IoT TECHNOLOGIES IN VITICULTURE: INNOVATION AND SUSTAINABILITY. THE IOF PROJECT CASE STUDY

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Abstract

The actual scenario, characterized at global level by cogent environmental challenges, urges the adoption of effective policies to fight climate change and variability. This is particularly true whit regard to agriculture, strongly affected by the mentioned phenomena. Traditional production areas have experienced, especially in recent years, substantial climatic changes with a general and constant warming trend observed in most production regions. As far as viticulture is concerned, specifically, as global temperatures continue to rise, several areas originally unsuitable for grape production because of insufficient warm climates are becoming adapted to support it. The climates of production regions merge with cultural factors at local level to create a unique combination reflected in the concept of terroir, the peculiar and complex interactions between each regions' physical and cultural factors, resulting in the quality and style of wine from a specific region. In this context, the application of IoT technologies through precision viticulture and remote vineyard monitoring represents a vital opportunity to innovate cultivation methods. The implementation of these technologies aims at optimising the wine production and quality and, at the same time, preserving the environment by lowering the carbon footprint, reducing water and electricity use and recycle vine and wine waste, thus promoting an effective agroecological transition. The present contribution will analyse the mentioned issues within the IoF project (www.iof2020.eu).

1. Introduction

The analysis at the core of the present discourse makes it necessary to consider the contribution of economic geography to the understanding of the "historical present", i.e. its institutional methodological structure and approach. As a science anchored to the investigation of the territory as a whole, economic geography does not, nor can it, deal exclusively with economic issues, but must constantly take into consideration also the physical, political, social, historical and cultural factors that those economic facts of that given territory are inextricably linked to. These same links give rise to so called spatial relationships, that take form both between economic subjects (individuals, families, communities, companies and entities of different nature and for various

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reasons operating in the economic field), as well as between economic subjects and the environment in which they operate and viceversa (Dematteis et al., 2010). The spatial relationships of the first typology, those between economic subjects, are called horizontal and basically concern the flows that affect these subjects (exchanges, movements of people, information, technologies, capitals) and the localization networks that derive from this interaction. The relationships of the second type, called vertical, or even ecological, identify the interactions that economic subjects have not only with the different natural contexts (climate, resources, altitude, position), but above all with the territory itself, embedded with all its human dimension, and organized in its different juridical, anthropological, historical aspects. The combination and intertwining of these two interpretative vertical and horizontal relationships provides both a framework useful to define the different hierarchies and territorial structures that characterize the present scenario, as well as a tool to analyse specific bundles of relationships, functional or critical, both on a local and global scale, which indicate the basic trend lines of the economy and contemporary society. This is particularly true with regard to agriculture, certainly the activity that, on one side, is most linked to natural conditions and to a whole heritage of traditions and, on the other side, creates continuous flows of economic exchanges at a global scale.

With specific regard to viticulture, at the core of the present analysis, research conducted in recent years shows that climate change will have an important economic impact on viticulture and will require changes aimed at the adoption of both mitigation and adaptation measures, as well as in business strategies and sector policies (Bethuel et al., 2017). Climate change is expected to have immediate and short-term effects, and medium/long-term ones; as to the first effects, they are mainly referred to yields, quality of wines and, as a consequence, prices and related incomes. As to the latter ones, it is vital to note how changes in the availability of production resources in most areas, combined with irreversible changes in the winemaking geographical distribution will cause a series of with economic and social impacts, related to changes in land values, in competitive relationships and employment distribution. It is fundamental to conduct an in depth analysis aimed at investigating the different aspects of the issue at stake. New climatic conditions make it necessary to adapt production techniques, with a predictable effect on costs; moreover climate change impacts on the unpredictability of phenological evolution, which makes it more difficult to plan production activities and poses a hazard to grapes with high oenological potential.

In this complex context, climate change is likely to represent one of the main drivers, if not the most relevant one, of the future (immediate and not) evolution of viticulture and winemaking techniques, with an inevitable process of selection phenomena among wine-growing territories and within them. Actors, both public and private, need to face the challenge of climate change both through mitigation and adaptation policies, in a perspective of environmental, social and economic future sustainability (Bethuel et al., 2017).

As a consequence of the mentioned scenario, the adoption of IoT technologies represents a fundamental tool to face the mentioned challenges and improve efficiency, all in the perspective of favouring the design and implementation of a sound agroecological transition (Soulignac et al., 2019).

2. Agriculture and ICTs

As to the possible definition of a framework for the analysis of ICTs in agriculture, the present contribution aims, as well, at questioning the central or peripheral positioning of ICTs tools as an essential step to measure the coherent place of the same digital tools in the support and development of agroecology, and the structure of a related new agricultural model. On one hand, digital agriculture is considered as a new model in itself, thus raising the question of its position in relation to other agricultural models, including that of agroecology. Digital tools can, for example, be added to the technological trilogy "certified seeds, fertilization and phytosanitary products" (Daniel et al., 2019); in such a scenario, farmers and agricultural producers might see their autonomy further reduced, and become more dependent on a market system capturing agricultural data and their associated decision models. Alternatively, on the other hand, digital tools are regarded as additional resources that can serve different agricultural models, certainly depending on the procedures adopted and how they are used, with farmers and agricultural producers remaining at the center of the final decision. As a consequence, it is possible to analyse how ICTs can support different types of agriculture and study the ways in which they can support agroecology, in particular, at the core of the present discourse. The mentioned support is fundamental to promote an effective agroecological transition within a territory, that needs to be planned and implemented. Following the approach adopted by Bergez et al. (2019), the method of designing a territorial agroecological transition is essentially based on numerous exchanges between actors within each territory kept into consideration.

In order to analyse the complex nature of the agroecological transition in agriculture, Duru et al. (2015a) propose a conceptual framework according to which the behaviour of the mentioned actors is determined by formal and informal norms and agreements that, through the use of technology, interact with material resources specific to farms, with supply chains and natural resources. The resources to manage are of two kinds: material resources, and cognitive resources. Three systems of material resources (MR) are identified, each one associated with a specific management process:

- The MR system of the farm (MR-F), used by farmers for their activities;
- The MR system used for collection, processing, and marketing activities all along the supply chain (MR-PC);
- The MR system used by actors for natural resources management at local level (MR-NT).

These three MR systems are interdependent and their management process is strongly influenced, better determined by technologies that are specific to it; the individual components of each system are also interconnected and interact, e.g. (to mention a few of them) fields, planned biodiversity (crops, domestic animals) for the MR-F system; transportation and processing equipment for the MR-PC system; water, soil, and landscape structures for the MR-NT system (Bergez et al., 2019).

It is vital to carry out an analysis and characterisation of current forms of agriculture (so called "Agricultural Systems in a Territory") and, afterwards, to proceed to design a future "Territorial AgroEcological System" (TAES), that entails the ecologisation of current Agricultural Systems in a Territory. The transition to a TAES (tTAES) requires a methodology that, as argued by Duru et al. (2015b), keeps into consideration the complementarities at local level, both biophysical (soil, climate characteristics and natural resources of the farms) and production-oriented.

The importance of the approach at stake is the potential to design, test and adapt a methodology to help local agricultural stakeholders in their desirable transition of local agricultural systems to TAESs. Five steps are encountered (Bergez et al., 2019):

- Analysis and characterisation of the current local agriculture;
- SWOT analysis and definition of the exogenous forces that will impact local agriculture in the future;
- Specific design of a Territorial Agroecological system (TAES) according to ecological principles (Biggs et al., 2012);
- Setting of steps to develop such a system, i.e. the transition to the TAES;
- Definition of a proposal of local governance and management to orient this transition.

It is fundamental, in each step and throughout the whole process, to keep into consideration the several interactions between farming systems, food chains and natural resources. The cited exchanges between actors require, in general, few tools and have a low technological intensity. At a minimum, the communication tools will disseminate the results from the design of the model, and even allow their enrichment and enhancement through social networks. Nevertheless, the concrete launching of a sound agroecological transition and, therefore, its routine operation, can be supported by different ICTs, as important tools to implement this same transition.

As a matter of fact, the agroecological transition of a territory does not concern only farmers, but the entire agricultural world up to researchers, actors in the food production circuits up to consumers, finally all those who interact with farmers production methods such as, among others, naturalist associations (Duru et al., 2015a; Bergez et al., 2019). As a consequence, such a transition requires a consistent amount of exchanges of data, information and knowledge, which can be facilitated by ICTs. Indeed, one of the strengths of these technologies is to break down the spatial and temporal barriers that usually prevent certain territorial actors from communicating effectively, thus slowing down or impeding the agroecological transition of a territory.

Proceeding to consider how ICTs support the agroecological transition, it is vital to investigate all information systems capable of valuing information, data and knowledge (Laborde, 2017). A differentiation of these digital devices tools according to their function is as follows: communication, functional use, knowledge management and decision support.

As to the first one, communication technologies facilitate the circulation of data, information and knowledge inside an organization or from an organization to its targeted public. They disseminate observation results, ideas or knowledge synchronously or asynchronously, and consist as well of applications that publicize events, products and so on (SCAR AKIS, 2016). These tools include videoconferencing systems, social networks or exchange of data systems.

As far as functional tools are concerned, these applications support repetitive processes that are easy to model. They include accounting management tools, online sales tools and similar devices. In addition to the facilitated organization of short circuits, these tools also promote positive and fruitful exchanges such as, for example, those between straw producers and manure producers, and therefore effective cohabitation between breeders and grain producers relevant from an agroecological point of view. In this field, crowdfunding potentially brings together holders of innovative projects and potential funders, all with the aim to enhance these web tools and versions that make the territories more autonomous by relying on internal strengths and resources (CEMA, 2015).

Thirdly, as to knowledge management systems, they include all those tools useful for creating, storing, disseminating and updating knowledge. The agroecological transition requires a great deal of knowledge (Daniel et al., 2019) in order to reduce the risks taken by farmers. In order to reach this objective, the adoption of tools that include a knowledge creation component, regards two types of possible aspects: on one hand, that related to web tools, that break down geographical barriers between farmers. They make possible multiple sharing of experiences, both positive and negative, and this empirical knowledge can be capitalized and combined with scientific knowledge. On the other hand, as data are becoming more and more abundant, coming from drones, sensors, connected objects, satellite images, traceability, observations and agricultural management tools, and so on, it is important to adopt a systematic collection and organize specific ways to extract knowledge from these data. These advances may lead to new decision support tools (DSTs) (Rose et al., 2016; Bergez et al., 2019; Le Guen, 2008).

As to this aspect, agroecology requires a solid educational program and ad hoc trainings need to be organized at different levels.

Finally, decision support, or decision-making, tools are based on two resources: data and knowledge that infers these data to produce actions. They range from the reasoned fight against pests (e.g. date of intervention, quantities) to issues such as the design of systems rich in biodiversity. The acquisition of contextualized knowledge could open the door to multifactorial decision support tools that cross economic, agronomic, social and environmental components, as cited above (Duru et al., 2015b).

It is vital to analyse the challenges to face with regard to the connection between ICTs and agroecology, as these challenges concern research, education, farmers and the food industry, and stakeholders at multiple levels. As an example, in France, several actors gathered around the #DigitAg, Digital Agriculture Convergence Institute (https://www.hdigitag.fr/en/). To meet its different challenges, which include the development of information systems for the agroecological transition, #DigitAg has identified six axes: axes 1 to 2 highlight the social and economic dimensions, required to bring results from the laboratory to the field; axes 3 to 6 correspond to the classic themes of collecting-organizing, visualizing, understanding and modelling applied to specific chains of digital data. Moreover, two major societal issues related to agriculture are identified and addressed through ad hoc operational supports.

As a matter of fact, the adoption of digital devices and communication tools by farming communities depends on practical criteria such as their usefulness, their ease of use and their return on investment. In such a scenario, the participatory design process of the tools at stake becomes fundamental, as argued by Thareau et al. (2019). Several questions might arise as to the technical knowledge critical or missing concerning each practice, or as to how it is possible to diffuse and validate knowledge in each community. Collaborative design based on users behaviour or needs are consistent with the agroecological principles of participatory research and final-users inclusion in research, as already argued (Pillaud, 2015).

For the proper use of these tools, the importance of data accessibility is critical. Their double public and private origin does not easily guarantee it, and questions arise about the monetary value of each data, its intellectual property or its traceability (#DigitAg, 2018). It is fundamental to develop portals at all levels, to collect and store agricultural data provided by actors involved in the value chain, as well as to have transparent data governance for the development of an agroecological system including ICTs as a necessary support (Agnès, 2019).

3. The IoF project

In the context of the European farming and food sector, the Internet of Food & Farm 2020 (IoF2020) project stems from the need to investigate and foster a large-scale implementation of Internet of Things (IoT) on order to contribute effectively to a paradigm shift in this field, by drastically improving productivity and sustainability. The project is composed by 5 trials, and 19 case studies (www.iof2020.eu) and, through the enhancement of the use of smart webs of connected objects, that are context-sensitive and can be identified, sensed and controlled remotely, in the agri-food sector, it is in line with recent initiatives towards the valorization of relevant opportunities offered by ICT, network and data–oriented technologies. The provision of solutions to facilitate the large-scale uptake of IoT, by addressing organizational and technological challenges faced by the European farming and food sector, is at the core of the initiative, that focuses on 19 use cases spread throughout Europe, and provides solutions to 5 agri-food areas: arable farming, dairy, meat, vegetables and fruits, taking into account their own needs and obstacles. Furthermore, the IoF2020 project involves all the stakeholders in the food chain: from farmers, cooperatives, equipment and logistic suppliers, food processing companies, to consumer organizations, including ICT developers, all with the aim of improving the technologies at stake, ensuring they meet the requirements and needs of the sector. In particular, the present contribution focuses on the Use Case (UC) dealing with Big Wine Optimization.

The Big Wine Optimization Use Case (UC)

European wine industry constitutes a sector of utmost importance for the continental economy; at global level and in terms of value, EU is the most important producer of wine, involving about 2.4 million vine growers. This "leadership" is rooted in historical savoir-faire, traditions, as well as in peculiar soil and climatic conditions of several areas. The wine industry in EU is composed by a constellation of small and medium enterprises and involves a broad range of other professionals such as consultants, service providers, marketing experts, and so on. As a consequence, in total, the European wine business has the highest share of EU agriculture revenues.

Nowadays, this sector encounters high pressure from emerging countries, such as China; in order to preserve the competitive advantage to third countries, European producers need to implement new cultivation methods, and precision viticulture and remote vineyard monitoring certainly constitute, in this context, two very promising technologies.

Alongside this, the organic wine sector is rapidly developing with excellent and promising, though challenging, market opportunities, and represents nowadays about 10% of EU vineyards (with higher rates in Italy, Spain and France). The deployment of IoT technologies both in conventional and, even more, in organic viticulture and wine-making processes enables the achievement of important goals; remote sensing and control actuators, information collection both in vineyards and cellars, big data analysis and management, and decision making are all important aspects to analyse, also with regard to the mentioned perspective of agroecology. Increased efficiency can

be achieved in inputs and labour resulting in higher quality, profit and environmental sustainability along with decrease in production costs.
The Use Case (UC) at the core of the present contribution, within the IoF project, addresses both conventional (for vineyard and cellar phase in France) and organic (for cellar phase in Italy) production systems.
The main challenges to analyse refer to what follows:

- Real time monitoring of weather conditions both at parcel and vineyard level.
- Optimization of the use of potable water resources during wine production.
- Manage a consistent amount of data (acquisition and handling) deriving from a high number of vineyards.
- Maximise the wine production and enhance and preserve its quality.
- Increase inputs efficiency thus reducing the costs related to the production and commercialization.
- Preserve the environment, through the reduction of carbon and water footprint, an improved control of electricity use and the recycle of vine and wine waste).
- Compliance with Quality standards and certifications (e.g. ISO 14001 and HVE 3 certifications).
- Manage storage, shipment and post-cellar phases with specific attention to reduce risks associated with un-controlled operations.

Furthermore, as to the socio-economic impact of the UC, this is particularly relevant due to the mentioned importance of this sector in the agriculture revenues in EU. As a matter of fact, wine production is a risky business due to the market volatility and the impact of weather conditions. Organic wines represent a precious opportunity for European producers as the market share is fastly and constantly developing (domestic and export), with increase rates of about 15% annually.
In the French UC, the end-user is Denis Dubourdieu Domaines (DDD), a winegrowing family since 1794 at the south of Bordeaux (Graves). They exploit 5 vineyards distributed over 300 parcels covering 135 hectares and producing around 600.000 bottles of wine per year. In addition, they exploit 200 hectares of forest to develop a neutral carbon balance in order to preserve the environment. DDD performs the complete activities related to the wine value chain from vine-growing to wine making and commercializing. DDD exports 60% of its production in more than 40 countries. French rules forbid the irrigation of the PDO French vines (PDO represents 99% of the wine production in Bordeaux). They are only irrigated by rain. This situation creates a strong dependency of the vine-growing on the weather conditions. In addition, the context is very difficult for producers in terms of pesticide use, especially in Bordeaux, because of a cool and temperate oceanic climate, vine growing is subject to the pressure of various diseases, rots and pests. Today, society and government push producers to reduce drastically use of pesticides and herbicides.
The Italian case study is based in Arcania vineyard and cellar in Friuli Venezia Giulia region, North-East of Italy. It is a society of 5 farmers, all certified organic since 1992, who manage 50ha of vineyard and directly process all the grapes in the society cellar, located in the Rive d’Arcano Castle. Produced wines are organic, PDO (several denominations) and a specific line offers also SO2-free wines. White wines (Collio, Colli Orientali and Grave Appellations) are particularly renowned in Friuli Venezia Giulia region, due to their qualitative aromatic profile gained thanks to the soils (specific clays) and the climate (cold and rainy). Nevertheless, this poses higher

challenges for the organic management of the vineyard and for the processing activities with zero or reduced aids. With regard to the production of organic white wines with no added SO2, this is particularly true due to the risks and complexity of the whole process, that requires a full knowledge of vineyard and cellar conditions and also of the procedures used in the following phases of the value chain, as final products are sold all-over the world and consumed years after their production.
The list of the project and business partners is the following:

- Denis Dubourdieu Domaines (DDD): a winegrowing family since 1794 at the south of Bordeaux (Graves). End-User.
- Process2Wine (part of ERTUS Consulting company): a software developer specialised in tools for wineries and vineyards. Technology provider
- Bordeaux INP - IMS Laboratory: Technical and scientific experts image analysis for vineyards and orchards. Research organization. Technology provider
- CEA-LETI: IoT Framework for Cloud and local data processing. Research organization. Technology provider
- STMicroelectronics - MMS Division (Grenoble/Rousset): Semiconductor Company and provider of Smart nodes and Gateways solutions including HW and SW.
- Vinidea- innovation broker specialized in the wine sector, with expertise in conventional and organic wine production and large experience in dissemination technical information at EU level. Technology provider and dissemination actor.
- ISVEA- development and validation of the analytical databases for remote acquisition. Research organization.

The overall objectives of the UC at stake relate to different aspects, from the societal impact, i.e. transform low added value jobs in the vineyard in high added value ones, to the environmental ones, by reducing carbon and water footprint. Moreover, it is vital to increase the tools available for organic wine-production and marketing, so offering better opportunities to farmers; increase the competitiveness of all-range winegrowers (from low to high range), all through the deployment of the IoT technology solutions, validated by the same UC, more extensively at regional, national and European levels. As to pest management, in conventional vineyard (France), the challenge is to optimize, and possibly reduce, the use of chemicals for plant protection through a precise identification of moment, product and positioning of the treatments. As mentioned, the aim is to reduce environmental impact, reduce use of resources and efficiently protect grapes. The actions to implement in order to reach these objectives are the following ones: knowing accurate weather conditions (precipitation, humidity, wind, temperature) in real time on a specific area, a set of parcels or a complete vineyard; providing, by the control centre, application maps as a result of the real time processing of the weather and vine conditions. These data are essential to be used for precision viticulture activities such as site specific decision making, variable rate spraying, fertilization, selective harvesting, and so on. The solutions deployed refer to the use of a high integrated weather station network with long range transmission capabilities to know accurate weather conditions in real time, and to the equipment of tractors with a spray actuator controlled from the data centre, which will send command to the same actuator, indicating where and the dose (e.g. fertilization, other treatments) to be applied.

As to selective harvesting, in conventional vineyard (France), it is vital to consider yield and grape quality, both at parcel and vineyard level; in order to reach this objective, vine conditions have to be analysed. TE sensor is dedicated for grape detection, phenological stages determination, disease status characterisation, all with the aim of performing a more automatic and quick processes in order to reduce the inspection time and to have accurate results. The use of image processing techniques based on video sensors with computer vision capabilities is deployed, with a twofold idea: firstly, to install fixed video sensors in relevant locations within the vines plots, that provide high temporal resolution measurements but at very low spatial resolution; secondly, to equip a tractor with the same kind of video sensors in order to get high resolution measurements but at low temporal resolution. In both cases, the image processing results (expressed in meta data, for instance fruit detection) are sent to the central station and then combined in order to make the decision process more reliable and accurate.

Furthermore, as regards the wine cellar monitoring, in conventional wine-making (France), in this specific part of the production chain, the activities performed and the scopes refer to: proper monitoring of temperature and humidity in different stages of vinification process in cellars as well as in bottle-storage warehouses, in order to avoid issues related to temperature (too high) and humidity (too low), and a consequent wine evaporation during summer time; strict controlling of the total dissolved oxygen level during bottle filling in order to optimize the wine aging; measurement of water and electricity resources used during production.

Shifting to organic wine production in Italy, the remote quality assessment refers to the possibility to frequently assess critical parameters on a large number of samples, that is vital all along the different phases of wine production, and also highly beneficial. These parameters refer to: polyphenols, sugar, organic acids and assimilable nitrogen in grapes during maturity; sugars, alcohol, volatile acidity, acetaldehyde, organic acids during fermentation; volatile acidity, color, acetaldehyde, and so on during barrel aging.

The transport of samples for testing procedures, from production sites in rural areas to laboratories for analysis would be economically and environmentally expensive; as a consequence, in most cases, presently quality assessment is performed only in punctual steps, with no preventive approaches that are essential for low-input and organic winemaking. In this context, the IoT challenge is to develop an uncoupled analytical system, preferably based on FTIR technology for multi-parameter analysis (already largely applied in wine sector), where inexpensive devices and simplified procedures allow the acquisition of the spectra at the production sites, and the elaboration of data to obtain the needed information and desired values is done remotely through internet data exchange. In this way, the unit cost per sample would strongly decrease, thus making it possible also for small wineries in remote areas to optimize their assessment system, with strong increase in quality and consistency of final products.

Furthermore, another IoT challenge, potentially developed in the most critical situation of organic winemaking but immediately transferrable in the conventional sector, refers to the control of wine quality during the last phases of the production chain, i.e. bottle transport and storage. In both phases a significant quality drop can occur because of long distance delivery and related exposure of wine cases to extreme temperatures and, also, of long storage of wine in uncontrolled conditions, that can accelerate degenerative phenomena. The low or absent presence of preservatives makes organic wine more exposed and sensitive compared to conventional one, though in both cases there is a joint interest of the producer and of the reseller to preserve brand image and reputation by avoiding that faulty bottles are purchased by final consumers. It is vital to perform a continuous assessment of some key parameters (e.g. temperature and wine absorbance at specific wavelength), at fixed intervals during the shelf life period, and to convey through internet and to elaborate obtained data in a central system. This is achievable through the development of a device able to automatically measure, in a non-destructive way, the mentioned key parameters as relevant indicators of the quality state of the product. The same central system, managed by and under the control of the producers, allows for early identification of problems and of the period when they originated; as a consequence, necessary measures to prevent such events resulting in quality reduction can be adopted in due time.

As far as IoT System components description is concerned, the technology at the core of the analysed UC covers the complete IoT value chain, i.e. it includes the three main domains: device domain (edge), network and application (Verdouw et al., 2016; Vermesan et al., 2015). The integration of all these three domains is vital for the successful implementation of the described system; for the sake of privacy issues, in some cases the processing in the network domain is performed in the device domain/edge.

Just to mention some concrete examples of the cited components, in the conventional sector (France), in the device domain, weather and crop conditions are monitored through the use of sensors (e.g. temperature, humidity, precipitation sensors), and the related collected data are sent through the internet and/or through a local network, and analysed for different purposes, especially for pests and diseases infestations. This allows the user to adopt effective decisions regarding spraying application, fertilization and other treatments for all selected fields. In the winery, sensors monitor the conditions during vinification process; data are sent and analysed again through the internet and/or through a local network, and the installed actuators are used to control the vinification process through the same platforms in an automatic or manual way.

As to the sensor node (= sensor + microcontroller + connectivity) and to the actuator node (=actuator + uC + connectivity), a multi-sensor/actuator node is integrated and deployed in the vine and the cellar. This solution supports the following operations modes: Weather station sensor node, Disease actuator node, Cellar sensor nodes. This solution includes several sensors (precipitation, humidity, wind, nitrate, brightness, etc.), computing, long range connectivity, and GPS capabilities are also supported. In addition an IBUS interface is provided and 150 multi-sensor/actuator nodes are considered. Fixed inspection sensor nodes based on video sensors with “embedded computer vision capabilities” to know the vine conditions (vine phenological stages, vine vigour, diseases, grape maturity, etc.) are deployed. This type of sensor node is installed in appropriated location within the vine plots (sampling).

As to the economic and social impacts foreseen for the end-users, they concern essentially two aspects:

- Reducing the costs of pesticides and fertilizers for the vine growers. As a consequence of simple and automated monitoring, both in the vineyards and the cellar, productivity gains are realized; the more the mentioned IoT solutions are implemented on other vineyards, the higher the economic impact would be at national and EU level. The remote assessment system of both must and wine allows a thorough control of critical phases of production as well as an accurate prevention of accidents, leading to an overall increase of wine quality and final value. This enables users to avoid losses due to faulty products, losses or strong depreciation of a lot of wine, in addition to advantages in commercial relationships. Moreover, for the industrial companies involved in the project for both the conventional sector and the organic one, the economic impact consists also in the development of a new market, with a relevant additional turnover generated by the sales of the IoT solutions, even within years after the end of the project. As argued above, the technology at stake is very easily extendible to other wine regions, with further increase of economic impact (ICT-Agri, 2012). Another aspect to consider is related to the fact that the implemented IoT system allows the monitoring of consumption of potable water and electricity, resources that are both very demanding in the wine production. It is, therefore, possible to carry out a detailed analysis of power consumption and, consequently, implement a sound investment strategy in renewable energies (auto-generation and consumption) by calculating the possible volumes of synchronous electricity consumption with solar energy. Moreover, the decrease of use of pesticides improves wine areas biodiversity as well as air, water and soil quality. It is possible to observe wider potentials to organically manage the vineyards, and this allows more farmers to convert to organic, thus improving their environmental performance. As already mentioned, remote analysis of musts and wines avoids all environmental costs of sample delivery to laboratory (on average 10 $KgCO_2e$/sample), together with avoided back transportation of refused lots of wine, that represents a significant saving in GHG emission (9 $kgCO_2e$/case).

- Transform jobs in the vineyard with low added value in high added value ones, thus enhancing the interest in the new generations of young people towards the work in the farms/wine domains, by offering more attractive jobs involving new technologies. The intergenerational issue is a vital issue to keep into due consideration, together with the reduction of risks associated with low inputs wines and the offer of really innovative products on the market.

It is vital to note how the implementation of the described systems based on IoT devices and solutions, in order to centralize the data, coming from different vineyards and cellars, and perform data analysis, system and risk management and decision making is strongly capable of improving the vine yield and wine production. This provides middle and small winegrowers and producers with new tools to optimize resources (manpower, fertilizers, materials, electricity, water, and so on) and contributes to preserve the environment by reducing the use of pesticides, chemicals and production resources. The deployment of a cost effective precision viticulture management and a global vineyard control system, in order to increase competitiveness, allows as well the optimization of the use of inputs in wine-making by controlling all environmental factors affecting the process (temperatures, humidity, oxygen, and so on). Considering a long term approach, the benefits would be multiple, and differ depending on the value chain actors:

- End-users. The adoption of the mentioned system will reduce costs (manpower, fertilizers, materials, electricity, water, and so on), improve the vineyards management by allowing real-time decision making thus increasing the vine yield and wine production. Furthermore, the described IoT system strongly contributes to the environment preservation, with huge benefits related to the potential numbers of winegrowing and wine producers who can adopt these systems, with a strong economic and environmental impact at regional, national, European and global levels.

- Services suppliers. They can develop new markets through the provision of high added value services and benefits for end-users.
- Technology suppliers. They enter in new markets involving IoT technologies, addressing the needs expressed in them.

It is fundamental to consider the creation of a new ecosystem composed by the mentioned actors; the cooperation between them and the potential common synergies allow the provision of integrated solutions and the setting up of new business models. The IoT solutions developed in the UC at stake, as already mentioned, hold a high potential to be used and deployed in other applications dedicated to the agriculture and farming, particularly in the fruit sector and beyond it; in order to create business opportunities, it is important to provide a global and integrated system solution and create an ecosystem and a strong partnership between all partners.

4. Conclusions

Digital tools and devices are increasingly present in agriculture; as argued in the present contribution, they prove particularly useful for designing and supporting an effective agroecological transition in rural areas. By allowing synchronized or unsynchronized exchanges among farmers and other actors in the value chain, producing and disseminating knowledge without spatial and temporal limits, helping all decision-making processes, ICTs are all resources capable of consolidating agroecology. At a global level, a significant work is ongoing aimed at developing and fine-tuning tools that are both relevant and effective, and beneficial from an economic, environmental and social perspective. The so called digital revolution must demonstrate its relevance, it requires social acceptance as well as an appropriation of its use. As mentioned above in the context of the IoF project, this acquisition of new skills is not self-evident; it is, therefore, fundamental to investigate, understand, guide and propose schemes on the use of this diversity of tools, and broaden the boundaries of each project to involve different territories and experiences as best practices for the near future.

Lastly, it is important to consider whether ICTs potentially save or consume renewable resources. As a matter of fact, whatever ICT is considered (sensor, database, website, and so on), their design, their use and then, possibly, their recycling are all activities with an environmental cost in terms of consumption of raw materials and non-renewable energy. As above argued, agroecology is based on the principle that agricultural production must be exemplary from an environmental point of view, particularly in relation to the consumption of fossil products; as a consequence, a sort of contradiction might be raised between the use of ICTs and agroecology. It is vital to resort to the Life Cycle Assessment (LCA) approach, that measures the environmental cost of an ICT. LCA, thus, can help to distinguish ICTs with a positive environmental balance and impact from those with a poor or even negative ones. A more systematic use of the LCA would have a positive impact by stimulating the production of tools that fit into the circular economy, as well as sobriety and energy efficiency (Duru et al., 2015b; Moraine et al., 2017). In addition to the environmental approach, the life cycle analysis of an ICT must also focus on economic issues with the “Life Cycle Cost” (LCC) method, as well as on social aspects with the “Social Life Cycle Assessment” method (sLCA). The three dimensions of sustainable development thus assessed contribute to establishing the relevance of the use of ICTs in agroecology, and represent the path for future research.

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