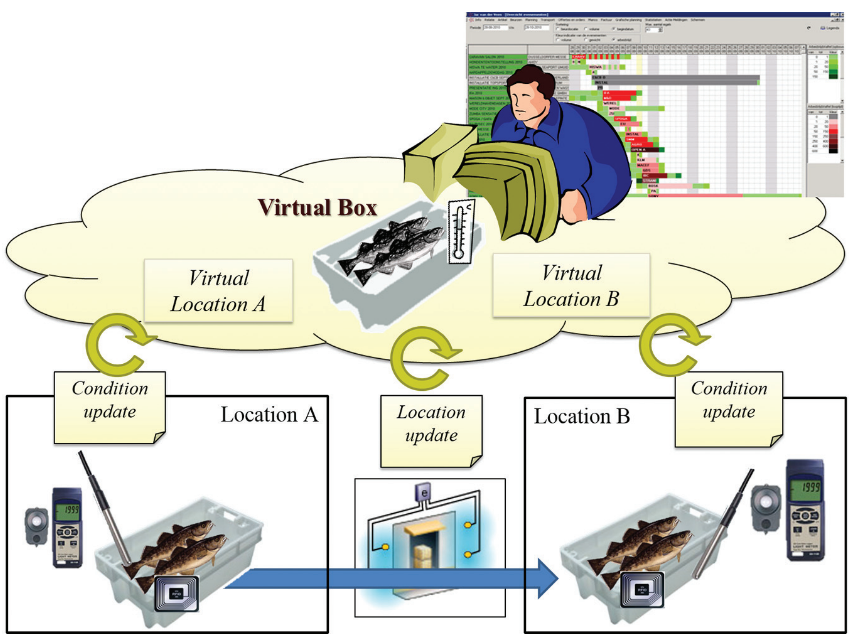

Figure 4.4 IoT enables the virtualization of agri-food supply chains: Example logistics of fresh fish, adapted from [14].

and one step back principle') [23]. There are some examples of Electronic Product Code Information System (EPCIS)-based traceability systems, which capture events of food items passing through a supply chain network, store these on one or more EPCIS-repositories and enable querying these events using appropriate security mechanisms [23–25]. Yet such solutions are still often implemented rather as closed systems than as open solutions serving dynamically changing business partners.

Sensor technologies are increasingly used for food safety and food quality management [26–28]. Temperature sensors for cold chain monitoring are common practice. Also sensors for other parameters including humidity, light, and ethylene are increasingly used. Furthermore, the majority of applied sensors are still fixed sensors and data loggers that are used to determine the causes of quality problems afterwards. The adoption of wireless sensors, especially Bluetooth, Zigbee, Wi-Fi and GPRS, is still in its infancy. The affordability of wireless sensors beyond temperature is a critical issue for wide-scale usage. Furthermore, many promising sensor technologies are still in an experimental stage of development, e.g. most chemical and bio sensors, electronic noses and Lab on a Chip [29, 30]. As a consequence, the microbiological quality is still measured in traditional laboratories, resulting in limited timeliness of food safety information. There are also solutions that add predictive analytics to quality monitoring solutions to determine remaining shelf life as well as to actively influence ripening processes, e.g. [28, 31–33].

Smart Food Processing and Manufacturing

Food processing plants are currently very much centrally controlled, which results in a limited flexibility. Application of IoT in food factories will be based on a more decentralised control concept. Machines become cyber-physical systems with embedded intelligence and local data processing and that communicate directly with other machines [34]. In such smart food factories, machinery is increasingly autonomous, managing its own service and maintenance requirements and adapting instantly to new production requirements. This approach is promoted by recent initiatives like the Industry 4.0 and Factory of the Future.

Smart Food Awareness

Consumers' trust in food, food production, the origin of food, and the actors involved is a core requirement for the functioning of European food markets and the competitiveness of industry involved. With the experience of scandals in mind, consumers increasingly expect transparency on which trust can be build. Transparency is not meant to know everything but to create awareness on the issues consumers are interested in, involving information on the safety and quality of products and processes, and increasingly on issues around environmental, social, and ethical aspects.

The IoT is rapidly changing the way of communication between consumers and food businesses. Having this in mind, the SmartAgriFood project has introduced a conceptual architecture for the Internet of Food and Farm [21], which is visualized in Figure 4.5. This can be considered as a kind of backbone for smart food awareness facilitating the feedforward as well as backward communication, finally required for making information available.

The majority of consumers currently have access to a wealth of food-related smartphone apps, including personalised nutrition advices, food traceability, recipes and purchasing support (including webshops). These applications are increasingly making use of connected sensors, wearables like smart watches, equipment at home (e.g. refrigerators, weighing machines) and outdoor equipment (e.g. in canteens, restaurants, super markets, fitness clubs). However, most consumer IoT applications related to food focus on specific functionalities and data, while the information exchange with other systems is limited.

4.3 Farming, Food and IoT: Where We Are Going

The previous section shows that, although there is a good technology base for application of IoT in farming and food, so far current IoT applications and technologies in the agri-food domain are still fragmentary and lack seamless integration. Especially more advanced solutions are in an experimental stage of development.

Operational applications are mainly used by a small group of innovators and still focus on basic functionalities at a high granularity level. However, we expect that this situation will change rapidly in the coming years. IoT technologies are currently maturing fast and most recently, IoT is in the spotlights of both users and technology providers in the farming and food domain. As a result, important advancements will be achieved, especially concerning:

- Ensuring the integration of existing IoT solutions with open IoT architectures, platforms and standards;
- Scaling-up the usage of interoperable IoT technologies beyond the innovators, including simplification of existing solutions to ensure attractiveness for the mainstream farmers and food companies;

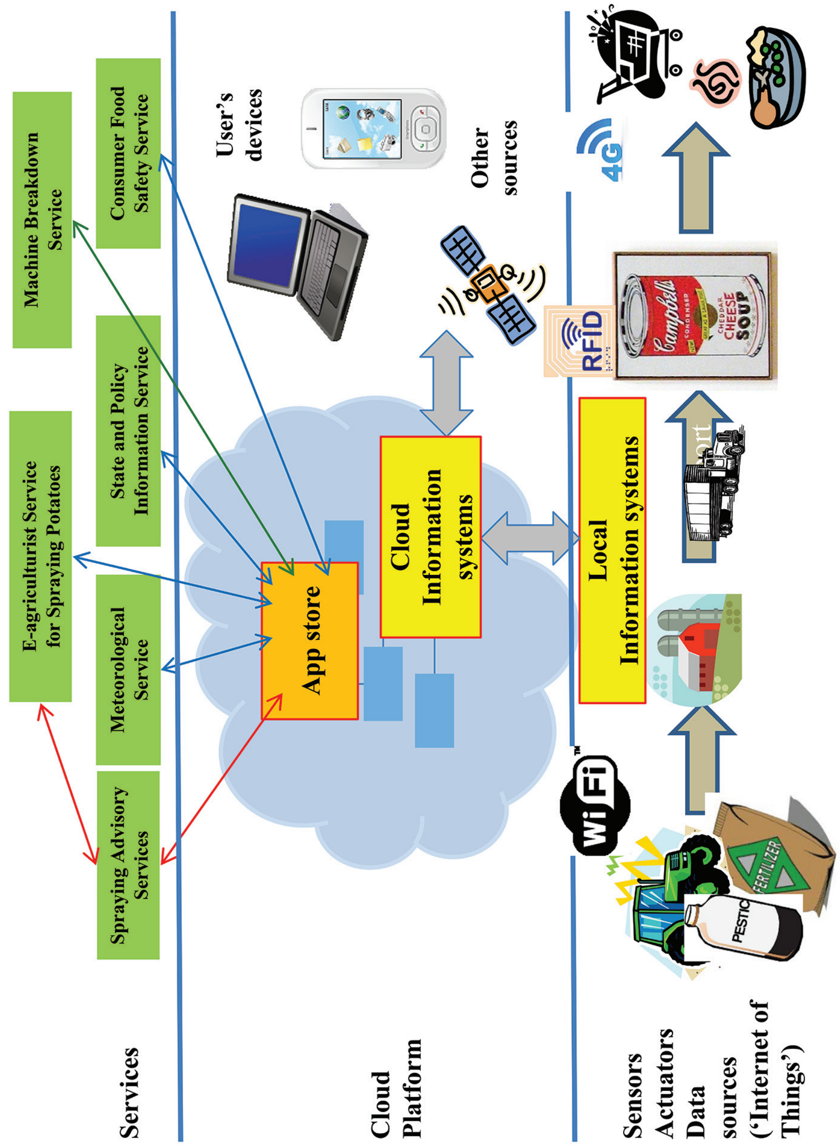

Figure 4.5 Conceptual architecture for the internet of food and farm as developed in the SmartAgriFood project.

- Further improvement of IoT technologies to ensure a broad usability in the diversity of the agri-food domain, e.g. different climate conditions, crop and soil types.

These technology developments are expected to drastically advance the development and application of the information technologies that were introduced in the previous section:

- ***Precision Agriculture*** will be extended to Smart Farming, in which a farm becomes a smart web of interoperable farm objects. A major improvement that will be added, is the seamless integration of sensing and monitoring, smart analyses and planning and smart control of farm operations for all relevant farm processes ('whole farm management perspective').
- ***Tracking and Tracing*** systems will develop towards end-to-end visibility and real-time tracking and tracing on a fine granularity level, e.g. up to individual products. Moreover, traceability will be increasingly integrated with smart sensing systems and consequently add data about product features, production methods, and ambient conditions.
- ***Food Safety and Quality Management*** systems will transform from a defensive, reactive approach towards a proactive approach, in which food chains can be monitored, controlled, planned and optimized remotely based on real-time information of a broad range of relevant parameters. To achieve this, more types of sensors will be put into practice, the timeliness of sensor information will be increased, the interoperability and thus end-to-end visibility of sensor data will be improved, more advanced remote control will be realized by implementing new actuators, and more intelligence will be added to food safety and quality management, for example: early warning in case of food incidents, rescheduling in case of unexpected food quality deviations and simulation of product quality based on ambient conditions (resulting in e.g. dynamic best-before dates).
- ***Food Processing and Manufacturing*** will increasingly be transformed into agile control systems in which processing machines function as autonomous connected objects with embedded intelligence. This will especially be achieved by integrating new and cost-effective sensors for real-time monitoring of processing activities, ensuring machine interoperability, and implementing algorithms for early detection of food safety and quality issues.
- ***Consumer Food Awareness*** will develop towards a fully consumer-centric approach that combines IoT technologies for different application

areas, including Smart Homes, Smart Shopping, and Smart Health and Leisure. These applications will combine food-related information from different stakeholders for personalised food intake advices.

IoT allows for the decoupling of physical flows and information aspects of farm and supply operations [14]. Farming processes and food supply chains can be monitored, controlled, planned and optimized remotely and in real-time based on virtual objects instead of observation on site.

Hence, farming and food will be transformed into smart webs of connected objects that are context-sensitive and can be identified, sensed and controlled remotely. This is expected to change agri-food processes in unprecedented ways, resulting in new control mechanisms and new business models such as:

- ***Data-Driven Farming***: IoT will help farmers to change from 'management by gut feeling' towards 'management by facts', which is of crucial importance to survive its increasingly demanding business environment. The IoT sensing and connectivity technologies allow to feed decision-making tools with timely and accurate operational data.
- ***Circular Economy/Green Farming and Food***: IoT will facilitate the control of using and distributing resources and it targets at a new dimension of symbiosis within the sector of food and farms. Collaboration with different industries can be facilitated that can supply their waste e.g. in form of heat, water, pressure or fertilizer. While also classical symbiotic systems like aquaponics will highly benefit from new IoT enabled control solutions facilitating distributed and autonomous operation.
- ***Autonomous Farm Operations***: IoT will improve the connectedness and intelligence of farm automation. As such it will enable farm equipment to become autonomous, self-adaptive systems that can operate, decide and even learn without on-site or remote intervention by humans. Examples are automated precise control of farming equipment, weeding robots and self-driving tractors.
- ***Demand-driven Farming***: IoT will enable farms to adjust and very accurately predict the volume and quality of supply by the precise and timely monitoring and control of production processes, also considering new interaction models that will communicate, feedback and predict the demand stemming from business as well as consumer side. As a consequence, farms can depart from the traditional supply-oriented, cost-price driven, anonymous approach to a value-based, information-rich

approach in which demand and supply continuously are matched, both in offline and online distribution channels and combinations.

- ***Outcome-based Agricultural Services***: IoT will significantly improve the possibilities to measure and control farm processes. As a consequence, farming will increasingly shift from competing through just selling products and services, to the ability to deliver quantifiable results that matter to customers, e.g. crop yield, energy saved or machine uptime [35].
- ***Urban Farming***: IoT will support to situate fully-controlled indoor food production in urban areas close to the consumers. It will combine the advanced sensing and actuating technologies of IoT with new cultivation technologies for indoor farming (especially hydroponics, lighting).
- ***Agile Food Factories***: IoT will enable a decentralised and flexible control concept for food processing by adding food sensors, local data processing and intelligence, and connectivity to food processing equipment.
- ***Virtual Food Chains***: IoT will enable to virtualize food supply chain management, which allows for advanced remote (re)planning, monitoring and control capabilities and for new business models, for example: specialised virtual orchestrators that provide added value services and local-for-global trade by SMEs.
- ***Personalised Nutrition***: IoT will allow for nutrition monitoring and personalised advices by using smartphones, that make use of connected sensors, wearables like smart watches, equipment at home (e.g. refrigerators, weighing machines) and outdoor equipment (e.g. in canteens, restaurants, super markets, fitness clubs).

4.4 Challenges

As seen in the previous sections, ICT technologies and IoT in particular are rapidly changing farming and the food industry. They have the potential to bring in the future, through large-scale deployments, huge benefits in the form of a more sustainable agriculture, ensuring food security with a lower environmental impact and guaranteeing healthier food production. However, reaping the full benefits will require overcoming certain IoT related challenges and barriers, both from technical and non-technical perspectives. At the same time, these difficulties bring new opportunities for technological development and value creation taking into account different types of stakeholders.

4.4.1 Technical Dimension

Speaking from a technical perspective, without trying to be exhaustive, the application of IoT to farming and food chains faces a series of challenges [15] such as:

Interoperability and Standardisation

Proprietary architectures, platforms and standards represent a barrier for the wide adoption of IoT in the agri-food sector due to the risks associated to vendor lock-in, incompatibility with other systems, etc. One of the challenges in the agri-food sector is to properly capture its particularities in the definition of new global, open standards and the alignment with existing standardisation initiatives from different stakeholders, stemming either from ICT (e.g. facilitated by the ETSI) or from agri-food (e.g. AEF, AgGateway, AgXML, GS1, ISO, UN/CEFACT) that need to be continuously aligned. In farming and food applications, one has to take into account farm management and traceability systems, agricultural machinery information exchange (including fleet management), and in general the specific data lifecycle (generation, collection, aggregation, visualization).

Enabling IoT Devices

Many of the benefits promised by IoT, including continuous and fine-grained monitoring of parameters and variables, will only come through technological breakthroughs such as the increase of computational power enabling edge computing/analytics, together with the drastic decrease of energy consumption in sensors and actuators to become (almost) energy-autonomous devices. The large-scale scope of farming applications also claims for more intelligence in the devices deployed in the field, including self-configuration and self-management capabilities. In traceability and food safety scenarios there is a clear challenge in developing new and cost-effective sensors and communication technologies, as for instance current biosensors, as well as RFID and NFC tags are not always viable (compared to the cost of the food product), in particular when targeting fine granularity, possibly at the individual product level. Further attention needs to be dedicated to the device characteristics, since food is rather a commodity with low profit margins and short lifetimes. Compared to tangible products from other sectors (e.g. clothing, furniture, multimedia), direct pairing of IoT with fresh produce is rather impossible often-requiring additional packaging. IoT potentials are not necessarily directly transferrable to food and farm, asking for additional efforts and costs, assuring that enabling IoT devices will neither be harmful to the environment, nor the consumers.

Enabling Network, Cloud and Communications

Connectivity is essential for making the best of IoT. However, IoT-intensive precision farming applications take place at food production (farms, aquaculture facilities), which are located in rural areas, where broadband coverage is still far too low, as only 4% of the rural European population has access to 4G connectivity, compared to 25% in towns and cities [36]. The massive deployment of smart devices will demand architectural changes in the communication networks (even at the Telco level) able to cope with specific data generation patterns and to rapidly adapt to changing traffic situations, thus bringing the need for advanced SDN/NFV technology. At the same time, agri-food is asking for IoT devices with a low power communication profile, even if this will reduce bandwidth and communication frequency, giving technologies like LoRa already quite some attention.

Information Services

Generation and collection of data is just the beginning in IoT applications. Extracting value from the data, in the form of meaningful and actionable information for the users, is the final goal. In this regard, although there are already good application examples, information services in the agri-food domain are still in an incipient stage. Short-term developments are mostly aimed at decision support systems, based usually on rules engines. More advanced data analytics, allowing for instance predictive modelling and production planning based on the demand (thus enabling *demand-driven farming*), are still a challenge in most agri-food applications. At this, object data has to be combined with a wealth of (3^{rd} party) archives such as historical and forecasted meteorological data, satellite data, soil-, water- and air-analyses, logistic systems, and data on prices, logistics, retail, food service, and consumers, diets, etc. In this context, the usability of the information services is also of high interest: farm management systems should be easily adaptable to holdings of different sizes, and with a low learning curve for the user, while facilitating interoperability for horizontal and vertical collaboration of business partners in the agri-food chain.

Data Security

As explained in Section 4.3, farming and food chains (following the trend in other industries) are becoming more and more data-driven, so data becomes a precious asset. Indeed, the data captured by farming machinery potentially conveys a large amount of information, which is critical to the farmers, such as soil fertility and crop yield, so farmers must have strong guarantees on the protection of their data, in particular in cases where such data is stored (and possibly processed) in cloud-based services. As a consequence, many users are currently concerned about data ownership, privacy and security, which too often results in a lack of confidence and a 'wait-and-see' attitude. On the other hand, aggregation of data from different farms has the potential for generating huge added value. However, farmers must understand clearly the benefits they will get from such aggregation, as well as having the guarantee that their individual data is properly protected. In other words, Digital Rights Management solutions must be brought to the farming domain, in particular for scenarios of data aggregation and data sharing. This will also facilitate a promotion of open data initiatives for agri-food purposes as well as enabling an inter-sectorial collaboration.

From a technical security perspective, there are additional challenges to be considered in the domain of ***trusted data***: the integrity and authenticity of the data generated and stored must be guaranteed. In traceability/safety applications, this is relevant to the origin of the product as well as the processing undergone, whereas in farming scenarios it is crucial, for example, in insurance-related issues. Trustworthiness requirements demand challenging solutions, such as low cost authentication mechanisms for devices/machines.

At the consumer side, security issues have to do more with personal data, thus bringing privacy at stake. For instance, IoT applications related to personalised nutrition imply privacy challenges because of personal and behavioural data captured from wearables, smartphones, etc.

IoT Platforms

As outlined in [37], there are numerous IoT platforms, stemming from open source initiatives as well as representing commercial IoT platforms. Besides the challenges with respect to governance, connectivity, fragmentation, interoperability, and stakeholders, it is emphasised that the need for decision support at the application level to capitalise on the IoT, requires a loosely coupled, modular software environment based on APIs to enable endpoint data collection and interaction. This is specifically true for small- and medium-sized companies representing the majority in farming as well as parts in the food chain. A particular IoT empowered app might be enough to help solving a very particular problem. Apps could help to process or interpret data and make suggestions or give advice. For example: sensors in the field are

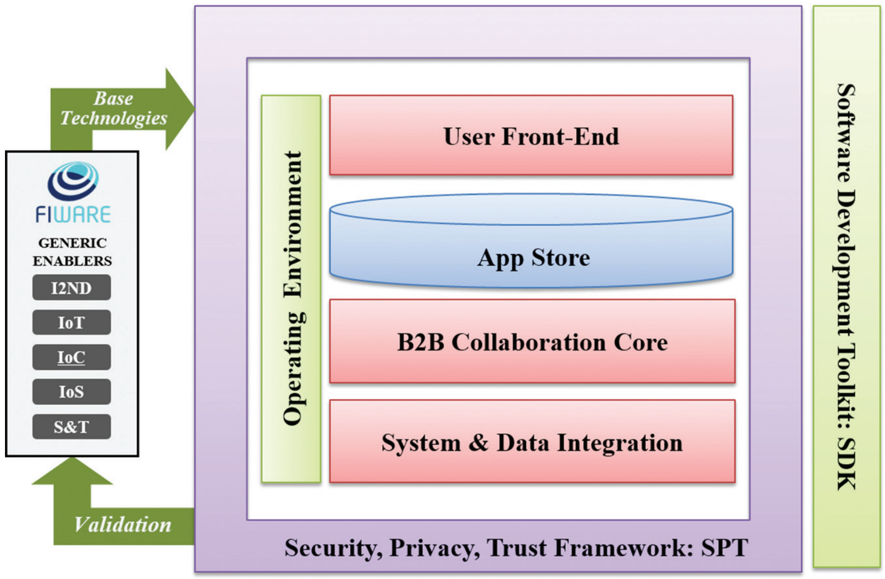

Figure 4.6 High-level picture of the FIspace architecture based on FIWARE GEs [38].

measuring the condition of the soil and consolidate this data in an app that is also predicting rain. As a consequence, the farmer is advised against spraying his field that day.

Therefore, the FIspace project has proposed an overarching architecture for enabling such kind of interactions, resulting in a multi-sided business-to-business collaboration platform [38], which is visualised in Figure 4.6. FIspace uses FIWARE Generic Enablers (GEs) but has two particular extensions for business collaboration: the App Store and the Real-Time B2B collaboration core. These key components are connected with several other modules to enable system integration (e.g. with IoT), to ensure Security, Privacy and Trust in business collaboration and an Operating Environment and Software Development Kit to support an ecosystem in which Apps for the FIspace store can be developed. The FIspace platform will be approachable through various type of front-ends (e.g. web or smartphone), but also direct M2M communication is possible.

4.4.2 Non-Technical Dimension

Besides the (non-exhaustive) technical challenges introduced above, from a non-technical perspective it is worth to mention other issues that are crucial towards the full development of IoT applications in farming and agri-food chains [15].

- ***Business models***: the common trend towards data-driven value chains opens the door to new, disruptive business models in traditional sectors such as farming and food industries. However, the sustainability of IoT-based businesses, both for the supply (providers of IoT technology) and demand (agri-food users) stakeholders must be investigated, specifically in the context of large-scale deployments. From the point of view of the users, the quantifiable benefit and profitability must compensate for the cost of acquiring, operating and maintaining the IoT solutions. Upfront costs of acquiring the IoT platforms and services are currently a real barrier preventing wider adoption, in particular by small-sized farms.
- ***Societal aspects***: IoT-based solutions for the agri-food sector still must prove their value massively to the users. IoT technologies enable to capture large amounts of data nearly in real time. However, data must be *beneficial to and useable for farmers* and all the stakeholders across the food chain. The benefits of the technology must be brought to real farming scenarios, thus dissemination and awareness are essential. An added difficulty in this regard is the heterogeneity of the agri-food value chain, including a large variety of holdings with many different sizes. In addition, to get the full benefit of IoT in farming applications it is essential that the users have certain digital skills. Currently, half of the EU population is not properly digitally skilled [36]. Thus, education and training in digital skills is essential to avoid creating a digital divide in the food and farm community. Farming cooperatives could play a key role in this regard.
- ***Policy and regulations***: policies will play an essential role in the widespread deployment of IoT-based innovations in farming and food chains. In line with the Digital Single Market strategy [39] of the European Commission, they must help in lowering the existing barriers, which are slowing down the adoption of IoT. Just to mention a few which are directly related to some of the challenges/barriers mentioned above:
    - Formulating clear security/privacy policies for protecting the farmers' data from unauthorised disclosure and for controlled and secure access to authorized third parties
    - Supporting the faster rollout of broadband internet access in rural areas.
    - Enhancing digital literacy skills and inclusion.

- ***Stakeholder involvement***: We observe the changing roles of old and new software suppliers in relation to IoT, big data and agri-food. The stakeholder network exhibits a high degree of dynamics with new players taking over the roles played by other players and the incumbents assuming new roles in relation to agricultural data, information and knowledge. IoT in particular also entails organisational issues of farming and the supply chain. Further technological development may likely result in two supply chain scenarios from a stakeholder perspective. One with further integration of the linear supply chain in which farmers become franchisers. Another scenario in which farmers are empowered by IoT and open collaboration. The latter would enable also small stakeholders to easily switch between suppliers, share data with government and participate in short supply chains rather than integrated long supply chains.

4.5 Conclusions

The envisaged Internet of food and farm in the year 2020 is not just a rudimentary vision, but a path for research, technological development and most importantly for innovation. New IoT based solutions that are making an optimal usage of digital devices and the virtual world in challenging as well as harsh environments are promising a huge impact for agri-food business, technology providers and last but not least for all of us as consumers. Innovative solutions will pave the way helping to feed the global population, reducing emissions and resource usage per kg of food as well as avoiding empty trips of transport capacities with all its impact on CO2 emissions and infrastructure maintenance. At the same time, consumers can become more aware of the overall agri-food chain that will help them to make informed decision when selecting specific produce. This can enable the opportunity to present consumers the full benefit of premium, organic and upcoming sustainable production methods as well as offer possibilities of better handling fair trade for farmers, hence facilitating their informed decisions.

As outlined before, the promising potentials of IoT technologies need to be based on an integrated usage of existing and mature methodologies and approaches that are already widely applied in the agri-food sector. Especially precision agriculture, traceability and food safety are cornerstones that are already part of the daily farm and food business practices. However, technology is still fragmented and data-rich management practices are not yet sufficiently in place, hampering to achieve a full extent of a symbiotic farm and food systems that are aiming at a continued increase of yields as achieved in the years before by non-Internet technologies. At the same time, IoT can be the key enabler to handle issues in relation to climate change, animal welfare and contributing to a healthy lifestyle of consumers.

Therefore, the potentials of an Internet of food and farm can enable e.g. autonomous farm operations, demand-driven farming and production as well as providing a personalised nutrition also based on virtual food chains. This will require technological and non-technological advances, while related difficulties will bring new opportunities for technological development and value creation. On the one hand, we need to work on data centric issues (e.g. interoperability, standardisation, security, service creation), while also finding new solutions to classical problems of using IoT devices and wireless communication in harsh and rural environments. On the other, heterogeneous types of stakeholders need to be empowered with the right digital skills, while policy and regulation have to be supportive in lowering barriers.

Finally, new and disruptive business models are in reach that will make use of the data-driven agri-food chain. However, the sustainability of IoT-based businesses, both for the supply (providers of IoT technology) and demand (agri-food users) stakeholders must be involved, specifically in the context of large-scale deployments for being able to mobilise a critical mass of end-users and validate the related benefits.

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