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# Selection of 4.0 sensors for small holders: the compromise between the advantages and the costs of the implementation

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## Abstract

The agricultural sector involves various environmental impacts, related to soil exploitation, water consumption and greenhouse gasses emissions. The advent of 4.0 technologies could help reduce them, e.g., by using sensors that constantly control the field. However, these solutions are often implemented by big producers that can easily bear their costs. Thence, in the case of small holders, can the benefits achievable with 4.0 technologies justify their implementation costs? To answer this question, an Italian field with three rows of tomatoes has been investigated as a case study. A row with a traditional irrigation system has been compared to two rows with a 60% irrigation scenario monitored with 4.0 sensors. Overall, one environmental sensor, three crop analysis sensors, three flowmeters, three valves and one network infrastructure have been selected and introduced. The key findings of the work allow for quantifying the amount of water that small holders can save; the positive Net Present Value recommends the investment, with a Pay Back Period of 1.9 years. In the next steps, additional 4.0 sensors will be tested in the agricultural supply chain of some selected small holders in the Mediterranean area, to check whether the 4.0 implementation could not only reduce water consumption, but also improve storage conditions and reduce wastage.

**Keywords:** 4.0 sensors; water consumption; agricultural management; sustainability; industry 4.0

## 1. Introduction

It is predicted that by 2050 the world will need to produce 70% more food to keep up with the growing population (Food and Agriculture Organization of the United Nations 2023), and this goal seems even more difficult to achieve due to ongoing climate and natural changes. In fact, soil degradation is spreading due to multiple factors: bad cultivation practices, irrational usage of water, herbicides and pesticides, tree cutting, fires, droughts, and intense rainfall. Over-exploitation impacts on climate change, which in turn affects the soil health, triggering a vicious circle. Agricultural practices affect the climate as livestock farming and industrial and transport activities do, but soil is also an essential resource for coping with the current climate change, due to its capacity to absorb carbon dioxide (IPCC Sixth Assessment Report 2022), so it appears as the solution, but in part the cause, of the problem.

In addition to environmental sustainability, economic and social aspects related to food and nutrition should also be considered, as delineated by the 2030 Agenda in its 17 Sustainable Development Goals (United Nations 2015). In this regard, the Food and Agriculture Organization (FAO) emphasizes the importance of taking actions to reduce inequalities and eliminate hunger and poverty in the world. Since agriculture does not only produce food but also generates income and livelihoods for rural populations, the FAO suggests increasing up to 60% the investments in agriculture and in rural infrastructure such as roads, storage and irrigation systems (Food and Agriculture Organization of the United Nations 2023). One way to improve farm yields and increase productivity by optimizing the potential of arable land and reducing wastage of water and electricity lies in the so-called *smart* agriculture. At the beginning of the 20th century, the agricultural production system was still characterized by a large use of labor, which, however, was not coupled with a high productivity. In the middle of the century, with the so-called "Green Revolution," production began to become more specialized, thanks to the use of fertilizers, plant protection products and selected seeds. Then, new technologies allowed for the sector to take a leap towards precision agriculture. Satellite technology supported agricultural machinery at this stage, allowing more targeted and effective interventions, according to the principle of applying the *right treatment* at the *right time* and in the *right place*. Now, with the so-called Industry 4.0, agriculture too has become even more technological thanks to the use of advanced strategies and tools that enable farmers to produce sustainably and efficiently by processing large amounts of data from the field. Each stage becomes interconnected to the others and objects and products become "intelligent:" they can exchange information leading to more specific and efficient interventions.

However, while big agricultural producers are likely to implement 4.0 solutions, small holders often lack economic resources. Hence, a question arises: are 4.0 technologies sustainable for small holders from an economic point of view? To answer this question, a case study has been analyzed in this study. The aim of the analysis is to evaluate the economic feasibility of installing several types of sensors, with a particular focus on a field located in Parma (northern-east part of the Italy). Before deeply analyzing the applicative case study, the next section summarizes the current scientific literature regarding the use of agriculture 4.0 and its technologies. Section 3 details instead the material and methods useful to this implementation. Results of the economic analysis are presented in section 4. Discussion, implications and conclusions are outlined in section 5.

## 2. State of the art

The *agriculture 4.0* paradigm mainly consists of five core technologies, covering sensors and robotics; Internet of Things (IoT), cloud computing, data analytics, and Decision Support Systems (DSS) (Dayioglu e Turker 2021). In particular, IoT innovations involve the connection of devices, tools and software aimed at optimizing processes and, consequently, consumption and revenues (Polymeni, et al. 2023). A crucial role is played by sensors, i.e., devices that allow measuring some selected parameters and communicate them to a management system. In agriculture, there are many useful factors to be kept under control to better manage huge plots of land, such as temperature, humidity, the amount of heat absorbed by the soil, the minerality of the soil, the presence of pests, up to extremely advanced chemical parameters. Thanks to the deployment of IoT technologies in agriculture, it is possible to constantly monitor the level of humidity in the soil, so as to activate irrigation only if necessary, allowing optimal conditions for different types of crops and, at the same time, considerably reducing water wastage (Preite, Solari e Vignali 2023). Other studies have highlighted the usefulness of implementing Wireless Sensor Networks (WSNs) in agriculture: the moisture content of the soil was maintained for vegetable growth, thus reducing costs and increasing agricultural productivity (Muangprathuba, et al. 2019), or enabling a full and complete control on the stages of the food supply chain (Capello, Toja e Trapani 2016), creating a very efficient management irrigation systems as described in (Senturk, Senturk e Karaka 2023). Overall, the combination of blockchain and IoT resulted powerful and can trigger significant transformations across several industries, paving the way to distributed applications and new business models (Christidis e Devetsikiotis 2016).

In agricultural industries, the search for new data sources has involved the use of different types of equipment, such as drones (Gupta, Kataria e Tripathi 2023) or new types of autonomous vehicles (e.g., Unmanned Ground Vehicles, UGVs). Data acquired by drones from the air contributes to more efficient spraying of crops and optimization of field management, thus increasing yields. Although it is still early days when it comes to the type of data collected and the use cases of analytics, some IoT scenarios are already bringing efficiency to the industry and helping to meet new market demands, improving procedures for irrigation, growing conditions and maturation identification (Das, et al. 2023). Moreover, the digital transition in agriculture seems to be able to support panning design and sustainable business (Martinho, et al. 2022), also from an economic point of view. For instance, a driverless tractor and a smart planter can reduce costs by 60% in comparison to a traditional scenario (Agenda Digitale 2023).

In Italy, the top high-tech agricultural sectors are cereals, wine, fruit and vegetables. However, only 3-4% of the agricultural area is cultivated with agriculture 4.0 devices. Technological, political, social, economic and environmental barriers inhibit their full development in the production chain (Da Silveira, et al. 2013), underling the complexity, energy management problems, lack of infrastructure, high costs of facility maintenance, security and privacy challenges of the agriculture 4.0 (Fang, et al. 2014). A significant amount of work still needs to be done to create and make available more scientific and technical financing programs, promoting skills and informing them about new technologies (Martinho, et al. 2022).

Of course, this situation is even more critical for small holders, that do not own the same financial resources as big farmers. Therefore, the authors of this paper wondered whether the implementation of 4.0 sensors in the agricultural field could allow even small farmers achieve the expected economic and environmental advantages with a positive cost-benefit balance, despite the more limited economic and technological resources.

To answer this question, a case study has been investigated. The next section illustrates the materials and methods used to carry out the research; then, results are presented and discussed before drawing the conclusions and future developments of the work.

## 3. Materials and Methods

The research is part of a European project whose aim is to increase the resilience and production efficiency of small-scale farms in the Mediterranean area. The project's partners, located in Italy, Spain, Tunisia and France, have delineated a framework that encompasses innovative strategies and technologies to reduce water consumption, improve storage conditions and overall reduce wastages in the fields and in the production chain (Smallders 2023). In this article, in order to evaluate the economic feasibility of a first series of selected commercial IoT devices that could be useful to small holders for agricultural monitoring of water consumption, soil and environmental conditions, a case study has been selected in a field located in Parma (Italy). A set of different sensors and actuators that could be integrated in small farms to collect relevant information has been defined, considering some basic functional requirements. Firstly, IoT devices should work in an outdoor environment, with an enclosure against dust and water. Second, the sensors deployed on the field should be provided with a power supply source, such as a battery, to guarantee life duration. Finally, sensors in the field must forward their collected data, e.g., through a wireless communication protocol: the main protocol selected for the IoT network architecture is Long Range Wide Area Network (LoRaWAN), which allows wide coverage, and is a reference technology in agriculture applications.

Taking into account those requirements, the following types of sensors have been selected:

- Flowmeter or water consumption sensor that periodically collects direct estimates of the flow consumption in the field, together with its actuator to be remotely controlled (Figure 1). It allows small holders to monitor water consumption trends, highlighting possible deviations from the average consumption levels.
- Crop analysis sensor (Figure 2): it can collect information about the crops growing or the soil status, in terms of moisture, temperature, and electrical conductivity. The analysis of historical trends allows small holders to enjoy a brighter vision of the soil status, supporting them in the decision about different farming activities.
- Environmental sensor (Figure 3): weather sensor that can monitor the outdoor conditions around the crops, collecting information about the pressure, $CO_2$ level, or humidity. This kind of sensor may also be deployed in indoor environments, to monitor the internal environmental status and prevent possible unhealthy situations, e.g., temperature and pressure of food items collected in several ways, such as in tanks.
- Network infrastructure IoT device (Figure 4): device with the aim to provide connectivity capabilities to other sensors/actuators and collect data from local networks (e.g., gateways).

**Figure 1.** On the left: the selected water consumption sensor (Talkpool OY1310 2023). On the right: the valve (MClimate T-Valve 2023).

**Figure 2.** Selected crop analysis sensor (Milesight EM500-SMTC 2023)

**Figure 3.** Selected environmental sensor (Milesight EM500-CO2 2023)

**Figure 4.** Selected network infrastructure (Gateway LoRaWAN Milesight UG67 2023)

In the case study, a field with three rows of tomatoes cultivated by an Italian small holder has been considered. In the first tomatoes' row, the operators do not have any type of sensors and they irrigate in a traditional way. This is the reference case, in which 100% of water is used for the irrigation. In the other two tomatoes' rows, 4.0 sensors have been implemented and a 60% irrigation has been tested.

Overall, 1 network infrastructure device, 1 environmental sensor, 3 crop analysis sensors, 3 flowmeters and 3 valves have been inserted, with the assumption that they can be sufficient and efficient since the field is homogeneous, without hills or depressions. The cultivated lines are 88 m long and 1.5 m wide, resulting in a cultivated area of 0.0396 ha. In the traditional configuration, the operators irrigate the field 3 days per week. The overall time of tomatoes cultivation is approximately 10 weeks, since in the final two weeks the farmers affirm that they almost do not irrigate. Therefore, the days of irrigation are 30 days. The pump used for the irrigation has a power of 4 kW (Xylem 2023). The cost of electric energy is estimated as 0.43854 €/kWh (Arera 2023). Considering those data, an evaluation of the environmental and economic consequences of the two different scenarios, namely the traditional with 100% irrigation and the 4.0 with smart sensors and 60% of irrigation, has been performed.

## 4. Results and Discussion

The total cost of the 4.0 sensors, required in the 60% irrigation scenario, resulted equal to 3112.50€, as detailed in Table 1. Moreover, a 10% of unforeseen costs for ruptures or malfunctions have been considered, for a total of 311.25 €.

**Table 1.** Cost of the network infrastructure, sensors and valves.

| Item | Description | Quantity | Price [€] |
|---|---|---|---|
| Network infrastructure | Gateway LoRaWAN outdoor IP67 Milesight UG67 | 1 | 597.80 |
| Environmental sensors | Milesight EM500-CO2 | 1 | 236.68 |
| Crop analysis sensors | Milesight EM500-SMTC | 3 | 1453.02 |
| Flowmeters | Talkpool OY1310 | 3 | 270.00 |
| Valves | MClimate T-Valve LoRaWAN Water Valve | 3 | 555.00 |
| *Total cost* | - | - | *3112.50* |

The Initial Investment ($I_0$) is equal to the sum of devices costs and unforeseen costs:

$$I_0 = 3112.5\text{ €} + 311.25\text{ €} = 3423.8\text{ €} \quad (1)$$

Three irrigation tests have been performed for both the traditional irrigation and the 4.0 case: Table 2 and 3 illustrate the irrigation time registered and the water supplied.

**Table 2.** Irrigation time and water supply in the traditional irrigation scenario (reference case).

| | Test 1 | Test 2 | Test 3 | Mean value |
|---|---|---|---|---|
| Irrigation time [h/day] | 6.8 | 6.8 | 7.7 | 7.1 |
| Water supply [liters/day] | 5629.8 | 4930.2 | 5481.3 | 5347.1 |

**Table 3.** Irrigation time and water supply in the 4.0 irrigation scenario.

| | Test 1 | Test 2 | Test 3 | Mean value |
|---|---|---|---|---|
| Irrigation time [h/day] | 4.4 | 4.2 | 4.5 | 4.4 |
| Water supply [liters/day] | 3590.4 | 2904 | 3828 | 3440.8 |

In order to calculate the Gross Cash Flow (GCF), the falling and the raising costs in the 4.0 and traditional irrigation scenarios have been considered, namely the pumping and installation costs. The pumping cost has been calculated as illustrated in Equation 2:

$$Pumping\ cost = \frac{Pump\ power * irrigation\ time * electric\ energy\ cost}{Area\ of\ the\ field} \quad (2)$$

Pumping cost resulted 9180.3 €/(year*ha) in the traditional irrigation (falling cost) and 5671 €/(year*ha) in the case of 60% irrigation scenario (raising cost), therefore with a difference of 3509,27 €/(year*ha). For the sensors' installation, two technicians were required. Considering a cost of 250 €/day and 2 days of installation and tests, the overall installation cost resulted 1000€/(year*ha), that is a raising cost in comparison with the traditional scenario, in which any 4.0 installation is required (0 €/(year*ha)). Therefore, the Gross Cash Flow has been calculated as illustrated in Equation 3:

$$GCF = (0\text{€} - 1000\text{€}) + (9180.28\text{ €} - 5671.01\text{€}) = 2509.3\text{€} \quad (3)$$

Figure 5 resumes the cost of the investment and its depreciation considered in 5 years, as well as the Gross Cash Flows generated by the pumping and installation costs. Then, several economic indicators were calculated to evaluate the convenience of the 4.0 implementation. An aliquot of 34% and a discount rate of 5% have been estimated. A series of factors have been calculated to estimate the Net Present Value, the Pay Back Period, the Internal Rate of Return and the Return on Investment: they are summarized in Figure 6 and explained below.

The Net Present Value (NPV) is commonly calculated to know the profitability of an investment project: NPV creates value when it is positive, while it expresses the unprofitability of the project when it is less than zero. The NPV is evaluated using Equation 4, where $NCF_n$ is the Net Cash Flow in year $n$, and $i$ is the evaluated discount rate (5%), calculated as illustrated in Figure 6.

$$\text{Net Present Value} = \sum_{n=0}^{5} \frac{NCF_n}{(1+i)^n} \tag{4}$$

$$NPV = -3423.8€ + 1799€ + 1713.3€ + 1631.7€ + 1554€ + 1480€ = 4754.3\ €$$

Since NPV is positive, the implementation of 4.0 sensors appears profitable.

The Pay Back Period (PBP) has been calculated to know the number of years that will pass before recovering the initial investments, i.e., before the cumulative value of cash receipts equals the initial outlay. The evaluated PBP was given by Equation 5, where $A_0$ is the year before the year of the economic recovery, *ILR* is the amount of the investment remaining to be recovered in $A_0$, and *CIF* is the cash inflow during the year of the recovery ($A_1$).

In order to calculate these parameters, it is necessary to evaluate the cumulative cash inflows, referred in Figure 6 as the total discounted.

$$\text{Pay Back Period} = A_0 + \frac{\text{ILR}}{\text{CIF}} \tag{5}$$

$$PBP = 1.9 \text{ years}$$

The result affirms that only 1.9 years are required to recover the initial investments of the 4.0 scenario.

The Internal Rate of Return (IRR) is the discount rate that equals the NPV to zero; in other words, it creates the actual value of the cash flows equals to the investments' costs. In Equation 6, *NFC<sub>n</sub>* is the Net Cash Flow each *n* year.

$$0 = \sum_{n=0}^{5} \frac{NCF_n}{(1+IRR)^n} \tag{6}$$

$$IRR = 47\ \%$$

The Return on Investment (ROI) is a widely used metric for evaluating the profitability of an investment. It is calculated as in Equation 7 by dividing the Average Annual Net Return (ANRI) by the Initial Cost of the Investment *(ICI)*, as illustrated in Figure 6:

$$\text{Return on Investment} = \frac{ANRI}{ICI} * 100 \tag{7}$$

$$ROI = \frac{1579.8\ €}{3423.8\ €} * 100 = 46.1\%$$

Finally, the amount of water wastage reduction was calculated. According to the performed tests in Table 2 and Table 3, in one day, the 60% irrigation scenario allowed a water saving of 1906.3 liters in comparison to the traditional scenario. Therefore, in 5 years, the saved water could be 285945 liters in the small field considered: it is a big amount, considering that the water scarcity is growing due to climate change.

**Figure 5.** Investments, depreciation for 5 years and grass cash flows.

| | **INVESTMENTS** | | | | | | **DEPRECIATION** | | | | | | **GROSS CASH FLOWS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 | |
| **Devices Purchase (DP)** | 3,112.5 | – | – | – | – | – | – | 622.5 | 622.5 | 622.5 | 622.5 | 622.5 | – |
| **Installing** | – | – | – | – | – | – | – | – | – | – | – | – | – 1,000.0 |
| **Pumping** | – | – | – | – | – | – | – | – | – | – | – | – | 3,509.3 |
| **Unforeseen cost (10% of DP)** | 311.3 | – | – | – | – | – | – | 62.3 | 62.3 | 62.3 | 62.3 | 62.3 | |
| Σ | **3,423.8** | – | – | – | – | – | – | **684.8** | **684.8** | **684.8** | **684.8** | **684.8** | **2,509.3** |

**Figure 6**. Changes in profit and loss accounts for 5 years.

| Year (n) | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| $1/(1+i)^n$ | 1 | 0.95 | 0.91 | 0.86 | 0.82 | 0.78 |
| Gross Cash Flows (GCF) = Falling costs - rising costs | | 2509.3 | 2509.3 | 2509.3 | 2509.3 | 2509.3 |
| Depreciation (D) | 0 | 684.8 | 684.8 | 684.8 | 684.8 | 684.8 |
| Earnings Before Taxes (EBT) = GCF - D | 0 | 1824.5 | 1824.5 | 1824.5 | 1824.5 | 1824.5 |
| Taxes (T) = EBT * Aliquot | 0 | 620.3 | 620.3 | 620.3 | 620.3 | 620.3 |
| Net value (NV) = EBT - T | 0 | 1204.2 | 1204.2 | 1204.2 | 1204.2 | 1204.2 |
| Initial unvestments ($I_0$) | 3423.8 | 0 | 0 | 0 | 0 | 0 |
| Net cash flow (NCF) = NV + D - $I_0$ | -3423.8 | 1888.9 | 1888.9 | 1888.9 | 1888.9 | 1888.9 |
| Total discounted = NCF $*1/(1+i)^n$ | -3423.8 | 1799.0 | 1713.3 | 1631.7 | 1554.0 | 1480.0 |
| **Net Present Value (NPV) [€]** | **4754.3** | | | | | |
| Cumulative value of total discounted | -3423.8 | -1624.8 | 88.5 | 1720.3 | 3274.3 | 4754.3 |
| **Pay Back Period (PBP) [years]** | **1.95** | | | | | |
| **Internal Rate of Return (IRR) [%]** | **47%** | | | | | |
| Average annual Net Return of Investment (ANRI) = Average of EBT$*1/(1+i)^n$ | 1737.6 | 1654.9 | 1576.1 | 1501.0 | 1429.6 | 1579.8 |
| Initial cost of the investment (ICI) = $I_0*1/(1+i)^n$ | 3423.8 | 0 | 0 | 0 | 0 | 3423.8 |
| **Return of Investment (ROI) [%]** | **46%** | | | | | |
| **Water saving [m$^3$]**= m$^3$ of water/day * 30 days * 5 years | **286** | | | | | |

## 5. Conclusions

The agricultural sector today is characterized by environmental and economic challenges. A brief literature review has shown that some sensors belonging to the so-called fourth industrial revolution allow to analyze and monitor data in the fields, thus reducing consumption and waste. However, only a small proportion of farmers use them, due to economic, cultural and technological obstacles. Within a project located in several Mediterranean countries, this work aimed to analyze whether the implementation of selected 4.0 sensors for monitoring water consumption and soil status could be a profitable investment also for small farmers. To this end, a case study was analyzed in Italy on three rows of tomatoes, comparing one row traditionally irrigated with two rows with 60% reduced irrigation monitored by selected 4.0 sensors. Using economic parameters, the profitability of the investment was then evaluated. To assess it, a time horizon of 5 years was considered. In addition to the running costs of the pump, which can be reduced since the water consumption is lower in the 4.0 scenario, also the installation and purchase costs of the sensors were considered, and an additional 10% of unforeseen costs were estimated.

Overall, the economic conclusions demonstrate that the investments create value and, in only 1.9 years, the investment could be compensated. Therefore, the implementation of environmental and crop analysis sensors appears feasible and profitable. Moreover, from an environmental point of view, also positive environmental consequences could be obtained by small holders, saving up to 286 $m^3$ of water in 5 years. From a qualitative perspective, the tomatoes that received less water do not present great changes if compared to the tomatoes' row irrigated traditionally, but further analysis based on the dimension, color, weight and yield will be performed in the next part of the project, in order to verify quantitively this perception. Moreover, in the future developments of the work, the authors will investigate the economic benefits and the environmental and technological performance of other types of sensors that can be used by small holders in the field, such as fuel consumption sensors, that provide data about the level related to the quantity of oil/gasoline used every day, localization sensors to track shipments, and plant health sensors, that monitor the health of specific crops and cultivars. Thanks to the additional future tests, the authors will aim to verify if the implementation of 4.0 sensors in the entire agricultural supply chain could reduce not only water consumption, but also improve storage conditions and reduce wastage, helping small holders to reach environmental and economic benefits in the fields as well as in the production chain.

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