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Identifying the ICT Challenges of the Agri-Food Sector to Define the Architectural Requirements for a Future Internet Core Platform

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Abstract: This paper discusses the specific challenges of the agri-food sector in the light of research carried out in the SmartAgriFood project. Using questionnaires and focus groups, our research identifies a number of business needs and drivers which enable the identification of suitable Future Internet technologies across the three sub-domains of Smart Farming, Smart Agri-logistics, and Smart Food Awareness. The universal need for information access and the importance of standards to enable this lead us to propose an integrated scenario for end to end information access from farm to fork. We conclude by discussing wider implications of such developments especially for climate change and urbanisation.

1. Introduction

The food and agriculture sector represents 5.9% of world GDP and at least 35% of worldwide employment. In the European context it is one of the largest manufacturing sectors (e.g. 13% of UK workforce) and over 20% of transport is dedicated to food and agriculture. Although the agri-food sector is a large commercial and industrial sector, it has one of the lowest penetrations of ICT technologies.

Over the past thirty years ICT technologies have been introduced in the agriculture and food sectors, improving food production and its transportation to the end consumers. The uptake of these solutions has been slow for a number of reasons. A key challenge for ICT in the agriculture sector is information management, both within specific domains and across the whole supply chain from farm to fork. This is compounded by specific characteristics of the sector, including the very large number of actors along the supply-chain and the heterogeneity of those actors and the consequent very poor information flow along the supply chain. A very conservative "need-to-know" attitude such that essentially information flows only "one-up, one down" makes this worse; for example, the farmer might communicate with the wholesaler or food processor but not directly with the retailer, a problem even more accentuated in complex supply chains for processed or packaged food.

Lack of information has been recognised as a critical issue for a long time in the agri-food sector. There is a need for greater transparency due to pressures from consumers desiring to know more about their food, and the need for tracking and tracing in the context of health and safety and responding to food emergencies such *E. Coli*. The difficulties in achieving this are due to a. complexity in products and processes, b. the multiplicity of culturally diverse SMEs, and c. the lack of appropriate institutional infrastructure to support transparency through the food chain. Another factor in the slow adoption of ICT technologies is that existing solutions (e.g., farm management information systems, logistics services) are closed proprietary solutions, the capabilities of which are directly proportional to their cost. Interoperability among such different systems is challenging.

The EU's Future Internet Public-Private Partnership (FI-PPP) program[1] aims to make service infrastructures and business processes more intelligent, more efficient and more sustainable through tighter integration with Future Internet (FI) technologies. The SmartAgriFood project[2] is one of the eight use cases in FI-PPP and addresses the challenge of applying ICT to three sub-domains: agricultural production ("Smart Farming") , the transportation sector ("Smart Agri-logistics") and improving food awareness for consumers ("Smart Food Awareness"). For each of these sub-domains, the project has gathered user requirements and is currently developing pilot implementations. The aim is to explore FI's capabilities to enable data integration amongst different systems, to allow easy and secure access to information along the supply chain, to simplify the discovery of stakeholders and services and the publishing of data to other stakeholders, to host a software modules in the cloud to reduce costs, and to enable service composition and mash-up to enhance the functionalities of applications offered.

2. Objective of the Paper

The objective of this paper is to describe the user requirements and business requirements identified in the agri-food sector and show how FI technologies will respond. In Section 3, we describe the methodology used to obtain user requirements, identify technological possibilities and the development of an over-arching vision which we entitle the "super-scenario". In Section 4, we discuss the business case for the use of these technologies in greater detail. Section 5 presents a discussion of our findings followed by a conclusion.

3. Methodology

This paper brings together the results from a number of different activities completed or under way, which included 1) an inventory of needs of agri-food for future functionalities of the internet; 2) an inventory of the potential capabilities of the FI to meet these needs; 3) specifications for experimentation for the three sub-domains; 4) designing a super-scenario for an integrated architecture covering the whole supply chain from farm to fork.

An approach is being used in the SmartAgriFood project to ensure a user-centred approach to scenario development (specified in [1]), which has ensured that the perspective of usage and users is integrated into the technology/concept design. The methodology involves a seven step process 1) a description and model is created defining the scope of the system; 2) User requirements and needs are elicited (in our case by means of questionnaires); 3) User needs and requirements are refined by means of focus groups; 4) The use-case driven requirements are then compared with existing (or planned) FI enabling technologies; 5) Based on the scenarios elicited, conceptual design of systems and architectures are elaborated and tested; 6) Systems are validated by means of pilots thereby demonstrating added value for the end users; 7) Finally the use-case specific proposal for large-scale experimentation is formulated. Obviously the work was not undertaken *ab initio* and full account was taken of previous research both theoretical and practitioner based.

As part of applying this methodology, a special work package on user community involvement and dissemination has ensured an effective dialogue between the agri-food chain members representing the user community, and the ICT community representing the

1 More information about the FI-PPP can be found at www.fi-ppp.eu

2 More information about the SmartAgriFood project can be found at www.smartagrifood.eu

solution providers. Users were represented both directly by specific partners (e.g. equipment manufacturer John Deere, supermarket chain BonPreu, trade association EHI) or indirectly via research institutes (DLO, MTT, KTBL, Campden BRI). Domain-specific capabilities and conceptual prototypes have been developed from this dialogue which meet current and future needs based on innovative solutions provided by the FI. Two main results of this work are used for this paper: a) corresponding to Steps 2 and 3, an inventory of long and short term needs of food chain users for future functions of Internet and 2) corresponding to Step 4, an inventory of future capabilities of Internet to meet these future long and short term needs of the food sector. For the first result, the objective was to identify end users' operational problems and their ideas for new FI-based functions and services. Ideas about possible applications in the future were also collected.

A questionnaire (n=135) was carried out in six different European countries (Germany, Hungary, Finland, Greece, United Kingdom and Spain). The report summarising these results was used as input to develop a focus group discussion guide. One or two focus groups per country were carried out in the same five countries (except Spain) with food chain members (n=69) and the findings were summarized. For the second result, the objective was to initiate a dialogue between the agri-food- and ICT-community. The partner universities within the project analysed the results from the questionnaires and focus group discussions, looked at current electronic applications and their limitations, and then identified potential FI solutions and applications for each of the three subdomains. This was based on their own expertise, and the results from the FI-WARE project[3] specifically the Generic Enablers (GEs) being developed in that project.

To achieve an integration 'from farm to fork', there is a need for an integrated approach to the whole supply chain. The methodology to pursue this integration is based on a series of collaborative vision and roadmap development sessions involving the wide range of food and agriculture actors who are participants in the project. This approach has been technology led, developing a 'super-scenario', but with continuous feedback from actors who are involved at various stages of the supply chain. The fundamental question posed in all these sessions has been, given the current structure of the food and agriculture industry, how technology can enable full farm to fork information and data integration, and what kind of business models would be associated with the deployment of these technologies.

4. Business Case Description

4.1 Inventory of Future Agri-Food Needs with Respect to FI's Capabilities

The results of both inventories that were carried out are available in detail in [1] and [2]. The inventory of long and short term future needs of food chain users resulted in a list of functions of the FI which was discussed with FI experts and was adapted for non-ICT professionals in the agri-food chain (Table 1). These ten functions have been mapped to the FI-WARE GEs mentioned above.

Only a few respondents to the questionnaires used really advanced internet technologies that are already available today, while the majority of the respondents use basic and simple systems and applications such as mailing systems, browsers and web sites or proprietary tools. For **farming**, the most important functions of FI should be getting as much information as possible for daily decision-making, and possibly share information and knowledge with neighbouring farmers. This also includes integration in a sensor data network. Many of these applications or systems already exist, but they are proprietary and

3 FI-WARE is the FI-PPP project that works on development of the FI Core Platform (www.fi-ware.eu)

because of their poor interoperability, investment and maintenance costs are relatively high. Cloud computing has the potential to solve some of these issues.

Table 1 Ten Identified Functions of FI as Interpreted by non-ICT Users

1	Internet is not limited to PCs – direct communication between all kind of devices
2	Mobile devices act as data collector, data viewer (display) and information transmitter
3	Quick and real-time exchange of large amount of data/video/3D information.
4	Content based browsing
5	Services of customized information – automatic integration of information on demand.
6	Positioning with higher accuracy for exact identification and controlling of devices.
7	Cloud computing; infrastructure is instantly available and accessible through the Internet at low costs
8	Higher privacy which guarantees the protection of personal data.
9	Global data warehousing and management capability.
10	Ability to monitor meeting set technical requirements and initiate automatic corrective actions and/or alarming system operators.

For **agri-logistics**, all the selected applications of FI should have the same practical benefits as cost reduction, better coordination and better information for decision making by ensuring the real-time exchange of very large amounts of data, and the proactive control of processes leading to increased efficiency and effectiveness. Potential FI applications that attracted interest: sharing online monitoring information from trucks during the transport of cargo, a flexible solution for on-demand dock reservation, and integrated freight and fleet management. For **food awareness**, tracing capability is seen to be the most important topic, providing knowledge about the origin, production and treatment of products.

A majority of the respondents indicated that the consumers are most interested in knowing what has happened to products throughout the whole chain. Communication of product-related information towards the consumer will therefore be an important issue. For all areas, the current problems of compatibility and standardization of the different systems need to be solved. The findings of the interviews and focus groups showed a considerable degree of consistency between different countries. There was a consistent demand for flexible data exchange, not limited to individual interface standardisation, but connecting the different areas of food industry.

4.2 Scenario Descriptions and Specification for Experimentation

Within each of the three main scenarios smart farming, smart agri-logistics and smart food awareness more detailed use cases were developed as basis for validating the applicability of the FI-WARE Generic Enablers (GEs) and to demonstrate certain system features and functional requirements for FI with respect to the agri-food domain [4][5][6]. The overall goal was to describe a number of specific use cases that can serve as test beds for demonstrating the usage of new technologies or service concepts that exploit the FI in innovative ways.

The **Smart Farming** scenario has been developed around a local sub-system integrating with the cloud as an enabler of the other GEs. The services' focus will be on precision farming, smart decision making as well as facilitating plant disease management. The use cases required context and situation awareness, aiming at a more effective exploitation of internal and external knowledge that is available in the overall farming community. This can have a great impact on the yield, while investing the same amount of resources; reduce efforts for a sustainable farming approach as well as reduce costs by accessing common infrastructures. Traceability of food ingredients and their production methods from field to final products will be an important prerequisite for food product quality assurance in the future. The **Smart Agri-Logistics** scenario was specifically based on the GS1 global traceability standard. The physical flows of products and logistics resources (objects), and the information flows for planning, control and coordination/orchestration will be decoupled for achieving real-time virtualisation. The future food supply chain will be based on intelligent event management. The standard event messages are enhanced with further data elements that will directly forward context information like delays or environmental conditions like the temperature. Business organisations are asking for a more intelligent chain that is analysing and reporting exchanged data to enable early warning and advanced forecasting. Waste can thus be reduced and the shipment dynamically controlled.

The **Smart Food Awareness** scenario is combining the consumers' request for information about the food and the retailers attempt to gain market share and increase turn-over while being able to explain the unique selling points and to ensure consumers trust the safety of the food. The interest in transparency domains might change at short notice but the infrastructure must be able to easily adjust to such changes. The transparency view is an extremely dynamic field depending on external unpredictable developments in e.g. life-styles, policy, food scandals, market shortages. Communication with consumers should not stop after the end of the act of shopping. As soon as a relationship of trust is established the retailer can provide additional services. The specification of those scenarios was directly connected to the development of experimentation environments for being able to test and validate the FI Core Platform developed by FI-WARE. Table 2 summarises those experimentation environments and the related infrastructures involved, which are serving as living lab environments in addition to the central FI-PPP experimentation infrastructure.

Table 2: Elaborated Food Chain Environments for Experimentation and Challenges Addressed

Experimentation Case	**Specification for Experimentation**	**Infrastructure Involved (Living Lab environment)**
Smart Spraying	The spraying case collects data from different sensor networks by using the cloud in addition to farmers' own geographically site-specified cropping information to forecast disease warnings to the farmer. These warnings trigger the farmer's use of Farm Management Information System tools in the cloud to prepare a task, plan and schedule for spraying. In the field, an on-board system controls the spraying. Spraying success is uploaded in the cloud and dispersed to the disease forecast server for prediction of future events.	Farming environment using intelligent ICT devices as extension to the farming machinery currently used. Mixture of classical systems, cloud dimension and IoT enabled device integration.
Greenhouse Management	Greenhouses are used to monitor environmental conditions like temperature, humidity, or soil pH. Sensors in the greenhouse collect data for the smart farming sub-system. Additional sensors and possibly IP cameras are installed in the greenhouses and functional modules like data analyser or notifier will be placed in the cloud. Also the enhanced farm management system will be integrated to support a number of registered services.	Enhanced farm management system in the future will be merged with the cloud, mixing with virtual reality, social network and including data from IoT enablers.
Flower and Plants	The flower and plants case is gathering information directly from the plants or the transport containers that are representing logistics units. They will be considered as autonomous units that shall be forwarded on real-time demand and not requiring analysis, planning and forecast of supplies by the retailers. The supplier can overtake further responsibility for their customer's inventory, reduce waste, assure availability of high quality products, decrease the lead time and finally maximise the flower quality for the consumer.	IoT based monitoring of flowers & plants combined with intelligent data/ context management, based on a cloud related migration with systems for quality based vendor managed inventory
Fresh Fruits & Vegetables	Forwarding of fresh fruits and vegetables is done in a complex network of dynamically interacting organisations. There is a poor data exchange from farm to fork. Static and dynamically changing information and exception reporting for crisis management are to be exchanged. Basic logistics planning and warehouse management systems are extended by mobile devices and scanners to generate events, monitor the context	Systems for global traceability coupled with the cloud and context/data management. IoT integration for virtualising the events and security framework for a decentralised cloud usage and communication routing.

Experimentation Case	Specification for Experimentation	Infrastructure Involved (Living Lab environment)
	and virtualise the produce flow as well as enable an autonomous data exchange in relation to the produce location forth and back the chain.	
Tracking & Tracing Awareness of Meat	Tracing meat requires the mapping of inputs and outputs during processing. It requires procedures for batch handling, including workflows for aggregation and disaggregation. Consumer and health data intelligently merged to derive meaning. Labelling and RFID approaches need to be combined with multi-tier mapping approaches that enhance the system beyond the individual borders of an organisation.	Labelling and meat identification, enhanced by intelligent and secure data/ context management. Mobile Devices and IoT handling for cloud based traceability enabling consumer response.
Tailored Shopping Experience	Retailers provide diverse data to consumers to establish trust, assure consumers' specific needs (e.g. comply with allergies), and to raise interest in additional/ premium products. Using fidelity card schemes, consumers are informed in accordance to their needs. There is no 1to1 match of product information and consumer interest. Several sources for product related information (e.g. producer, laboratories, label owners, logistics) need to be integrated in relation to a specific physical product beyond its general type. Data needs to be further specialised in relation to the individual consumer. The retailer must assure that an information source provides correct data and its validity for the specific product, beyond a pure technical dimension.	Retail infrastructure, enhanced with mobile devices and cloud based environment including secure data/ context management, based on an application ecosystem. Retail based IoT integration, including scanners/ cameras for real world interaction.

These experimentation cases have been elaborated and initial test beds have been installed, and have already been used for further validation of the impact and applicability of the related business models. It has become clear that the dimension of an increased resource use seems very feasible when exploiting the potentials of FI. Farming could potentially provide more output with the same resources, while the envisaged reduction of waste along the overall food chain could have an even larger impact on the exploitation of resources. Moreover, after analysis and the first tests in the scenarios, it has become clear that these scenarios are complementary, and largely connected, while each element can bring an added-value for the other. This dimension of a super scenario development is further described in the next section.

4.3 Super Scenario Development

The 'super-scenario' is a scenario for the deployment of technologies to integrate all data across the sub areas and thus provide end to end (farm to fork) data integration. It is still work in progress but here we outline the key elements. Our analysis of the agri-food sector shows that there is a need for this end-to-end integration primarily due to a number of business drivers: a) regulatory pressures, b) consumer pressure for more transparency, and c) the need for effective tracking and tracing especially under conditions of food and health emergencies. Furthermore, the need for access to information pursuant to appropriate standards has been expressed clearly in Section 4.2. and in view of this, we need to design ways that will allow users to make their data easily accessible to other stakeholders if they so wish. Also, we need to provide an automated way to integrate information produced by different systems, to enable an easy integration of these systems, and thus produce far more advanced services in a simpler and cheaper way. For example, stakeholders in the food chain should be able to discover, subscribe to and combine data from services offered by different parties. In such an environment, e.g. a farmer could easily discover a meteorological or state's policies notification service to combine it with an advisory service (e.g., an electronic agriculturist). This automatic service discovery and services composition along with data correlation is expected to enhance the functionalities offered to the end users, and concurrently fulfil explicit business requirements.

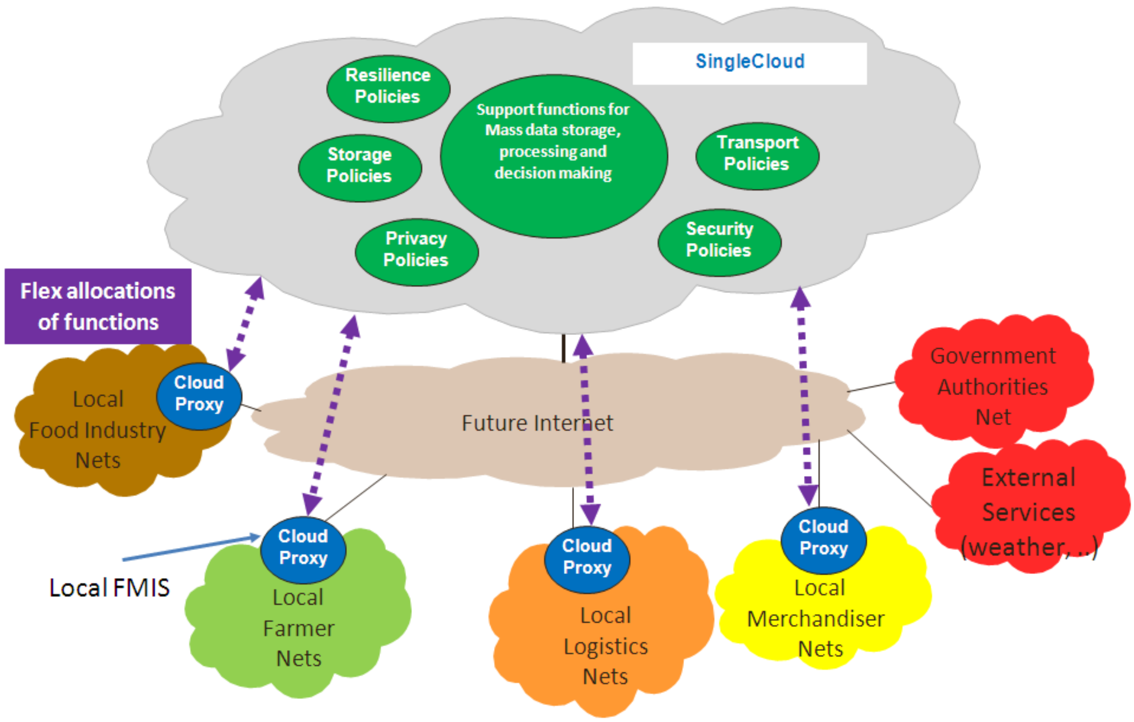

Figure 1: Advanced Services Along the Agri-Food Supply Chain

Taking this a step further, an actor in the agri-food supply chain should be able to discover other stakeholders all over the world and form with them business relationships in a simple way. In other words, future technological solutions (especially those provided by FI) should allow the dynamic formation of new business links among stakeholders and among services and stakeholders[7]. These links will support the flow of information among the different systems in the agri-food supply chain using flexible means for interoperability, security and authorisation schemes (i.e., different stakeholders will have different privileges in accessing data). The dynamic formation of links in this business environment also requires technical solutions to enable "trust" among the involved entities.

To turn this into reality, FI technology needs to provide a number of advanced yet generic services along the whole food supply chain (Figure 1). For example, the FI is expected to enable the attachment and accessing of end devices (e.g., sensors, tracking devices) and machinery (e.g., tractors). Additionally, the FI is expected to allow cloud implementation of services that will facilitate the effective accessing, processing, and analysing of massive streams of data from these end systems. It will also provide the means for service developers to build sophisticated services and provide the means to use expert systems that will improve the "intelligence" of control processes possibly using distributed schemes. Finally, it is expected that generic interfaces among the services located in the cloud, the underlying network infrastructure and the end devices will improve considerably the quality of experience of end users.

5. Discussion and Conclusions

The SmartAgriFood project has systematically identified a set of needs on the part of the agri-food community and identified a number of technologies that can be brought to bear to fulfil those needs. The implications of the technological developments go beyond merely those specific to the agri-food sector. We noted in the introduction the significance of the agri-food sector in economic and employment terms. Agri-food also represents one of the sectors of human activity with the largest environmental footprint (i.e. carbon footprint and water footprint) and the success or failure of the food and agriculture sectors impacts human beings very directly as we have seen in recent years with substantial spikes in basic food costs and the consequent direct human impact. The use of FI technology in the agri-food sector may in some areas reinforce industrial agriculture which has until now had a relatively negative impact on the environment but our focus on precision farming is an area in which potentially the greater use of technology should result in a reduction in environmental impact due to the reduction in external inputs.

Equally the development of more efficient logistics systems will help reduce waste[4]. The increase in food awareness resulting from the use of technology at the retail end will also permit more environmentally conscious purchasing behaviour in end consumers. Perhaps the most radical impact of these technologies lies in the possibility of making the food supply chain more fluid, more responsive, easier to participate in, enabling farming to respond to consumers' needs and their willingness to decide on the way how their food shall be produced. This would have implications both in terms of food sovereignty and security but also in terms of food production ethics.

These issues become even more important with the ever growing urbanisation of human populations. The "food shed" of a large city is substantial and food supply chains need to be both protected and made more resilient. Concurrently urban food production needs to be encouraged given the ecological and environmental challenges we face. The technologies described above can also make a contribution to urban food management both in increasing efficiency but also by making data across the board more available and easily managed. This will make planning, provisioning and the introduction of small scale food production all easier to achieve in an urban environment.

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4 Various authorities put food waste in Western Europe as ranging between 40% and 60% out food grown.

