Adopting the Internet of Things technologies in Agriculture: an analysis of the benefits in the organic wine industry

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Abstract: Researchers and practitioners are paying increasing attention to the opportunities enabled by Internet of Things (IoT) technologies in the agrifood industry, in terms of efficiency (e.g. reducing the consumption of water and pesticides), product quality and traceability. However, there is still limited clarity on the matter, and on the benefits enabled by IoT technologies. The literature is still mainly focused on the analysis of specific case studies: just a few authors provided some preliminary qualitative analysis of the benefits, whereas quantitative assessment are still rare. For these reasons, this paper aims to qualitatively analyse the IoT-enabled benefits, by focusing on organic wine industry, providing some first evidences that can be useful in order to encourage the diffusion of IoT solutions in farms. The paper attempts to provide a twofold contribution: from an academic viewpoint, this study contributes to the knowledge in this field by providing a structured classification of the existing body of research on the role of IoT for Smart Agriculture, and an assessment approach that can be replicated for other supply chains; from a practical perspective, companies belonging to the organic wine industry can gain useful information on benefits enabled by IoT technologies.

Keywords: Internet of Things, Smart Agriculture, Wine industry, Organic, Benefits

1. Introduction

In human history agriculture has always played a fundamental role, since it is responsible for producing essential resources. Although we currently rely on agriculture to produce the majority of food eaten by people, this industry is facing new challenges, e.g. water shortage, negative impacts of pesticides on human safety. As in other industries, Information and Communication Technologies (ICTs) are offering new opportunities to face these problems.

Among ICTs, Internet of Things (IoT) plays a crucial role in making agriculture more "smart". IoT describes a new paradigm in the human and technological development in which - through the Internet and its future developments - potentially every object of our everyday life acquires a unique identity in the digital world (Miragliotta, Perego and Tumino, 2012). Smart Agriculture applications based on IoT (e.g. sensor networks to monitor microclimate parameters) can improve decision making, thus increasing productivity and product quality. For example, Hwang et al. (2010) proposed a pig farm monitoring system based on IoT, in which data gathered by temperature / humidity sensors and video cameras are used to automatically control some farm facilities (e.g. humidifiers and air conditioners). Kaewmard and Saiyod (2014) proposed an automation system based on data collected with a wireless sensor network. They also developed an irrigation system that – on the basis of the collected data – help reduce water usage. Khelifa et al. (2015) proposed a new strategy for smart irrigation in southern Algeria regions to optimise water consumption thanks to IoT-enabled monitoring and remote control of the irrigation system.

Despite the growing attention paid to these applications, there is still limited clarity on the matter, and on the benefits enabled by IoT technologies.

In line with this premise, it is essential to provide a clear and comprehensive picture of the potentialities of IoT for Smart Agriculture. By focusing on the organic vineyard industry, this paper has a twofold purpose: (i) to categorise the research on IoT for Smart Agriculture and (ii) to analyse the IoT-enabled benefits in a specific industry (i.e. the organic wine industry), in order to provide some preliminary evidences that can encourage the diffusion of these IoT solutions.

2. IoT for Smart Agriculture: literature review

The paper selection process included the following stages:

Identification of the unit of analysis: IoT applications for Smart Agriculture;

Sources: papers published on international peer-reviewed journals and proceedings of international conferences were considered. The analysis was conducted covering the major journals in the fields of Smart Agriculture (e.g. Computers and Electronics in Agriculture, Decision Support Systems, Precision Agriculture, Sensors) and the most important proceedings of international conferences on IoT (e.g. Communications and Mobile Computing

Conference, Future Generation Communication Technologies);

Search of relevant papers: the keywords for the search were identified (e.g. “Smart Agriculture”, “Internet of Things”, “Wireless Sensor Networks”) and the papers were collected mainly through library databases (Isi Web of Knowledge, Scopus and Google Scholar). For each paper, the abstract, the introduction and the conclusions were carefully examined in order to select the most relevant ones for the purpose of this review. To avoid the omission of other important papers, the majority of the cited contributions were also cross-referenced and, if necessary, included in the analysis;

Paper selection: more than 100 articles were downloaded; then, those addressing the topic summarily or as a collateral research theme were excluded. Consequently, 32 papers published from 2010 to 2016 have been selected to be examined in depth;

Analysis of the selected papers: the selected papers were classified and examined according to the main research method adopted (namely literature review, simulation, case study, analytical model, survey and conceptual framework) and the content.

As shown in Table 1, different methods were used by the authors. The majority of the papers were based on case studies (47%), thus tackling the application of IoT solutions within specific farm contexts. Di Palma et al. (2010) and Ryu et al. (2015) provided notable examples. More specifically, the former presented a practical case study, starting from a real problem and reaching the best Smart Agriculture architectural solutions with particular focus on hardware implementation and communication protocol design. The architecture was tested in several pilot vineyards sites throughout Italy and France. The latter illustrated the case of a connected farm based on IoT systems, analysing the advantages that can be obtained compared to traditional farms.

The papers based on conceptual frameworks (28%) attempted to use causal maps, matrices or other decision support systems in order to show the potential impact of IoT solutions, thus promoting the diffusion of Smart Agriculture solutions. For example, He et al. (2011) proposed a decision support system to facilitate fertilisation decisions.

Table 1: Classification of each paper by Method

Research method*	**Papers**
Case study (15; 47%)	Arazuri, Arana and Jaren (2010); de Lima, Silva and Neto (2010); Hwang et al. (2010); Tamayo, Ibarra and Macías (2010); Di Palma et al. (2010); Chaudhary, Nayse and Waghmare (2011); Zheng et al. (2011); Lopez et al. (2012); Zhang et al. (2013); Coates et al. (2013); Gupta et al. (2014); Kaewmard and Saiyod (2014); Jayaraman et al. (2015); Ryu et al. (2015); Chaudhary et al. (2015)
Conceptual framework (9; 28%)	Pontikakos, Tsiligiridis andv Drougka (2010); Diaz et al. (2011); He et al. (2011); Togami et al. (2011); Chebbi et al. (2011); Jiber, Harroud and Karmouch (2011); Lea-Cox et al. (2013); Channe, Kothari and Kadam (2015); Stočes et al. (2016)
Simulation (4; 13%)	Liao et al. (2012); Santos et al. (2014); Goumopoulos, O’Flynn and Kameas (2014); Khelifa et al. (2015)
Literature review (3; 9%)	Ruiz-Garcia and Lunadei (2011); Rehman et al. (2011); Suprem, Mahalik and Kim (2013)
Survey (1; 3%)	Aubert, Schroeder and Grimaudo (2012)
Analytical model (0; 0%)	
* The first number in brackets represents the number of papers, whereas the second the percentage on the total amount of papers (32).	

The analysis confirmed that a comprehensive view of IoT-enabled benefits in the field of Smart Agriculture does not exist yet. There are just a few authors (e.g. Arazuri, Arana and Jaren 2010, Zheng et al. 2011) that made a first attempt to summarise in a qualitative way the positive effects on farms due to the adoption of IoT for specific industries (e.g. tomato, wine, fruit). Moreover, models to quantitatively evaluate the benefits are still rare (4 papers use simulation, 0 papers propose analytical models).

Based on these premises, this paper aims to present an overview and a quantitative assessment of the benefits that can be achieved through the use of IoT solutions for Smart Agriculture. The analysis was performed in the case of the organic wine industry. Although the quantitative results cannot be generalised, the same approach can be replicated in other industries.

3. Assessing the benefits of IoT in Agriculture: the case of the organic wine industry

Before describing the structure and the outputs of the research activities, it is necessary to define the scope of the analysis, i.e. the organic wine industry. After analysing the differences between organic and non-organic supply chains, through the conduction of interviews with industry experts and farms that have already adopted IoT technologies (e.g. WSN - Wireless Sensor Network), we decided to focus on the former for several reasons:

- more pressure on product quality and company image;
- more stringent production requirements;
- higher profits;
- higher growth potentialities;
- presence of more “open-minded” entrepreneurs.

The preliminary steps of the research project were intended to analyse the main processes and understand the peculiarities of the organic wine supply chain. It was possible to identify the activities that were impacted the most by IoT technologies, i.e. spraying pesticides, irrigation and fertilisation. For these three activities, an activity-based model aiming to assess economic & environmental benefits and investment costs has been developed. The impact of IoT in terms of reduced resource requirements was evaluated by leveraging the experience gathered in interviews with industry experts and farms' owners. In addition, data from ISTAT[1] documents and industry reports were used. A specific analysis was carried on in order to investigate how the impacts may vary depending on the vineyard size.

The IoT solution considered within the analysis was composed by a GPRS gateway, several sensors - in order to monitor different parameters (e.g. air temperature, soil moisture, leaf wetness), useful accessories (e.g. solar panel regulator, batteries) and a central software to better manage the information in real time.

The analysis allowed the identification of the activities that could benefit the most from the IoT implementation. In particular, spraying pesticides is the most impacted activity in terms of benefits enabled, thanks to the possibility to precisely know the right amount of pesticides to be used for the treatment (reduction of 40% of pesticides usage – 1,300 €/ha per year). The benefits were evaluated considering three main drivers which affect the total cost: pesticides costs, labour costs and fuel costs. IoT technologies could also lead to positive effects on CO_2 emissions when vehicles are used for the spraying pesticides, leading to a reduction of about 714 kg/ha per year.

The absolute economic benefits achieved thanks to the reduction of water usage appears much lower than the ones obtained thanks to the reduction of spraying pesticides (reduction of 30% of water usage – but only 235 €/ha per year, since current costs are already low). This is an important result, since most of the interviewed farmers thought this would have been the activity most impacted by the IoT introduction (instead of reducing pesticides). This result is mainly due to the low cost of water in Italy, which is among the lowest in Europe.

With regard to fertilisation, this activity is generally carried out with a lower frequency compared to previous ones. Therefore the economic and environmental benefits are quire limited (reduction of 20% of fertilisers usage - 60 €/ha per year), resulting only from the accurate identification of the proper intake of nutritional resources.

As for the investment costs, it should be noticed that the same sensors needed to support decision regarding spraying pesticides can be used to facilitate water management and fertilisation as well (cf. Table 2).

Table 2: Parameters to be monitored for each activity

	Spraying pesticides	Irrigation	Fertilisation
Solar radiation	X	X	X
Rainfall intensity	X	X	X
Air temperature	X		X
Air humidity	X	X	
Wind intensity	X		
Atmospheric pressure	X	X	
Diametrical growth	X	X	
Soil moisture	X	X	X
Soil temperature	X	X	

For this reason, the cost analysis based on the IoT architecture presented below covers all of the sensors needed to enable all the three activities considered (cf. Table 3).

Table 3: IoT architecture

Base system	GPRS gateway unit with weather station
	GPRS gateway unit
	Wireless node unit
Sensors	Rain gauge, wind intensity and direction with solar shield
	Air temperature and humidity
	Leaf wetness
	Diametrical growth
	Soil moisture
Accessories	Solar panel 20W
	Solar panel regulator
	Poles and supports weather sensors
	Poles GPRS
	Battery 65 Ah
	Battery holder
	Wireless node battery
Installation and services	Installation costs
	Computer services (n° 1 GPRS unit with weather sensors)
	Computer services (n° 1 GPRS unit without weather sensors)
	Software

The cost analysis showed that the costs related to the base system represented from 22% (5 hectare company) to 45% (50 hectare company) of the total costs needed for the implementation of a complete IoT architecture. The costs connected to installation, computer services and software don't vary significantly (in absolute terms) on the basis of the company size, and have therefore an higher incidence on small companies (64% of total costs) than on large ones (20% of total costs).

Finally, comparing costs and benefits, the model allowed farms to evaluate the time required to pay back the investment, for different company sizes (cfr. Table 4 and Graph 1).

Table 4: NPV[2] and Payback Time[3] of the investment

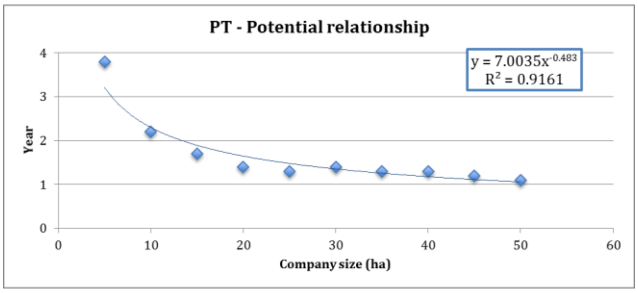
	5 ha	10 ha	20 ha	30 ha	40 ha	50 ha
NPV 1 year	-18,453	-16,144	-11,526	-17,032	-12,414	-7,796
NPV 2 years	-11,497	-1,958	17,120	26.074	45,152	64,231
NPV 3 years	-4,935	11,425	44,145	66,741	99,461	132,180
PT (years)	3.8	2.2	1.4	1.4	1.3	1.1

[1] The Italian National Institute of Statistics is an Italian public research organisation with the aim to to serve the community by producing and communicating high-quality statistical information.

[2] Discount rate assumed: 6%

[3] It refers to the discounted payback time of the investment.

Graph 1: NPV and Payback Time of the investment



The results show that small companies (5 ha) require a long time (i.e. four years) to pay back the investment due to the difficulty to pay back the software fixed costs; however, for medium size companies (10 ha) the balance improves significantly thanks to the possibility to cover fixed costs (i.e. software, installation, gateway) with greater benefits. For companies with size between 20 and 40 ha the value of Payback Time is close to 1.5 years because of the necessity to add other technological components in order to extend the coverage of the wireless sensor network. Finally, for large companies (50 ha) results are characterised by a further slight improvement (about 1 year).

In addition to this, the analysis showed that for small companies a variation in costs structure and in the main input data could lead to significant deviations of the results compared to the base case. Instead, shifting the focus on larger companies (equal or greater than 10 ha), the analysis allowed to highlight that an input data variation would not impact significantly on the overall results obtained in the baseline scenario. It can be concluded that for small companies the investments affordability is particularly conditioned by the specific business context, weather conditions and characteristics of the technological architecture. However, these factors have minor impacts on the economic investment considering medium and large size companies.

4. Conclusions

This paper investigated - through an in-depth literature review - the role of IoT for Smart Agriculture, and illustrated the most diffused research methods to assess the benefits achievable by farms' owners. The analysis focused on a set of 32 selected papers published from 2010 to 2016.

In addition, an activity-based model aiming to assess economic & environmental benefits and investment costs has been developed, considering a system composed by a software and several sensors, and including the three activities most impacted by IoT, i.e. spraying pesticides, irrigation and fertilisation.

This paper has both academic and practical/managerial implications. From an academic viewpoint, this study contributes to the knowledge in this field by providing a structured classification of the existing body of research on the role of IoT for Smart Agriculture, and an assessment approach that can be replicated for other supply chains. From a practical perspective, companies belonging to the organic wine industry can gain useful information on the identification of the activities that could benefit the most from the IoT implementation, and on benefits that can be obtained.

This study has one potential limitation that should be noted. Although efforts were made to be all-inclusive, some studies could have been omitted from this review. Nonetheless, the authors are confident that the present review offers an accurate representation of the body of research on IoT for Smart Agriculture published during the specified timeframe. The viewpoint adopted (i.e. aimed at providing a comprehensive vision on the topic) is particularly significant as it paves the way to the origination of a new stream of research in the field of Smart Agriculture.

In addition, further research should be carried out to develop two aspects of this work. The first is to refine the framework and to test it in several farms. The second aspect involves generalising the framework, to adapt it to for use in the process of evaluating the effectiveness of other technological innovations in the field of Smart Agriculture.

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