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The agricultural innovation in the Italian landscape: drones adoption

MASTER OF SCIENCE IN
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Abstract

The increase in population and changes in food consumption patterns are two of the societal challenges that agriculture is called upon to face. Furthermore, agriculture is in a peculiar situation since it is highly impacted by the climate changes, but concurrently it contributes to pollute the environment. Therefore, drones could be a possible solution to overcome this issue. UAVs have increasingly been used within farming operations for more than a decade and are shown to provide many benefits. Despite the technology can be considered quite mature within the agricultural sector, both the adoption of drones by farmers and academic research in this field are still limited. After a brief excursus on the use of drones at an international level with a focus on the agricultural sector, this thesis, developed in collaboration with the Drones Observatory of Politecnico di Milano, provides an overview of the use of drones in the Italian landscape highlighting modalities of application as well as factors influencing their adoption in farming operations. The findings are of interest to policy makers as well as drone manufacturers and dealers.
This study is among the first to consider adoption intent among Italian farmers of use of UAVs for agricultural operations.

Key-words: Drones, Unmanned aerial vehicles, Italian farmers, Precision agriculture, Technology adoption.

Abstract in lingua italiana

L'aumento della popolazione ed i cambiamenti nelle diete alimentari sono due delle sfide derivanti dalla società che l'agricoltura è chiamata a fronteggiare. L'agricoltura, inoltre, è strettamente correlata al cambiamento climatico in quanto, da una parte ne è influenzata, dall'altra può considerarsi artefice poiché contribuisce direttamente ad inquinare l'ambiente: i droni potrebbero essere una possibile soluzione al superamento del problema. Da circa un decennio, l'impiego dei droni nell'ambito agricolo ha subito un incremento, mostrandone molti vantaggi nell'utilizzo; fatta questa premessa, nonostante la tecnologia nel settore agricolo possa essere considerata abbastanza matura, sia l'adozione dei droni per la coltivazione sia la ricerca accademica nell'ambito è ancora limitata. Dopo un breve excursus sull'utilizzo dei droni a livello internazionale con un focus sul settore agricolo, questa tesi, sviluppata in collaborazione con l'Osservatorio Droni del Politecnico di Milano, si è soffermata sul contesto italiano, con lo scopo di fornirne una panoramica sull'uso dei droni, evidenziandone le modalità di applicazione nonché i fattori che influenzano la loro adozione nelle attività agricole. I risultati sono di interesse per i policy maker nonché per i produttori e i rivenditori di droni.
Questo studio è tra i primi a considerare l'adozione degli UAV tra gli agricoltori italiani a supporto delle attività agricole.

Parole chiave: Droni, Veicoli aerei senza equipaggio, Agricoltori italiani, Agricoltura di precisione, Adozione della tecnologia.

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Executive Summary

The agricultural sector is under economic pressure due to intense regulation and international competition. On the macro level, agriculture have to face several challenges of today's societies. One challenge is greater food needs due to a growing population and changed food consumption patterns. Another challenge is sustainability. On one hand, agriculture can have negative impact on the environment. On the other hand, agriculture can absorb carbon, produce substitutes to fossil-related products, and improve biodiversity.

Innovation might be the solution. Agriculture has historically undergone innovation-based revolutions. In 2015, the terms ''*fourth agricultural revolution*'' or ''*agriculture 4.0*'' were proposed. These terms referred to the impact of sensors, satellites, digital technology, and robotics, not least in terms of paving the way for precision farming. Part of this revolution is also represented by Unmanned Aerial Vehicles (UAVs).

UAVs, also known as drones or Unmanned Aerial Systems (UAS), are remotely controlled by an operator on the ground or pre-programmed to fly specific routes. They are one of the most promising innovative technologies invented in recent years to promote smart farming. Agricultural UAVs not only minimize labour requirements and cut down production costs, but they also facilitate accurate crop protection products spraying, which ensures the safety of agricultural products and the environment and at the same time reduces the risks associated with the use of chemical pesticides. However, previous studies on agricultural UAVs have mostly focused on technical problems such as software and hardware design. Few studies have examined factors affecting the drones' adoption process by farmers.

This Thesis, developed in collaboration with the *Drone Observatory* of Politecnico di Milano, aims at, firstly, mapping drones' application cases at international level considering all the relevant sectors, in particular, with a specific focus on agriculture. Secondly, it aims at providing an overview of the drones' adoption in the Italian landscape highlighting modality of applications as well as factors influencing their adoption in farming operations. Overall, this work provides useful insights on the relevant role of drones in the agriculture industry.

Consequently, the Thesis is organized in five parts. The first chapter will provide a general overview of the actual drones' applications in agriculture and subsequently it will show the state of the art of the academic research on the factors affecting the UAVs adoption process by farmers. Afterwards, the second chapter will present the research questions for which this Thesis was written, and the two main methodologies adopted to address them, i.e., the census of application cases and the survey to farmers. In the third chapter, results derived by the census and the survey will be displayed. While in the fourth chapter, a discussion of the main findings will be provided through comparisons among results and use of the academic literature in their support. Finally, the last chapter will draw conclusions, and limitations to the research activity carried out and hints for possible future research development will be highlighted.

Literature Review

UAS are mostly being used for military applications but in recent years particular attention has been paid to the integration of drones into the civil sectors, including the agricultural sector.

In the literature, many characteristics can be found to classify drones. However, wing type and the level of autonomy are the most relevant features in agricultural operations among the several classification drivers. Based on the type of wing, it is possible to identify, in turn, three categories: single-rotor (helicopters) and multi-rotors UAVs, fixed wing aircrafts, and hybrid vertical take-off and landing (VTOL). According to the autonomy level, drones can be classified, in turn, into teleoperated, tele-commanded, and autonomous.
Subsequently, UAVs can be equipped with many payloads. The payloads of a drone encompass all the sensors and actuators that are not involved in the control of its flight. In the precision agriculture domain, two types of payloads can be identified: sensors and spraying system.
Then, according to the existence or not of a physical interaction with crops, two main clusters of precision agriculture applications involving UAVs can be found: remote sensing and aerial spraying. Recently, further UAV applications emerged in the precision farming paradigm like sowing, aerial mustering, pollination, harvesting, marketing, and crop damages assessment.

Despite the promise of its enormous potential, the adoption of precision agriculture technology, including drones, by famers has generally fallen short of expectations. Therefore, it is worthwhile to identify key factors influencing the adoption of UAVs. Many factors can affect the growers' willingness to adopt drones in their farming activities. They can be classified into four main clusters which includes farmer and farm characteristics, attitudinal factors, and external factors. Farmer characteristics encompasses age, education level, gender (namely being male), precision agriculture technology literacy, and traditional technical specification. Within Farm characteristics were identified the following variables: availability of a successor, family income, farm size, income ratio, livestock, number of agricultural workers, number of borrowing channels/access to credit, and renting out. Regarding the Attitudinal factors, the following variable were identified: perceived ease-of-use/attitude confidence, perceived usefulness/job relevance, and understanding level. Finally, External factors includes cooperative membership, neighbour privacy concerns, presence of a village cadre in the farmer's family, collaboration with neighbouring farmers, and peer influence.

The literature suggests that there are significant differences in the farmer and farm characteristics of “current adopters” and “prospective adopters” groups and “non-adopters” group. However, it is difficult to precisely outline the traits of the “drone adopter” because there is not always a conformity in the results of the extant studies. They depend by several factors from country to country and from one drone applications to another.

Objectives and Methodologies

Drones are one of the most up-and-coming innovative technologies invented in recent years adopted in agricultural activities. Few studies have examined influencing factors and users’ behaviours in the implementation process. Moreover, that research focus only on few specific countries – namely, China, Germany, USA, and Australia. Therefore, it is relevant to provide the literature with a cross-section of agriculture on the Italian context about the adoption of drones in farming operations. Based on the literature gaps just evidenced, three research questions (RQ) have been developed:

> RQ1: “What are the areas and modality of application of drones at an international level with a specific focus on agriculture?”
>
> RQ2: “What is the state of use and diffusion of drones on farms in Italy?”

> RQ3: "What factors can foster or curb the adoption of drones by Italian farmers?"

Regarding RQ1, the main objective is providing a general overview of the current level of adoption of UAVs worldwide and to take stock of the situation on the use of drones in agriculture compared to other sectors/civil use. Whereas RQ2 and RQ3 directly refer to the Italian agricultural sectors and aim at providing an overview of the level of adoption of UAV by Italian farmers and, finally, trying to derive some factors affecting the adoption process.

In order to address to the aforementioned research questions, two methodologies have been used. The census of drone applications aims at addressing the first research question (RQ1). It was performed by revising news and articles not coming from academic literature. It has to be noted that the scope of the census leaves out all the drone applications for military purpose and final consumers uses. In other words, only business uses are taken into consideration. Then, the work was carried out considering only publications related to the period from 2019 to 2021.

The survey aimed at answering the last two research questions (RQ2 and RQ3). The scope of the analysis was mainly targeted to study the level of drone adoption among the Italian farms and to assess possible factor affecting UAVs adoption. The survey is the result of a cross-sectoral joint work between *Smart AgriFood Observatory* of Politecnico di Milano and *Drone Observatory* of Politecnico di Milano. The unit of analysis was the single agricultural firm of any size and sector, excluding livestock, with headquarters in Italy.

Empirical Analysis

First, an overview of the main area of applications of drones, with a specific focus on agriculture, considering Italian as well as the international context is provided. Second, the main results arisen from the survey issued to Italian farmers are showed.

Regarding the census, 816 articles from newspapers, magazines, and blogs were collected. The main areas of drones' adoption were Public Administration (31%), Logistics (13%), and Environmental Safeguard (13%) followed with less extent by Healthcare and Pharmaceutical (8%), Utility (7%), Agriculture (7%), Entertainment and Media (6%), and Infrastructure (6%). Considering the scope[1] of drones' applications, it is possible to see that Inspections (30%), Transportation (29%), and Security and Surveillance (14%) are the most diffused types of activity carried out by UAVs.

Half the uses are either only announced or are in a state of experimentation (23% and 29% respectively), while 30% of the applications are in an operative state. Then, few times the articles reported a case of UAVs used just once in order to face a single necessity.

In the vast majority of applications, activities are performed using multi-rotor wings drones and VTOL drones endowed with camera RGB or distributor and other material transport systems.

From a geographical perspective, Europe, America, and Asia are the continents more active in the development and introduction of solutions based on drones.

[1] Scope 1.

Subsequently, an overview of the most common benefits sought is presented. Time reduction is the most recurrent benefit adopters look for, followed by the possibility to achieve higher security in performing the activity and to reach uncomfortable places.

Finally, an overview of the different application scopes divided per sector is provided. In the logistics domain, drones are almost all used for transportation of materials; whereas the vast majority of drones' uses in environmental safeguard is mainly concentrated in the inspections. Likewise, in the infrastructure industry, drones are mainly adopted to carry out inspections. Also, companies working in the utility sector, mainly adopt drones to conduct inspection. While the main purpose of UAVs' use in the healthcare and pharmaceutical sector is the transportation. Conversely, in the Public Administration there is not a scope which is the most popular, but in this case there are three main applications: inspections, research and rescue, security and surveillance.

Focusing on the agricultural sector, 55 evidences of adoption have been reported divided into dispensing and inspections activities. More in detail, the main purposes of application are related to the release of materials (fertilizers, crop protection products, seeds and water) followed with less extent by crop monitoring and field surveys and mappings. From a geographical perspective, things don't change much from the general context; Europe, America, and Asia still are the leading continents.

Regarding the state of application, the agricultural sector mirrors what happens in the other industries. Indeed, more than half of cases are in a state of announcement or experimentation. While 39% of applications is currently ongoing at fully power.

Only multi-rotor wings and VTOL drones were used in agriculture, and, in the vast majority of the reported cases, they were endowed with dispenser of liquids, granules, powders, telecamera, camera RGB, thermal camera, or other sensors.

Focusing on benefits, time reduction is still the benefits most sought followed by cost reduction and increase of production yield.

For what concerns the survey, 360 farmers followed the invitation and answered the questions related to drones. Growers in the sample are on average 51 years old with 26 years of experience in farming activities with a medium-high education level, and most of them are located in the northern Italy. Companies surveyed grow medium-large cultivated land area and they have a medium-high income. For what concerns the crop typology, cereals are the most diffused crop typology followed by vineyards, olive groves, and leguminous plants.

Moving to the descriptive result of the survey related to drones, half of farmers have an average knowledge of the technology and they got to know about drones mainly through specialized media, scientific magazines, fairs or congress, and general media. Among respondents, 12%[2] of farmers declared they used drones in their farming operations in the past. They decided to invest in UAV technology mainly for their curiosity in experimenting something new. Nevertheless, they did not achieve the desired results and they stop using drones because they did not encounter any benefits from the introduction of the new technology and due to lack of internal skills.

Moving to the actual situation, only 4,4%[3] of farmers declared to currently make use of drones in their farms. The most diffused applications are the use of mapping services of crops and land through data collected by drones, spreading fertilizers, and crop monitoring without the production of maps. In the vast majority of the applications, companies integrated drones with existing solutions in order to improve

[2] Total sample: 342 farmers.
[3] Total sample: 360 farmers.

environmental sustainability, to experiment new solutions, and to improve effectiveness. Almost all farmers employed a multi-rotor wings UAV endowed with multispectral camera or telecamera. Farmers reported to have been able to reduce the environmental impact, improve the accuracy and/or quality of data collected and increase in the amount of data collected.

Looking at the future, 19%[4] of farmers stated that they are willing to invest in drone technology. The main scopes of application will be use of mapping services of crops and land through data collected by drones, performing crop and field monitoring without the production of maps, and spreading of crop protection products. More than half of respondents will integrate drones with their existing resources in order to improve the efficiency of their farming operations.

Farmers reluctant to the adoption of drones complained about an uncertainty of the return on investment and lack of knowledge about the cost and benefits of drone technology as the main blocking factors.

Results Discussion

This study carried out a census of 816 application cases and a survey to 360 Italian farmers. Agriculture results as the sixth sector per number of application cases. Drones are mainly used in aerial spraying, crop monitoring, and field surveying and mapping. Farmers use drones mainly to improve efficiency both in terms of time and cost and to increase the crop yield. Regarding the Italian context, the current level of drones' adoption is very low, but in the future, it is expected to grow a lot. Education level, farm size, and farm income plays a relevant role in the adoptions process. However,

[4] Total sample: 360 farmers.

in the future also SMEs will start new drone-based projects. Whereas farmers' age seems not to play a relevant role. Nevertheless, many farmers are reluctant to invest in UAV technology due to uncertainty of the return on investment and lack of knowledge about the cost and benefits of drone technology. Until farmers will not be fully aware of the potentiality and benefits about the use of UAVs, their adoption will be always limited.

Conclusions

As any other research, this Thesis presents some limitations. The census is based mainly on Italian, European, and American (mainly USA) newspapers and specialist magazine. Moreover, not all the articles reported all the information desired, hence, some statistics are not based on the full number of articles collected.

Regarding the survey, the first limitations was the number of farmers that followed the invitations to the section about drones compared to the total number of respondents. Moreover, very few companies reported to currently use drones. This low number did not allow to further analyses, otherwise meaningless. Additionally, future case studies could go into more detail on aspects such as the reasons for the introduction and abandonment of technology and the benefits achieved.

Despite its limitations, this Thesis is of interest both for drones' manufacturers/service providers and policy makers. Drones' manufacturers and service providers can get ideas from the results highlighted in this Thesis to better design marketing campaign choosing the best farmer type to address. Whereas policy maker and governments can play a crucial role giving grants and facilitating the access to funding, especially for SMEs that has limited resources and struggle to reach economies of scale to absorbs an important investment as the one in drone technology.

Future research may concentrate on other countries in order to enrich the literature which is limited in this field and may be of interest to deepen the correlation between the type of cultivation and their characteristics and the drones' adoption rate.

Introduction

According to the Food and Agriculture Organization of United Nations (FAO, 2018), to feed the world population estimated to reach nearly 10 billion people by 2050, the world agricultural productivity must increase about 60%, posing a big challenge for agriculture.

Agriculture is in a peculiar situation since it is highly impacted by the climate change (e.g., higher temperature, strong phenomena such as storm wind and hurricane, and water scarcity). As it is an industry highly dependent by seasonality, the loss derived from the effect of climate change, that destroy entire crop plantation compromising the annual yield, is difficult to replace in the very near feature. At the same time farming operations directly contribute to the environmental pollution. Indeed, intensive agriculture has several negative impacts on the environment (Daponte *et al*., 2019). On one hand excessive fertilizers application can cause pollution risks for the environment due to the emission of a significant amounts of nitrogen and phosphorus to natural ecosystems, on the other hand insufficient fertilizer can lead to soil degradation and loss of fertility. Additionally, pollution of aquifers and rivers, and consequent degradation of water-related ecosystems are rising due to agricultural chemicals seeping into nearby water (Ahmad *et al*., 2020). Furthermore, the health risk aspect of the use of chemicals in agriculture needs to be taken into consideration as well (Ahmad *et al*., 2020). Chemicals may threat farm workers, as well as families and possibly the inhabitants of the areas surrounding farming fields. Finally, pesticides absorbed by crop and natural resources (i.e., water and soil) end up in the food chain, affecting both livestock and humans, with huge negative impacts on the public health.

Agriculture is also facing many economic challenges in terms of productivity and cost-effectiveness along with the increasing labour shortage partly due to the depopulation of rural areas (Cerro *et al.*, 2021). Moreover, it should be considered a change in food consumption patterns, including diet diversifications and food trends (Frankelius *et al.*, 2017; Daponte *et al*, 2019).

Therefore, agriculture needs to be addressed with a new approach, relying more on ad hoc production processes, technologies, and tools (Cerro *et al.*, 2021). Thus, chemicals such as fertilizer and pesticides would be only applied where needed instead of being spread over a large area. At the same time, such advanced farming techniques may lead to increasing crop productivity and quality to feed an ever-growing population (Daponte *et al.*, 2019). In such a context, drones, as part of a large technology mix, have the potential to play a relevant part in filling the gap between actual production and future need.

Unmanned Aerial Vehicles (UAVs) – also known as drones or unmanned aerial systems (UAS) – are emerging tools for use in agriculture, mainly due to their flexibility in delivering multiple applications being one of the smart farming techniques that have developed the most in recent years (Amaral *et al.*, 2020) and it is expected in the future they will play a crucial role in the development of the agricultural sector (Daponte *et al.*, 2019; Radoglou-Grammatikis *et al.*, 2020; Cerro *et al.*, 2021). Drones can help farmers in a wide variety of operations, including analysis and planning of crop plantation as well as field monitoring to determine the growth, health of crops, and spraying. However, several security and safety concerns, lack of trained pilots, and UAS traffic management issues are some of the factors that can curb the growth of the commercial drone market along with privacy concerns and, above all, ambiguities in regulations and limitations to the use of drones in agricultural operations (Abdullahi *et al.*, 2015) Radoglou-Grammatikis *et al.*, 2020; Cerro et al., 2021).

The Federal Aviation Administration (F.A.A.) defines a UAS as "[…] an aircraft that is operated without direct human intervention from within or on the aircraft". Furthermore, Maddikunta *et al.* (2021) defined UAV as "[…] one type of aircraft that can fly autonomously in the air without the involvement of a pilot on board, and the aircraft's motion is controlled remotely by an operator".

Drones are devices of various sizes, capable, in fact, of performing several activities by flying in the sky without the need of a pilot on board, who instead remains on the ground or on an adjacent vehicle and drives the drone by means of a control mechanism. At times, these machines are able to operate in a completely autonomous way. From a technical perspective, a drone consists of a hardware part – the drone infrastructure, with all its components: frame, engines, flight controller, batteries, wings – and a software part – the algorithm implemented on the onboard computer chip allowing the drone to gather, process and interpret data, and to be controlled from the ground. In addition, UAVs can carry several types of payloads (cameras, sensors and substance dispensers are a few examples) that help them performing different tasks.

Consequently, the objective of this Thesis is twofold. Firstly, it maps drones' application cases at international level considering all the relevant sectors, in particular, with a specific focus on agriculture. Secondly, it tries to provide an overview of the drones' adoption in the Italian landscape highlighting modality of applications as well as factors influencing their adoption in farming operations. Overall, this work provides useful insights on the relevant role of drones in the agriculture industry. In so doing, it produces interesting considerations and suggests possible hints for future research, providing a contribution to the current academic literature. The research is organized as follows. In the chapter *Literature review,* the main state-of-art contributions are analyzed and studied. The different drones' characteristics and drones' applications in agriculture are reported as well as the several factors influencing UAVs' adoption process by farmers. The section *Objectives and Methodologies* highlights the main research objectives and the methodologies adopted by the study in addressing the researched questions. In *Empirical Analyses* the main findings obtained from the census and the survey to farmers are showed. While in *Results Discussion,* a critical analysis of the main findings through comparisons among results and use of the academic literature in their support is provided. The last chapter is dedicated to *Conclusions*, to highlight the main research limitations, and to suggest insights for future research development.

1 Literature Review

The first chapter presents the current state of the art of the literature regarding the adoption of drones in agriculture. The aim is, firstly, to give a preliminary overview about the use of UAVs in supporting farming activities; secondly, to analyse the farmers' drone adoption process, highlighting factors affecting the farmers' willingness.

1.1 Methodology of the literature review

The literature on the use of drones in agriculture is broad, hence, it requires a structured approach to its review. Therefore, a structured searching process for published or in press articles was performed on the online database Scopus[5] as it has a comprehensive coverage including many disciplines and scientific journals of different ranking (not only top journals). The research was carried out by running a query which linked the concept of drone with the one of agriculture. Results were further limited by language (English) and year. For the purpose of the Thesis, papers only from 2011 to date were collected since UAV and systems around them made their breakthrough in agriculture around 2011 (Cerro *et al.*, 2021). Resulting in the following query: TITLE-ABS-KEY ((drone* OR uav) adoption AND in AND agriculture)

[5] https://www.scopus.com/

AND PUBYEAR > 2011, where keywords ending with "*" could have different endings. The Scopus query resulted in 2000 articles that were expected to hold information on the use of UAV in agriculture. Among these papers, there were many that were not relevant to the open-field agriculture. Therefore, a manual selection procedure was adopted to filter only the articles that were relevant to the research. The "skimming" process was articulate into three steps. Firstly, the title was used as discriminant to remove papers that were not relevant. For example, a paper with the title «Stakeholder perspectives on the adoption of drones in construction projects» was selected by the query because its abstract contained the terms drone, UAV, and agriculture. However, the title clearly does not describe a use of drone in agriculture. Therefore, it was removed from the list, resulting in 1271 of relevant articles (Figure 1).

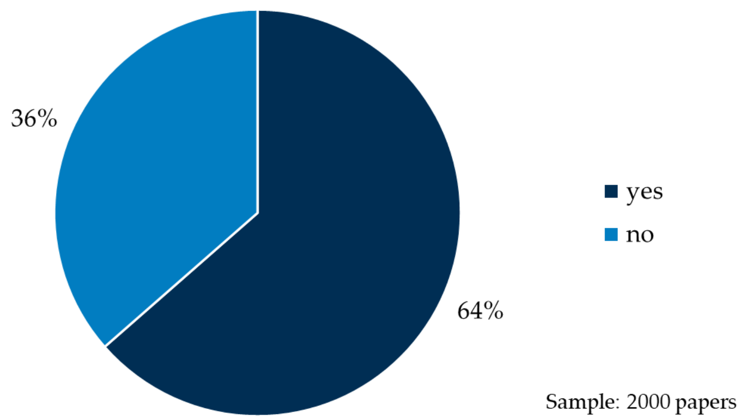

Figure 1. Relevance of papers

Secondly, for those papers with relevant titles, it was read the abstract. Articles were divided into three major categories identified according to the content of the abstract itself: *Technical*, *Application in agriculture*, and *Other* (Figure 2). Application in agriculture includes articles dealing with a possible use in farming operations without entering in too much detail with technical specifications of the technology itself.

Conversely, Technical papers treat the topic of drones applied in agricultural from a technical point of view, focusing on describing the technical features and functionalities of technology, including the design of drones themselves and the payloads as well as the software component. Whereas, Other encompasses marginal topic not well developed in the literature yet, and for this reason were grouped under a general category. This latter cluster is composed by four main sub-categories: *Economic*, *Policy & Regulations*, *Sustainability*, and *Technology adoption factors* (Figure 3).

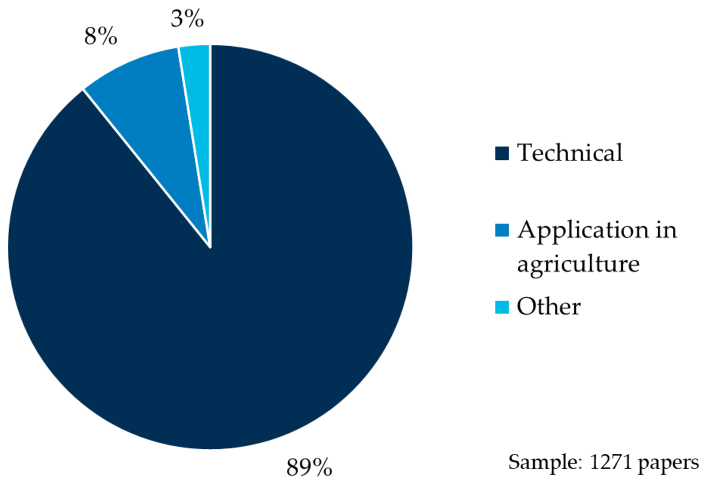

Figure 2. Categories of papers

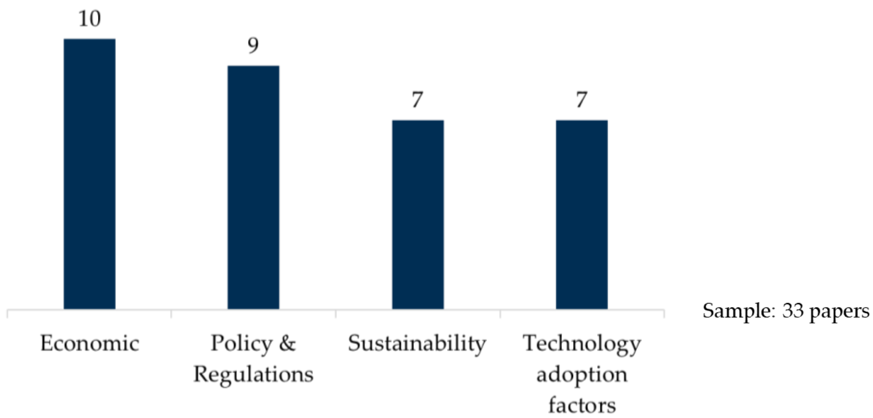

Figure 3. Papers belonging to Other category

Therefore, only papers within application in agriculture and technology adoption factors categories were selected. It is worthy to note that, among the papers treating the application in agriculture topic, only the ones dealing with the subject in a general way, without focusing on a specific application, were taken into consideration.

Third, to assess the reliability of the articles selected, the source of each paper was classified according to the Scimago Journal & Country Rank[6], which assigns a “grade” to the quality of journals on a scale from Q1 to Q4, where Q1 is the highest quality and Q4 the lowest. Documents labelled as “n.a.”, are articles whose source either was not present in the Scimago database or was present, but they did not have any rank. Consequently, papers ranked as Q4 were discarded as well as articles whose source was not found in the Scimago database. Resulting in a final number of 35 papers (Figure 4).

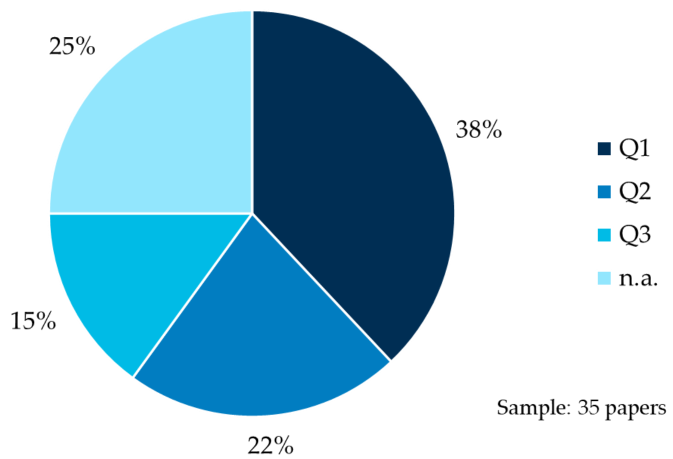

Figure 4. Scimago Journal & Country Rank of papers in the literature review

[6] https://www.scimagojr.com/

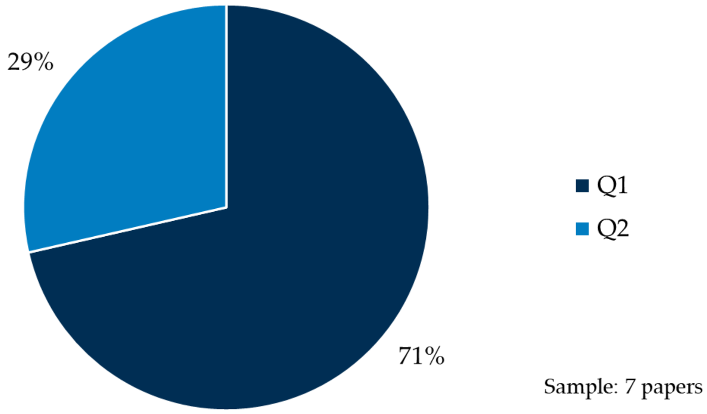

Figure 5. Scimago Journal & Country Rank of the papers related to the Technology adoption factors in the literature

The first deck of documents related to application in agriculture was used to give a brief general introduction about the use of drones in agriculture, whereas the second bunch related to technology adoption factors were used to deeply analyse the UAV adoption process by farmers.

Subsequently, the relevant articles were downloaded with the help of Google Scholar[7], organized in an Excel sheet with all the relative information, and analysed one by one. They belong to a variety of journals, mainly in the field of agriculture, crop science, engineering, earth and planetary science while some others belong to business or management and economics. The journals of papers in the literature review are the following: *Agriculture (Switzerland)*, *Agronomy*, *Advances in Agronomy*, *Aviation*, *California Agriculture*, *China Agricultural Economic Review*, *International Journal of Agricultural and Biological Engineering*, *Computer Networks*, *Energies*, *IEEE Access*, *IEEE Internet Computing*, *IEEE Sensors Journal*, *IOP Conference Series: Earth and Environmental*

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[7] https://scholar.google.com/

Science, International Food and Agribusiness Management Review, Journal of Agricultural and Environmental Ethics, Journal of Cleaner Production, Journal of Rural Studies, Lecture Notes of the Institute for Computer Sciences, LNICST International Food and Agribusiness Management Review, Precision Agriculture, Procedia Computer Science, Remote Sensing, Remote Sensing Applications: Society and Environment, Social-Informatics and Telecommunications Engineering, Technological Forecasting and Social Change, and *Technology in Society*.

The vast majority of the selected papers are article and conference paper, while in a minority share of them are book chapter, review, and short survey (Figure 6).

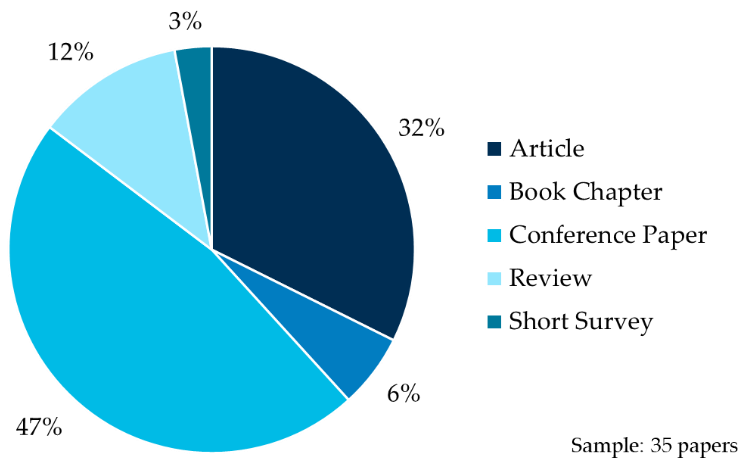

Figure 6. Document type of papers in literature review

Then Figure 7 shows the distribution of papers over time. It is possible to note that more than half of articles adopted are concentrated in the last three years, witnessing a progressively increasing attention around the topic during the last period of time.

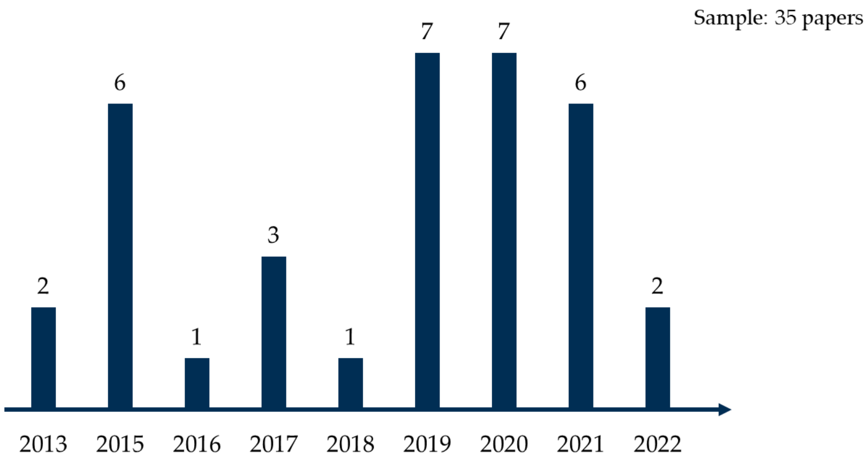

Figure 7. Temporal distribution papers in the literature review

In conclusion, a brief section about drones applied in agriculture from a "practical" point of view was inserted within the literature review. The aim of this part is to enrich the chapter with some hints coming from the business context, in addition to the knowledge developed at academic and research level. For this purpose, report issued by the main consultancy companies were adopted along with reports published by some other relevant companies and influential magazine about drones. The consultancy company selected were *Deloitte*, *Enrst & Young*, *Kpmg*, and *PWC*. As reported by Il Sole 24 Ore, they are the "Big Four" of consultancy industry. Moreover, *Dronezine* magazine and a report from *Eni* were adopted.

1.2 Drones in agriculture

Unmanned aircraft systems are mostly being used for military applications (more than 80%), but in recent years particular attention has been paid to the integration of drones into the civil sector, especially in agricultural (Urbahs and Jonaite, 2013).

In the literature, many characteristics can be found to classify drones (Cerro *et al.*, 2021; Amaral *et al.*, 2020). According to Cerro *et al.* (2021), wing type and the level of autonomy are the most relevant features in agricultural operations among the several classification drivers.

Based on the type of wing, it is possible to identify, in turn, three categories (Abdullahi *et al.*, 2015; Puri *et al.*, 2017; Hassler *et al.*, 2019; Ahmad *et al.*, 2020; Radoglou-Grammatikis *et al.*, 2020; Cerro *et al.*, 2021; Maddikunta *et al.*, 2021, Velusamy *et al.*, 2022). The first category includes single-rotor (helicopters) and multi-rotors UAVs. Their main advantage is the capacity to perform hovering flights and provide superior performance at low velocities and allow to perform low altitude flights with minimum risk (Cerro *et al.*, 2021). Multi-rotors have become well diffused thanks to their simplicity in comparison to helicopters. In addition, the reduction of price has made them an affordable solution for multiple tasks (Moskvitch, 2015; Cerro *et al.*, 2021). The main shortcoming of commercial drones is their lower payload capacity in comparison with helicopters (Cerro *et al.*, 2021).

The second category encompasses fixed wing aircrafts. They offer high-speed flights for longer durations, and they also have a higher payload capacity (Ahmad *et al.*, 2020; Cerro *et al.*, 2021). However, they are not able to perform static flights and they usually require higher altitude to perform safe flights along with a runway for take-off and landing. Moreover, the manoeuvrability endowed in rotary wings is a great advantage over those with fixed wing (Cerro *et al.*, 2021).

Finally, the third group includes hybrid vertical take-off and landing (VTOL). They are a hybrid of fixed wing and multi-rotors models, combining the advantages of the two previous categories. They can be equipped with sensors and controlled remotely, as well.

According to the autonomy level, drones can be classified, in turn, into teleoperated, tele-commanded, and autonomous (Cerro *et al.*, 2021). The first presents a lower level of autonomy, hence, they are mainly used for recreational or hobby purpose. The second category are endowed with an automatic controller on board that is in charge of maintaining a stable flight and they are mostly adopted in non-structured environments or when the flight plan cannot be defined in a priori mission definition, i.e., when the trajectory depends on the findings (e.g., visual inspections). The last presents the highest level of autonomy, which can perform flight plan without human intervention.

Then, as said in the Introduction[8], UAVs can be equipped with many payloads. The payloads of a drone encompass all the sensors and actuators that are not involved in the control of its flight (e.g., the gimbal with the RGB camera) (Daponte *et al*., 2019). In case of precision agriculture, two types of payloads can be identified (Radoglou-Grammatikis *et al*., 2020). Great part of payloads falls under the sensors category. Sensors embedded on drones can be location-based sensors, electrochemical sensors, temperature and humidity sensors, or optical sensors which include multispectral camera, hyperspectral cameras, laser, multiscanner, thermal camera, RGB camera and Light Detection and Ranging (LiDAR) systems (Daponte *et al*., 2019; Radoglou-Grammatikis *et al*., 2020; Cerro *et al*., 2021; Maddikunta *et al*. 2021). Of course, there are other payloads that a drone can carry on (Radoglou-Grammatikis *et al*., 2020). For instance, it is possible to endow UAVs with a spraying system or other objects like goods that have to be moved to a specific destination. However, there is always a trade-off between endurance (maximum time of fight) and payload to consider (Cerro *et al*., 2021).

[8] See pp. 13-16.

According to the existence or not of a physical interaction with crops, two main clusters of precision agriculture applications involving UAVs can be found: remote sensing and aerial spraying (Radoglou-Grammatikis *et al.*, 2020; Cerro *et al.*, 2021). Recently, there have been also some emerging applications that are coming out concerning, for instance, livestock, pollination, and harvesting as well as insurance and marketing (Hassler *et al.*, 2019; Naji, 2019; Ahamad *et al.*, 2020; Maddikunta *et al.*, 2021).

Remote sensing applications in agriculture deal with non-contact procedures to gather information on the state of the field. Two main types of applications may, in turn, be reported into this cluster: environmental monitoring and crop monitoring (Cerro *et al.*, 2021). Continuous crop monitoring could be considered an essential aspect of precision agriculture and requires the registration of sensor data over long periods of time. Thus, agricultural fields can be monitored by using cameras and sensors attached to UAVs which allows very high spatial resolution, choice of independent operation timing, and operability in variable weather conditions compared to satellites and traditional aerial photography systems which suffer from inadequate frequency or cloud cover conditions (Primicerio *et al.*, 2012; Urbahs and Jonaite, 2013; Moskvitch, 2015; Ahmad *et al.*, 2020; Radoglou-Grammatikis *et al.*, 2020; Maddikunta *et al.*, 2021). Six different applications of drone in remote sensing were identified (Daponte *et al.*, 2019; Mukherjee *et al.*, 2019; Naji, 2019; Ahmad *et al.*, 2020; Amaral *et al.*, 2020; Cerro *et al.*, 2021; Maddikunta *et al.*, 2021):

- *Nutrients Evaluation and Health Assessment*. Integrating multispectral aerial data on soil and crop with geophysical data allows adapting the application of nutrients to each zone of the field. Thus, soil-available nutrients monitoring is essential for crop growth assessment and allows performing appropriate variable-rate fertilization to avoid unnecessary damage to sustainable production capacity.

- *Water Stress Analysis*. It is a precision agriculture task aiming at optimizing crop production by adapting management actions such as watering to the needs of the soil.
- *Yield and Biomass Estimate*. Images captured by cameras mounted on drones can be processed to get information that allows to predict yields based on the progress of the crop growth and stress. Yield estimates by using aerial images from UAVs over main cereals in the world, such as maize, rice, wheat, barley, or Sorghum along with grass, cotton, Norway spruce, Scot pine and Mediterranean riparian forest can be found in the literature.
- *Soil Monitoring*. Monitoring erosion of the soil is also relevant, since it can cause a progressive degradation of hillslopes, especially in steep-slope agricultural landscapes.
- *Weeds Detection*. Accurate weed maps of the crop-field are required to optimize the application of herbicides. In this regard, fixed wing UAVs are also used in weed detection. Furthermore, artificial intelligence techniques have been extensively used to detect weeds by using aerial images obtained from drones.
- *Environmental Monitoring*. UAVs have probes to be able to act as mobile elements in wireless sensor networks to gathering data. Not only open-air, but also indoor agricultural uses of UAVs can be found in the literature.

Aerial Spraying was very likely the first UAV application in agriculture. Recently, a relevant number of use cases of aerial pesticide application have been reported against a wide range of crops with promising results in East Asian countries such as Japan, South Korea and China (Amaral *et al.*, 2020; Cerro *et al.*, 2021). Furthermore, the use of drones in the irrigation process can help to ensure that water is used effectively in the farming lands and in the identification of areas that are contributing to the wastage of water in the farming fields (Naji, 2019). Without doubt, drones dedicated for aerial spraying missions need to exhibit a higher payload capacity (higher dimensions and cost). Nevertheless, UAV aerial spraying ability is not limited to crop protection, but it is also applied to crop fertilization. However, this task is not yet well widespread since regulations how to apply fertilizer, pesticides, and phytosanitary products vary from country to country (Moskvitch, 2015).

Recently, further UAV applications emerged in the precision farming paradigm. As the agricultural technology advances, in the near future, farmers may plant their crops using the drone-planting systems. If this is achieved, it will significantly reduce the labour costs as farmers will be able to use compressed air in the drones to fire seed pods directly into the farming area (Naji, 2019; Ahmad *et al*., 2020). Then, most of the cattle ranchers who own lots of acres or land are starting to use drones to locate and gather farming animals (aerial mustering) along with detecting unwanted animals in their farms that are preying on their livestock (Naji, 2019; Ahamad *et al*., 2020; Maddikunta *et al*., 2021). In addition, the decrease in honeybee population has become a critical issue worldwide. Therefore, the introduction of drones as robotic pollinator reduces the impact of this phenomenon (Ahmad *et al*., 2020). However, some obstacles still need to be overcome, above all, the wind generated by UAV's wings have been observed to disperse the pollen (Maddikunta *et al*., 2021). Another upcoming application of drones concerns fruit and vegetable harvesting (Hassler *et al*., 2019; Amhad *et al*., 2020). Drones can effectively indicate the optimum harvesting time of a crop or fruit by analysing the data taken by crop monitoring, and they can perform picking and aerial transport. However, the latter need further research in this field. Finally, farmers are used to engage UAVs also for purposes not directly related to pure farming operations. It is the case in which drones are adopted to perform photos and films for marketing campaigns and to make documentary films about agriculture and demonstrating research. Drones can be also used to assess damages caused by natural disasters (Abdullahi *et al.*, 2015). They can help farmers to survey large fields and obtain the accurate data about the percentage of field damaged in order to be compensated by insurance companies.

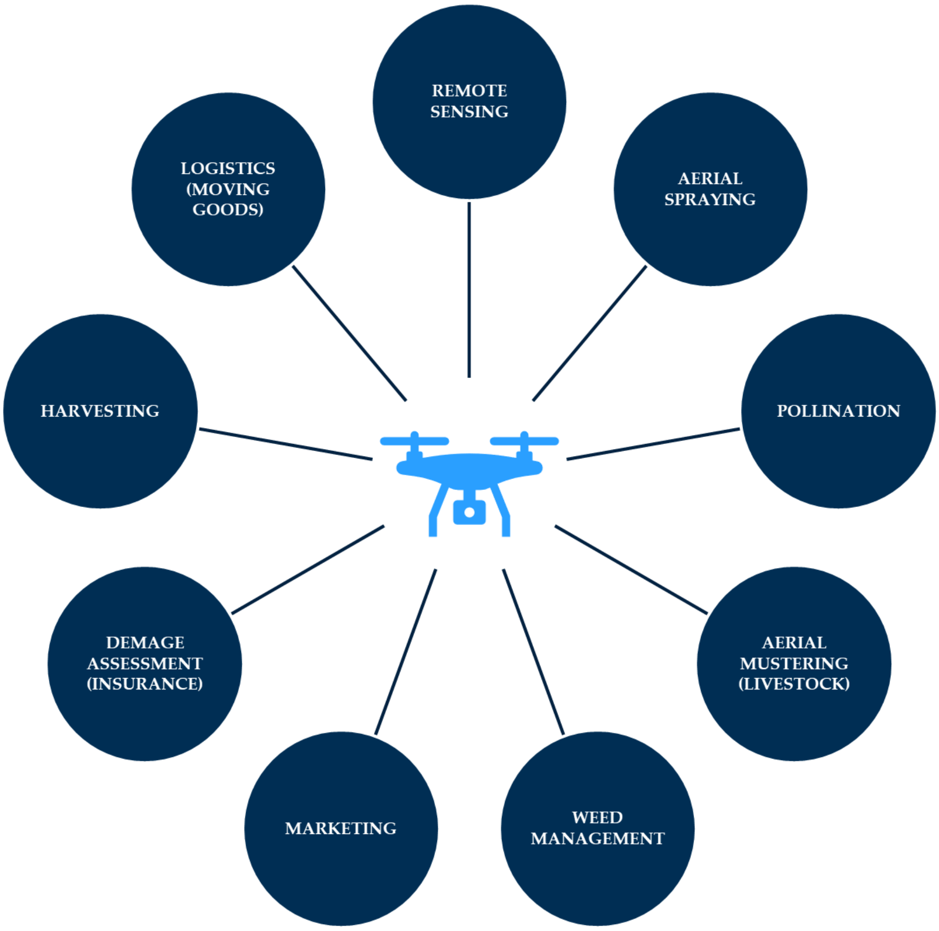

Figure 8. Drones' applications in agriculture

1.3 Drones' adoption in agriculture

Despite the promise of its enormous potential, the adoption of precision agriculture technology, including drones, by famers has generally fallen short of expectations (Thompson *et al.*, 2019). It is widely recognized that this available technology has not yet been integrated into agriculture as expected despite the multiple offerings of the platform (Ahmad *et al.*, 2020). It is evident that smart farming evolves technologically at a fast pace in both research and market domains, but its adoption from end-users does not follow the same footsteps. Moreover, UAVs are a new agricultural technology at an early stage of diffusion. They are in effect a Precision Agriculture Technology (PAT). However, they differ from PAT because they are a multifunctional and flexible tool able to work both alone providing several functions and also in complement with other PAT (Michels *et al.*, 2020). Therefore, adoption patterns of drones may not correspond to the adoption patterns for PAT.

In conclusion, it is worthwhile to identify key factors influencing the adoption of UAVs. Compared to the PAT, the literature in this field is still limited. Few studies focus on the UAV adoption process by farmers and factors affecting it (Table 1), and no one is related to the Italian contest.

Table 1. Papers adopted in the literature review regarding factors affecting drones' adoption

		Purpose	Country	Sample	Drone application
1)	Zheng et al., 2019	Investigating farmers' willingnes to use drones.	China	897 farmers	Aerial pesticide spraying
2)	Michels et al., 2020	Focusing on the actual adoption decision.	Germany	167 farmers	—
3)	Skevas and Kalaitzandonakes, 2020	Identify factors affecting the farmers' UAVs adoption.	USA	809 farmers	—
4)	Wachenheim et al., 2021	Highlighting the role of social forces that influences the technology adoption.	China	854 farmers	Aerial pesticide spraying
5)	Zuo et al., 2021	Studying factors influencing the future UAVs adoption by farmers	Australia	991 farmers	Irrigating
6)	Michels et al., 2021	Analysing latent factors affecting farmers' UAVs adoption process.	Germany	167 farmers	—
7)	Skevas et al., 2022	Examining the influence of peers effects on farmers' drone adoption.	USA	809 farmers	—

Many factors can affect the growers' willingness to adopt drones in their farming activities (Table 2). They can be classified into four main clusters: *Farmer characteristics*, *Farm characteristics*, *Attitudinal factors*, and *External factors*.

The first two clusters – namely farmers characteristics and farm characteristics – make up what is called in literature «Resource endowment» (Wachenheim *et al.*, 2021). It encompasses the natural and acquired resources and also the capabilities of farmers and their family members. The impact of resource endowment on technology adoption is not constant over time or place (Wachenheim *et al.*, 2021).

«Farmer characteristics» encompasses *Age*, *Education level*, *Gender* (namely being male), *Precision agriculture technology literacy*, and *Traditional technical specification*. It is generally believed that older people have relatively conservative thinking, and they are less motivated to learn and master new skills, hence, they show a lower willingness to adopt new technology (Zheng *et al.*, 2019; Michels *et al.*, 2020). However, the literature is mixed. Michels *et al.* (2020) and Skevas and Kalaitzandonakes (2020) demonstrated empirically that age has a negative influence on the farmers' adoption process. One of the main barriers to technology adoption is the habit, namely older farmers are less keen to change their habits than younger farmers (Michels *et al.*, 2020). Furthermore, another barrier is represented by the short planning horizon. Older farmers have shorter time horizon than their counterpart (Michels *et al.*, 2020; Skevas and Kalaitzandonakes, 2020). Then, older farmers have less experience with digital technologies. Conversely, other studies did not find any evidence about (Zheng *et al.*, 2019; Wachenheim *et al.*, 2021; Zuo *et al.*, 2021). In particular, Zuo *et al.* (2021) reported that the average age of Australian irrigators who is willing to introduce drones in their farm is similar to the one of irrigator who are reluctant to the change in technology.

Farmers with higher education level are more likely to have technological and analytical skill to use a drone and to effectively exploit the information provided by them (Michels *et al.*, 2020). Therefore, it is expected that the higher the education level, the stronger the ability to learn and master new technologies, resulting in a higher inclination to invest in UAVs (Zheng *et al.*, 2019; Wachenheim *et al.*, 2021).

Nevertheless, the literature in this case is quite aligned to state that the education level of the household does not provide a real impact on the farmers' adoption process (Zheng *et al.*, 2019; Michels *et al.*, 2020; Wachenheim *et al.*, 2021). Managing a drone is relatively simple, hence, education is relevant only when farmers want to embark in an advanced drone application (Michels *et al.*, 2020). Moreover, higher education level gives farmers more career choices. Consequently, they may decide to leave the farming profession and therefore they could be less incentivized to invest in new technologies (Wachenheim *et al.*, 2021). Only Zuo *et al.* (2021) in their survey on Australian irrigators reported a positive influence of education level on the willingness to adopt.

It is common thought that males are more likely to take risks than females, while females are thriftier in agriculture production, tending to reduce use of agricultural input (Michels *et al.*, 2020). Therefore, women are expected to have lower adoption intention on new technological machineries (Zheng *et al.*, 2019). Coherently, many studies support this statement (Zheng *et al.*, 2019; Michels *et al.*, 2020; Wachenheim *et al.*, 2021). Zheng *et al.* (2019), in their study on Chinese farmers, highlighted the fact that men are more prominent to adopt drones to apply spray plant protection products than women since men tend to be more actively involved in the production process in China, they may have a better understanding of the high labour, low efficiency and safety concerns associated with traditional backpack sprayers. In contrast with the extant literature, Zuo *et al.* (2021) did not found any statistical evidence about the influence of the gender – namely being male – on the technology adoption process. Looking at the past use, men seem to be more prone to adopt UAV technology, while when comes to the future use there is an equal share between men and females (Zuo *et al.*, 2021).

Having a prior experience with PAT means that the farmer might have learnt some technical skills required to use another PAT and therefore it is expected that they can easily cope with another or more advanced technology. As expected, Michels *et al*. (2020) exhibited that PAT literacy has a positive effect on the adoption process. This result witnesses that farmers with past experience in the use of PAT are more opened and skilled in introducing new and advanced technology such as drones. Moreover, farmers that have already in place a PAT infrastructure in their farms are more prone to adopt drones in order to exploit synergies among them.

Finally, Wachenheim *et al*. (2021) reported also the traditional technical specification has a negative influence on the adoption process. Farmers who stick with traditional technology, are less prominent to invest in new advanced technology such as drones (Wachenheim *et al*., 2021).

Within the «Farm characteristics» were identified the following variables: *Availability of a successor*, *Family income*, *Farm size*, *Income ratio*, *Livestock*, *Number of agricultural workers*, *Number of borrowing channels/Access to credit*, and *Renting out*. The literature supports that availability of a successor on the farm can increase the willingness to adopt drone in agriculture (Skevas and Kalaitzandonakes, 2020; Zuo *et al*., 2021). Farmers might be more incentivized to adopt new technologies to increase the profitability of the business, leaving to the successor a more productive a profitable farming operation (Skevas and Kalaitzandonakes, 2020).

A higher income reduces the subjective cost of the innovation and the associated risks (Skevas and Kalaitzandonakes, 2020) since farmers can face bigger investments, as the ones required by introducing new technologies such as drones (Michels *et al*., 2020). Therefore, it is expected that richer farmers are more likely to adopt drone in their farms. Indeed, Skevas and Kalaitzandonakes (2020) provide empirical evidence about a positive influence of family income on farmers' adoption intention. Whereas other studies focused on the income ratio, i.e., the balance between income coming from farming operations and off-farm income deriving from other businesses (Zheng *et al*., 2019; Wachenheim *et al.*, 2021; Zuo *et al.*, 2021). Farmers who concentrate solely on their farm business is expected to be more likely to be interested and incentivised to invest in new technologies. In line with Skevas and Kalaitzandonakes (2020), if the agricultural income accounts for a great part of the family income, meaning that the farm is important to the household, the willingness to adopt should increase (Zheng *et al.*, 2019; Wachenheim *et al.*, 2021). This result confirms that there is a higher attention to adopt practices that increase the efficiency of operation when agriculture accounts for an important slice of the family income (Zheng *et al.*, 2019). In addition, Zuo *et al.* (2021) provided a surprisingly result, showing that there is a quadratic relation between drone technology adoption and net farm income and off-farm income percentage. When the net farm income increases, also the willingness to invest in drones increases. However, the latter increases until a certain threshold, after which it starts to decrease because the cost borne outweigh the benefits. A similar reasoning hold for the off-farm income. Off-farm income plays an important role in the farm management since can improve the financial position of the farm. However, when the off-farm income component is too high, it means that farm business is not the main source of revenues for the farmers, hence, they may be less incentivized to introduce a new technology.

A fully equipped "ready-to-fly" drone for agriculture is quite expensive, hence, the authors expected that economies of scale have an important role in the decision-making process (Michels *et al.*, 2020). Indeed, farmers who manage a larger cultivated land area should be more likely to adopt new technology because they can benefit from learning curve (Zheng *et al.*, 2019). Indeed, Michels *et al.* (2019), Wachenheim *et al.* (2021), and Zuo *et al.* (2021) reported a positive correlation between the farm size and the willingness to adopt UAVs. Introducing drones in large farms allow to achieve benefits in terms of time cost reduction – farmers do not have to walk long distances around their fields anymore for scouting and monitoring – and in terms of organization reducing organizational complexity – information is stored in an information system, and it is digitally available and easily retrievable. This result is mainly due to two reasons. On one hand, higher cultivated land area enables farmers to exploit better economies of learning and economies of scale; on the other hand, having larger farms allows to obtain a discount or other favourable terms of hiring a drone for application (Wachenheim *et al.*, 2021).

Regarding the presence of livestock farming within the farm, the literature is mixed. Since there are very few feasible applications of drone in a livestock farming, it is expected that livestock farming has a negative effect on the adoption process (Michels *et al.*, 2020). Indeed, Skevas and Kalaitzandonakes (2020) reported that raising livestock reduced the likelihood to introduce drones in farming operations due to two possible reasons. First, lack of crop specialisation; second, concerns about the effect of the noise generated by drones on the livestock (Skevas and Kalaitzandonakes, 2020). Conversely, Michels *et al.* (2020) did not provide any evidence that livestock has a negative effect on the adoption process since most applications of drones are more suitable for arable farming. Nevertheless, adoption of drones is expected to take-off also in livestock farming. They can be engaged in tracking down pasture cattle, pasture management, and ensuring the yield and quality of maize which can be used to feed animals.

Zheng *et al.* (2019) identify the number of agricultural workers as another relevant factor in the farmers' decision process. It is expected that in a larger family the intent to adopt new technologies is lower due to the fact that if there are few people available to work in the fields, there is a stronger demand for technology that can lower the labour intensity (Zheng *et al.*, 2019). However, Zheng and his colleagues was not able to prove it.

Having a larger number of borrowing channels available allows farmers to find additional cash flow easier, reducing the risk associated with negative cash flow (Wachenheim *et al.*, 2021). Therefore, farmers who have more financial ability are to invest money in new technology which does not pay off in the initial years. Accordingly, Wachenheim *et al.* (2021) and Zuo *et al.* (2021) found a positive influence of number of borrowing channels on the willingness to invest in new technology. Having greater farm debt increase the likelihood to place further investments, for instance in UAV technology, because it could be seen as a higher capability to get access to capital (Zuo *et al.*, 2021). However, having greater farm debt requires to certain capability to manage it, otherwise the situation can backfire resulting in a higher pressure on the farmers who may be reluctant to increase debt towards banks (Zuo *et al.*, 2021).

Finally, Skevas and Kalaitzandonakes (2020) proved that renting out land has a negative correlation with the willingness to adopt drones in farming activities. Renting out could be an indicator that the farm is not so relevant, i.e., farmers are not completely dedicated to the farming operation, hence, they are less interested in introducing drones in the farming operations.

Regarding the «Attitudinal factors», the following variable were identified: *Perceived ease-of-use/Attitude confidence*, *Perceived usefulness/Job relevance*, and *Understanding level*. Among them, the one having the higher impact was the perceived usefulness, followed by perceived ease-of-use and understanding level. Perceived usefulness is defined as the farmers' perceptions of how the technology will improve such things as efficiency, production, and profitability (Zheng *et al.*, 2019). The economic profitability is not the only thing that matter, but farmers have to be able to assess the economic benefit. In most areas of application, drones do not provide an immediate economic benefit, but the information gathered through them can be used to improve on-farm decision making leading to future economic benefit (Michels *et al.*, 2020). The literature is well aligned on saying that a higher perceived usefulness increases the likelihood to adopt a UAV technology (Zheng *et al.*, 2019; Michels *et al.*, 2020; Skevas and Kalaitzandonakes, 2020; Wachenheim *et al.*, 2021, Michels *et al.*, 2021). If farmers feel that the information provided by the UAV is useful for their farming activities, they have a higher intention to use a drone. In other words, if a drone provides useful information, for instance documentation of storm damage for insurance claims, and the farmer understands the benefit of this information, the grower has a higher intention to use a drone (Michels *et al.*, 2021).

Perceived ease-of-use is defined as the ability to master relevant knowledge, techniques and methods of operation associated with the technology (Zheng *et al.*, 2019). Zheng *et al.* (2019) and Michels *et al.* (2020) reported that perceived ease-of-use has a positive effect on the adoption process. Perceived ease-of-use reflects farmers' confidence in using the technology (Zheng *et al.*, 2019). In fact, Zheng and his colleagues showed that farmers that indicated a high level of mastery of UAVs had an intended adoption rate of 82%.

In their study, Michels *et al.* (2021) further investigate the factors perceived usefulness and perceived ease-of-use, demonstrating that they are, in turn, positive affected by job relevance and attitude confidence respectively. Farmers exhibiting a high confidence level in managing a drone and the data provided by UAV or digital instruments to further process the data collected, perceive the application of drone as easier. Consequently, they have a higher intention to use a drone as well. Likewise, Zheng *et al.* (2019) found that a higher level of understanding of drone technology has positive effects on the willingness to adopt drones. Moreover, drones can display a high multifunctionality since they can be used on their own or in combination with other PAT. Therefore, farmers perceive a drone as more useful if they recognize that its several functions have also relevance for several on-farm activities. Likewise, these farmers show a higher intention to use drones since they can be supported in several tasks by a UAVs. However, Wachenheim *et al.* (2021) found perceived ease-of-use not significant, while providing statistical evidence of a positive influence of attitude towards new technology on the farmer's adoption process.

Finally, «External factors» includes *Cooperative membership*, *Neighbour privacy concerns*, *Presence of a village cadre in the farmer's family*, *Collaboration with neighbouring farmers*, and *Peer influence*. This cluster encompasses variables aiming at analysing the impact of the social environment on the adoption process. Many times, when an innovation is introduced, the social contest and the exchange of information play a relevant role in the adoption process. Traditionally, farmers are conservative (Skevas *at al.*, 2022), hence, early adopters (Rogers, 1962) are crucial in the development and evaluation of applications and play a role model for others (Frankelius *et al.*, 2017). Farmers do not only think about economic benefits of the technology, but they also consider the resulting interaction in their social networks and its impact.

Wachenheim *et al.* (2021) did not exhibit significant evidence about a possible influence of cooperative membership and collaboration with neighbouring farmers. Actually, the authors admit that the results may be affected by a lack of functionality of cooperatives and lack of variability in response, respectfully in the surveyed region (Jilin Province, China). Indeed, evidence in the literature supports that farmers who participate in community organizations are more open to access to new technologies and cooperatives facilitate knowledge spill over, taking advantage of learning about technology from others, and this may increase adoption (Skevas and Kalaitzandonakes, 2020). Likewise, exchanging information and coordinating with neighbouring farmers on agricultural production practices had a positive effect on the UAV adoption process (Skevas and Kalaitzandonakes, 2020). Collaborating with neighbours allows farmers being more openminded and knowing more information about new agricultural practices and technologies (Skevas and Kalaitzandonakes, 2020).

Moreover, Skevas and Kalaitzandonakes (2020) stated that a higher level of perceived neighbour privacy concerns in the use of UAVs can curb the technology adoption. Farmers usually care about the consequence of their farming choice on the local community, entailing a social cost in their decisions (Skevas *et al.*, 2022). In this situation, a social conformity plays an important role in farmer technology adoption decisions (Skevas and Kalaitzandonakes, 2020, Skevas *et al.*, 2022).

According to Wachenheim *et al.* (2021) the presence of a village cadre plays an important role on the new technology adoption process with a positive influence. A village cadre connects farmers with a broader social network allowing farmers themselves to acquire more information about new technology reducing the extant lack of information, hence, decreasing the general uncertainty that made farmers risk adverse (Wachenheim *et al.*, 2021).

Finally, Skevas *et al.* (2022) examined the relevance of peer effects on UAV adoption by farmers. According to the empirical study carried out by Skevas and his collegueas, the adoption decision of neighbouring farmers affects a farmer's decision to adopt UAVs. Therefore, when approaching farmers' technology adoption, also characteristics and attitudes towards the UAV technology of neighbouring farmers should be considered (Skevas *et al.*, 2022). The reduced work motivation of older neighbours, who are close to retirement, can reduce the probability farmers adopt drone in their farming operations. Then, neighbours with high income are more likely adopt innovative technology, hence, this technology can then spill over to farmers themselves, through direct communication or willingness to conform with peers. Furthermore, neighbours can positively influence farmers by sharing and showing their knowledge and beliefs about the environmental and economic benefits of using agricultural drones. This result is the witness that farmers talk each other and influence each other's behaviour regarding the adoption of agricultural innovations.

The literature suggests that there are significant differences in the farmer and farm characteristics of "current adopters" and "prospective adopters" groups and "non-adopters" group (Skevas and Kalaitzandonakes, 2020). However, it is difficult to outline precisely the traits of the "drone adopter", because there is not always a conformity in the results of the extant studies. They depend by several factors from country to country and from one drone applications to another.

For sure, it is possible to notice that very likely a farmer who is a "drone adopter" is not an old female, with a low income mainly not deriving from farming activities and grows a small land area. Beyond farm and farmer characteristics, also the attitudinal characteristics play a relevant role. Results reported above can provide some tips to drone manufacturers and dealers. Sellers of drones should make farmers more aware of the multi-functionality and suitability of drones for on-farm procedures to increase farmers' willingness to adopt a drone (Michels *et al.*, 2020). Then, suppliers are suggested to lend drones to farmers for tests runs or to run practical demonstrations with farmers on their farm (Michels *et al.*, 2020). Finally, UAVs are a new agricultural technology at an early stage of diffusion, hence, the level of interaction between nearby farms on issues related to technology use is higher than in a case where technology is already well-established (Skevas *et al.*, 2022). This result likely suggests that farmers follow the practices of their more successful neighbours. Therefore, when addressing farmers' UAV adoption decisions, neighbours' characteristics and attitudes towards the UAV technology should be taken into consideration, and not only those of farmers (Skevas *et al.*, 2022).

The success of any technology depends upon its user's acceptance (Maddikunta *et al*., 2021). Several advantages provided by UAVs and their versatility in performing multiple tasking along with affordable prize and vantage point make them a valuable tool to be used in precision agriculture (Cerro *et al*., 2021). Thanks to their flexibility in fulfilling several functions and well collaborating with the existent PAT, drones can increase production yield and reduce cost exploiting precision actions on crop fields. Concurrently, they can heavily enhance the environmental impact of farming operation being a low emission vehicle[9], reducing the impact of the phytosanitary aerial spraying activity, and foster the safeguard of biodiversity and limiting the deforestation issue increasing the surrender of plantation without the need to enlarge crop fields. In the face of many advantages UAVs can bring to support farming operations both from an economical and environmental point of view, there are still many barriers curbing their adoption. Adaptation and accurate usage of high tech and sophisticated technology like UAV's require skills and knowledge. High ability requirements for flying UAVs by the farmers with no or limited flying skills will also affect the willingness of use (Skevas and Kalaitzandonakes, 2020). Therefore, the usage of UAVs by the farmers with limited or no skills is a challenging task (Maddikunta *et al*., 2021). Another concern emerged, that may affect the acceptance of UAVs, is about some hidden potential externalities and social cost related to the use of drones (Skevas and Kalaitzandonakes, 2020). Agriculture and agricultural production are increasingly under scrutiny by society (Cerro *et al*., 2021). Ensuring the privacy of others and to avoid any legal implication faced due to privacy violation may also hinder the acceptance of these UAVs in agriculture (Maddikunta *et al*., 2021). High costs, legal

[9] Referred to electric UAVs.

obstacles along with missing trust in the analysis models of the spectral images were stated as barriers to the adoption of drones (Michels *et al.*, 2020). The low feasibility is primarily linked to perceived high time investment and work-load due to, for instance, limited flight range or constant updates to the software. Furthermore, it takes time to convene the data collected by the drone in an application map. Additionally, perceived lack of benefit to using a technology or missing trust in the technology itself are the main reasons behind the higher trust towards traditional technology than the new one by farmers. Skevas and Kalaitzandonakes (2020) in their empirical study reported that the vast majority (83%) of the famers surveyed did not feel that the introduction of UAVs can reduce farm input cost, and a bit less respondents (65%) did not perceive that the new technology can lower the environmental footprint of farming.

Therefore, a big challenge is to encourage and motivate the farmers to accept the UAVs. So, there is the need to design and develop effective user acceptance models which identify and provide solutions for ease of use, willingness to use and ensuring the privacy of others for successful adaptation and usage of UAVs in agriculture and to get full benefits from this high tech and sophisticated technology (Cerro *et al.*, 2021). First, there is a need for clarifying the legal status of drone applications for farmers by policy makers. Second, a better communication as well as demonstration of the technology's benefits poses an opportunity for developers and providers of drones and equipment integrating drone technology aiming at increasing the trust of "non-adopters" in the use of drones farming operations.

Table 2. Factors affecting farmer's' adoption process of drones

INFLUENCING FACTORS	Zheng et al. (2019)	Michels et al. (2020)	Skevas and Kalaitzandonakes (2020)	Wachenheim et al. (2021)	Zuo et al. (2021)	Michels et al. (2021)	Skevas et al.(2022)
Farmer Characteristics							
Age	Null	Negative	Negative	Null	Null	–	Negative
Education level	Null	Null	–	Null	Positive	–	–
Gender (Male)	Positive	Positive	–	Positive	Null	–	–
Precision agriculture techonlogy literacy	–	Positive	–	–	–	–	–
Traditional technical specification	–	–	–	Negative	–	–	–
Farm Characteristics							
Availability of a successor	–	–	Positive	–	Positive	–	–
Family income	–	–	Positive	–	–	–	Positive
Farm size	Null	Positive	–	Positive	Positive	–	–
Income ratio	Positive	–	–	Positive	Quadratic relationship	–	–
Livestock	–	Null	Negative	–	–	–	–
Number of agricultural workers	Null	–	–	–	–	–	–
Number of borrowing channels/Access to credit	–	–	–	Positive	Positive	–	–
Renting out	–	–	Negative	–	–	–	Negative
Attitudinal Factors							
Perceived ease-of-use / Attitude of using drones in agriculture	Positive	Positive	–	Null / Positive	–	Positive	–
Perceived usefulness / Job relevance	Positive	Positive	Positive	Positive	–	Positive	Positive
Understanding level	Positive	Positive	–	–	–	–	–
External Factors							
Coperative membership	–	–	Positive	Null	–	–	–
Neighbour privacy concerns	–	–	Negative	–	–	–	Negative
Presence of a village cadre in the farmer's family	–	–	–	Positive	–	–	–
Collaboration with neighbouring farmers	–	–	Positive	Null	–	–	–
Peer influence	–	–	–	–	–	–	Positive / Negative

1.4 Drones and agriculture: a "practical" point of view[10]

Agricultural production has drastically increased in recent years, and studies predict that aggregate agricultural consumption will increase by 69% from 2010 to 2050. This increase will be mostly caused by population growth from 7 billion to 9 billion by 2050. This means approximately 1 billion tons more of wheat, rice and other cereals, and 200 million more tons of livestock per year, on almost the same agricultural surface area. This, coupled with growing environmental and regulatory pressures, presents a disheartening challenge for the global farming industry. Since most land suitable for agriculture is already farmed, this growth must come from higher yields. Therefore, digital agriculture revolution can provide the solutions to the problem of feeding the world sustainably. Today drone technologies are upsetting business models and reshaping industry landscapes, including agriculture.

Drones allow farmers to constantly monitor crop and livestock conditions by air to quickly find problems that would not become apparent in ground-level spot checks. Drones have revolutionized agriculture by offering farmers major cost savings, enhanced efficiency, and more profitability. By quickly surveying vast stretches of farmland, drones can map the property, report on crop health, improve spraying accuracy, monitor livestock and irrigation systems, and more. The ability to collect and analyse this data in real time has tangible outcomes for farmers such as better crop yield, fewer resources expended on weeds and herbicides, and overall improved management decisions. Furthermore, the use of precision farming technologies such as drones not only increases production and optimizes the use of resources, but also

[10] The section was developed taking inspiration from report of the following companies: *Deloitte*, *Dronezine*, *Eni S.p.a.*, *EY*, *KPMG* and *PWC*.

reduces waste and ensures food traceability and quality. Together with sensors, 5G, artificial intelligence and more, smart agriculture is coming to life, a rapidly growing sector that promises to reduce the use of pesticides by 85% and increase yields (and turnover) by up to 20%.

The increasing convergence of tech and agriculture ("AgTech") makes the industry attractive for new entrepreneurial initiatives, financial investment, and enterprise clustering and this is evident by the developments across companies and organizations. According to estimates by the Agriculture Drones Market Report by Markets and Markets, the agricultural drone market is now worth 1.2 billion dollars [11]and should quadruple in 2024. The growth through 2024 will be mainly due to an increasing awareness of the pros and cons of drones in agriculture among farmers.

Digital agriculture and big data will not only affect producer buying behaviour, but also change the way seed and agrichemical companies market, price and sell products

Smart agriculture, including drones, is set to become the farmer's most useful ally, thanks to its potential in terms of environmental sustainability – reducing consumption and improving yields – and in providing essential tools to tackle the most immediate problems. At the same time contributing to the well-being of the planet.

[11] It refers to the year 2021.

2 Objectives and Methodologies

2.1 Literature gaps, research questions, and methodologies

Unmanned aircraft systems are mostly being used for military applications (more than 80%), but in recent years particular attention has been paid to the integration of UAVs into the civil sectors, especially in agriculture. Drones are one of the most up-and-coming innovative technologies invented in recent years adopted in agricultural activities. They can not only reduce labour requirements and increase yield production as well as lower the use of pesticides and safeguard the environment. However, previous research on agricultural UAVs have overly focused on technical problems such as software and hardware design. Few studies have examined influencing factors and users' behaviours in the implementation process. Moreover, that research focus only on few specific countries – namely, China, Germany, USA, and Australia. Therefore, two main gaps were identified from extant literature. Drones' adoption is a topic not well explored by researchers and experts. The results by previous studies highlighted several variables influencing the farmer's adoption process related to farmer characteristics, farm characteristics, attitudinal factors, and external determinants that are case specific to the context and the drone application under consideration. Therefore, it is worthwhile to deepen this research field in order to enrich the "list" of influencing factors and try to find general adoption patterns among the farmers. In addition, there are no studies focusing on the Italian context. Agricultural sector is certainly one of the most interesting sectors for the Italian economy, accounting for 2.2%[12] of the national GDP (ISTAT[13]). It is particularly appreciated for the great fame of Italian products all over the world, going in fact to define a series of expectations of excellence towards the "Made in Italy". Indeed, Italian agriculture is the first country in Europe in terms of added value in 2020 with 31.3 billion of euro (ISTAT) and it is the third largest agricultural economy in Europe after France and Germany. Therefore, it is relevant to provide the literature with a cross-section of agriculture on the Italian panorama about the adoption of drones in farming operations.

Based on the literature gaps just evidenced, three research questions (RQ) have been developed:

> RQ1: “What are the areas and modality of application of drones at an international level with a specific focus on agriculture?”
>
> RQ2: “What is the state of use and diffusion of drones on farms in Italy?”
>
> RQ3: “What factors can foster or curb the adoption of drones by Italian farmers?”

Regarding RQ1, the main objective is providing a general overview of the current level of adoption of UAVs worldwide and to take stock of the situation on the use of drones in agriculture compared to other sectors / civil use. Whereas RQ2 and RQ3 directly refer to the Italian agricultural sectors and aim at providing an overview of the level of adoption of UAV by Italian farmers and, finally, trying to derive some factors

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[12] It refers to the year 2020.
[13] https://www.istat.it/

affecting the adoption process of Italian farmer. The latter is, for sure, relevant for agricultural drone manufacturers and dealers in order to better identify potential adopters and address them in wright manner. Likewise, also policy makers can take inspiration from this in order to proper design policy aiming at fostering the diffusion of UAVs in the Italian agricultural sector.

In order to address these research questions, census of drone applications through articles from newspapers and specialized magazine and survey delivered to Italian farmers were performed.

2.2 Census

The census of drone applications aims at addressing the first research question (RQ1). It was performed by revising news and articles not coming from academic literature. It has to be noted that the scope of the census leaves out all the drone applications for military purpose and final consumers uses. In other words, only business uses are taken into consideration. Then, the work was carried out considering only publications related to the period from 2019 to 2021.

A first phase of the census consisted in identifying relevant articles from Italian as well as international *specialist publications* like magazine about drones, *other specialist publications* such as magazine not directly dealing with UAVs but with inherent application fields like logistics and healthcare, *generalist publications* like the major newspapers, and *others* relevant sources such as local newspapers and social networks (Figure 9). In particular, the following is the complete list of sources adopted:

- Specialist publications: *Drone Blog News*, *Urban Air Mobility News*, *Dronezine*, *RotoDrone*, *Quadricottero News*, *UAS Vision*, *The UAS Magazine*, *sUAS News*, *Unmanned Systems Technology*, *eVTOL.com*, *Inside Unmanned Systems*, *eVTOL Insights*, *Mirumir*, *Droni.it*.

- Specialist publications from other sectors: *Transportonline*, *Trasporto Europa*, *Il Giornale della Logistica*, *Pharmacy Scanner*, *Cnet*, *Webnews*, *National Geographic*, *Sky Sport*.
- Generalist publications: *La Stampa*, *Il Corriere della sera*, *Il Sole 24 ore*, *La Repubblica*, *TGcom24*, *Corriere Comunicazioni*, *Corriere del mezzogiorno*, *Il Resto del Carlino*.
- Others: *CBI Insight*, *Key4Biz*, *Tio 20 minuti*, *Quotidiano.net*, *Corriere di Brescia*, *Corriere di Torino*, *Ravenna Today*, *Bloomberg*, *LinkedIn*, *Unione Sarda*, *Corriere di Bergamo*, *Corriere del Veneto*, *Futuro prossimo*, *Apolitical*, *La Nazione*.

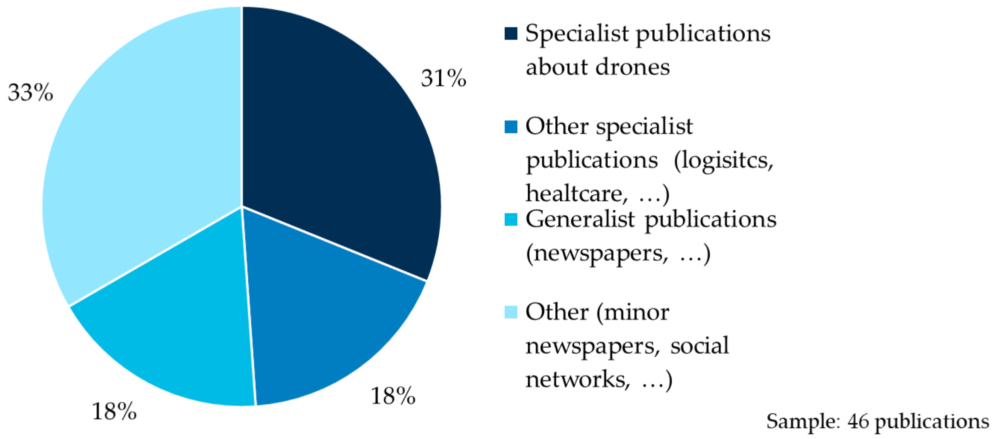

Figure 9. Sources adopted for of the census divided into categories

Regarding specialist publications, there was not the need to refine the search by using keywords since they were completely dedicated to the UAVs world. Therefore, only a distinction from articles dealing with military field and private use (consumer) was performed looking title by title. Conversely, a skimming procedure through keywords was adopted for the other typologies of source. In detail, keywords used were "*Drone*", "*Drones*", "*UAV*", "*UAVs*", "*UAS*", "*RPA*", and "*RPAs*". These are the most adopted terminology used worldwide in the mass media and academic literature to refer to drones (Aydin, 2019).

On a weekly basis the aforementioned sources were revised, and inherent articles were catalogued using Diigo[14] platform through research tags. Thus, all the relevant articles retrieved were put in the platform's database containing all the selected article.

Subsequently, having identified all the considerable news, they were deeply revised and mapped on a structured Excel file. Per each article, the following data were taken down:

- Title
- Summary
- Application sector

  The sectors identified for the census are the following: *Agriculture*, *Utility*, *Entertainment and Media*, *Infrastructure*, *Environmental Safeguard*, *Telecommunications*, *Logistics*, *Healthcare and Pharmaceutical*, *Art and Culture*, *Automotive*, *Insurance*, *Public Administration*, *Mobility*, *Mass Consumption*.
- Detail of the sector

  Per each sector, a set of details were envisioned in order to better classify the application inside the sector itself. An example, the Agricultural sector was broken down into *Fields/Crops*, *Pesticides*, and *Plant*.
- Scope 1

  Scopes taken into consideration for the purpose of the census were *Research and Rescue*, *Inspection*, *Security and Surveillance*, *Inventory*, *Transport*, *Dispensing*, *Media, Art and Show*, *Maintenance*.

[14] https://www.diigo.com/

- Scope 2

  It is intended to understand the “action” or “what”. For example, Research and Rescue was subdivided into *First Aid Operations*, *Research for People*, and *Research for Animals*.
- Scope 3

  It is intended to understand “what” o “where”. For example, First Aid Operations can be *Generic First Aid*, *First Aid at sea*, *First Aid in the ocean*, *First Aid in the mountain*, *First Aid in areas affected by environmental disaster*.
- Category of the operation

  According to the European regulation, there are three types of categories: *Open*, *Specific*, and *Certified*. They differ based on some parameters such as drone’s weight, needs for a license to fly the drone, flight eight, presence of civil people, BVLOS flight, and many others.
- Status

  A usage can be *Operative* if it is on-going; *Experimentation* if the use of drone is on-going but it is not on the market or it is still in the ramp up phase; *Announcement* if it is near to be launched on the market or *Una tantum* if it is used only once.
- Year
- Date
- Continent
- Country
- User Company/Entity
- Service Provider

- Other actors involved
- Drone Model

  It is intended as the drone manufacturer and the model declared by the manufacturer itself.
- Drone typology

  To date, there different types of drones: *Fixed wing*, *Rotor wing (conventional configuration (helicopters))*, *Multi-Rotor wings*, *VTOL (Vertical Take Off Landing)*, *Balloon*, *Airship*, and *Other*.
- Payload

  There are many payloads a drone can carry-out, among them the following were selected: *Camera, Camera RGB, Thermal Camera, Multispectral Camera, Hyperspectral Camera*, *Laser Scanner*, *Optical Reader*, *Other Sensors*, *Dispenser of liquids, granulates, powders*, *Distributor and other material transport systems*, *Radar*, *Detector of gas, radiation and other substances*, and *Other*.
- Flight typology

  Based on whether the pilot is able see the drone when flying, there are two main types of flight: *VLOS (Visual Line of Sight)* and *BVLOS (Beyond Visual Line of Sight)*.
- Scope of the project

  It aims at understanding if the use of drone is introduced for some specific purpose or projects such as *Covid-19*, *AAM (Advanced Air Mobility)*, *5G*, and *AI (Artificial Intelligence)/Data Analysis*.
- Benefits achieved

  Of course, the benefits derived from the adoption of drones can be many. Therefore, the most relevant were selected: *Time saving*, *Cost reduction*, *Increase* *yield*, *Quality/Accuracy data enhancement*, *Environmental impact reduction*, *Higher security in performing the activity*, *Reaching uncomfortable places*.

- Source

In Figure 10 is reported an extract of the Excel sheet used to map drone applications.

ID	Nome	Link	Descrizione	Settore	Dettaglio	Ambito 1	Ambito 2	Ambito 3	Categoria operazione	Stato	Anno	Data
626	Italy: First European trials, drone delivery of transplant kidneys imminent	https://www.urbanairmobilitynews.com/medical-pharmaceutical-transport/italy-first-	A Torino, un team di ricerca sta per iniziare i test che impiegano droni per il trasporto di reni umani.	Sanità e farmaceutico	Organi	Trasporto	Consegna di sangue, organi e altri materiali facilmente deperibili	Consegna in strutture sanitarie	n.d.	Sperimentazione	2021	07-set-21
627	Piano Urbanistico: Droni per Mappare gli Edifici	https://www.droneblog.news/piano-urbanistico-droni-per-mappare-gli-edifici/	Al fine di redigire il nuovo piano urbanistico, il Comune di Soliera si è avvalso dell'utilizzo dei droni per mappare gli edifici presenti.	Pubblica Amministrazione	Comune	Ispezioni e sopralluogo	Rilievi e mappature	Mappatura territorio	n.d.	Utilizzo una tantum	2021	07-set-21
628	Sospese le ricerche del 39enne disperso da 11 giorni nelle montagne del Bellunese	https://www.lastampa.it/cronaca/2021/09/06/news/sospese-le-ricerche-del-39enne-	Droni impiegati durante le ricerche di un escursionista scomparso nel bellunese.	Pubblica Amministrazione	Protezione civile	Ricerca e soccorso	Ricerca di persone	Dispersi in montagna	n.d.	Utilizzo una tantum	2021	07-set-21
629	Israele, leader di al-Fatah evade insieme a cinque compagni da un carcere israeliano: allerta in tutto il Paese	https://www.lastampa.it/esteri/2021/09/06/news/israele-leader-di-al-fatah-	L'esercito israeliano ha setacciato ogni angolo, servendosi anche di droni di supporto ricercare gli uomini evasi.	Pubblica Amministrazione	Esercito	Ricerca e soccorso	Ricerca di persone	Fuggitivi a seguito di reato	n.d.	Utilizzo una tantum	2021	07-set-21
630	Linee Telefoniche Distrutte Sostituite da Droni	https://www.droneblog.news/linee-telefoniche-distrutte-sostituite-da-droni/	Droni, dotati di unità cellulari poste sulle ali, vengono utilizzati per sostituire le linee telefoniche distrutte dall'uragano Ida.	Telecomunicazioni	Celle telefoniche	Erogazione	Emissione segnali	Emissione rete internet	n.d.	Utilizzo una tantum	2021	08-set-21
631	How drones are delivering medical supplies and saving lives in Africa	https://www.suasnews.com/2021/09/how-drones-are-delivering-medical-supplies-and-	In Botswana, è stato introdotto l'uso di droni per consegnare prodotti sanitari di emergenza alle remote popolazioni del Paese.	Logistica	Logistica umanitaria	Trasporto	Consegna di farmaci, dispositivi medici, materiale sanitario	Consegna in luoghi pericolosi o difficili da raggiungere	n.d.	Operativo	2021	09-set-21
632	BVLOS Trials of Long-Endurance Surveillance UAS for Canadian Coast Guard	https://www.unmannedsystemstechnology.com/2021/09/bvlos-trials-of-long-	Defense Research and Development Canada (DRDC) sta finanziando le prove nel tentativo di trovare un nuovo sistema di sorveglianza UAV a lunga durata per la distribuzione sulle navi della	Pubblica Amministrazione	Guardia costiera	Sicurezza e sorveglianza	Sicurezza territorio e persone	Pattugliamento	n.d.	Sperimentazione	2021	09-set-21
633	Un kit per la distribuzione con drone di organismi utili e per i servizi in agricoltura	https://www.quadricottero.com/2021/09/un-kit-per-la-distribuzione-con-	La collaborazione tra Koppert e Aermatica3D ha permesso lo sviluppo di un innovativo kit specifico per la distribuzione di insetti e acari utili attraverso l'uso di un drone	Agricoltura	Piante	Erogazione	Rilascio materiali	Supporto alla lavorazione delle colture	n.d.	Operativo	2021	10-set-21

Figure 10. Extract of the Excel file adopted to systematize the selected articles

2.3 Survey

The survey aimed at answering the last two research questions (RQ2 and RQ3). The scope of the analysis was mainly targeted to study the level of drone adoption among the Italian farms and to assess possible factor affecting UAVs adoption. The survey is the result of a cross-sectoral joint work between *Smart AgriFood Observatory* of Politecnico di Milano and *Drone Observatory* of Politecnico di Milano. The unit of analysis was the single agricultural firm of any size and sector, excluding livestock, with headquarters in Italy. Before starting to launch the survey, it was validated by the following actors: *Image Line*, *five farmers belonging to the Advisory Board of the Smart AgriFood Observatory*, *Confagricoltura*, *Coldiretti*, *CIA*, *xFarm*, *Agrocolus*, and *Abaco*. Then, the survey was submitted to several Italian farmers from 10/07/2021 to 31/12/2021 using Opinio[15], a survey platform provider. Firms were mainly selected from the database of the *Smart AgriFood Observatory* which contains more than 2000 contacts. Moreover, to reach as many farms as possible and to enlarge the current database, were exploited the following intermediary channels:

- Exhibitions, Magazines, Blogs, Newspapers: *Image Line*, *Terra e vita*, *Agrifood.tech*, *Ruminantia*, *Fiere di Cremona*, *Pianeta PSR*, *Freshplaza*, *Italyfruitne*s, *Other newspapers*.
- Trade Association: *Confagricoltura*, *Coldiretti,* and *CIA (Confederazione Italiana Agricoltori)*.
- Other: *Ismea*, *Agricultural Institute*, *Other exhibitions (agricultural fair)* and *Partners and sponsors*.
- Social networks*: Facebook*, *Linkedin*, *Twitter*.

The first part of the survey addresses the topic of Agriculture 4.0 in general, trying to identify which are the 4.0 solution that farmers invest in, the level of investment in precision farming solutions and factors affecting their adoption. Whereas the second part is the one of most interest for the purpose of this Thesis, being devoted to the usage of drone in agriculture. The section dedicated to drones was structured into four sub-sections:

1. Introduction survey drones
   It aimed at understanding the level of knowledge of drones, the means of knowledge, the actual and future level of adoption, and factors may curb drone adoption.
2. Current adoption of drones

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[15] https://survey.opinio.net

This section is addressed only to those who reported to currently use drones in their farms. The objective in this case was to understand which is the scope, which reason foster them to invest in UAVs, benefits sought, drone characteristics, its role and payload.

3. Past adoption of drones

   This section is addressed only to those who reported to have used drones in the past in their farms. In this case farmers were asked the reasons why they adopted drones and why they leave them.

4. Future adoption of drones

   This section is addressed only to those who are going to introduce drones in their farming operations in the next three years. The purpose was to understand the scope of the applications, role of the drone, and the benefits sought.

Questions to submit to farmers regarding drones were accurately identified by a panel of experts belonging to the *Drone Observatory*. After having closed the survey and gathered the information, only successfully completed answers were considered in the analysis. The total number of responders was 1594 farms. In addition, for the scope of the analysis, only farms that had successfully answered to the drone section were considered, resulting in a final number of 360 valid answers with a response rate of 22,6 %. To investigate the research questions (RQ2 and RQ3), data was extracted and organized in a structured Excel file. Then analyses were carried out on the same Excel file, exploiting the several functionalities provided by the application, one above all pivot table. Firstly, it was found the statistics for each question. Subsequently, cross analyses were carried out by combining farmers and farms characteristics, extrapolated from the *Smart AgriFood Observatory*' databases, with data gathered from the survey. Crossings were done taking inspiration from the reviewed literature about drone adoption and based on the data available.

Farmers' age is considered to be an important factor in the adoption of drone in agriculture (Zheng *et al*., 2019; Michels *et al*., 2020). Therefore, the age was compared with the level of knowledge about drones, actual usage of drones and future adoption of drones; all measured through a Likert scale from 1 (respectively, "I do not know the topic"/"This technology is not used at all"/"This technology will not be used") to 7 ("I perfectly know the topic"/"This technology is heavily used"/"This technology will be heavily used").

Larger farms are more likely to be the adopters of drones since it allows to better amortize the cost exploiting economies of scale and economies of learning. (Michels *et al*., 2020; Wachenheim *et al*., 2021; Zuo *et al*., 2021). With this purpose, a comparative analysis between cultivated land area and actual and future level of UAVs adoption was done.

The extant literature reports income as a relevant factor in the adoption process since farmers can reduce the risk of investment (Skevas and Kalaitzandonakes, 2020). Indeed, a cross analysis between income and actual and future level of UAVs adoption was built.

Moreover, a university degree should provide farmers with the technological and analytical skills to manage with a drone and also to effectively use the information gathered through UAVs (Michels *et al*., 2020). It is expected that a lower education level can be an inhibit factor towards technology adoption. So, education level was compared with the level of knowledge as well as the actual and future level of drone adoption.

Additionally, many times we have heard of an Italy advancing at two different paces. The northern Italy presents a higher advancement compared to the one of southern

Italy. Hence, an analysis of actual and future level of UAV divided per area of Italy was carried out. This can display some possible discrepancy among North, Centre, and South of Italy.

Finally, four cluster of farmers were identified by crossing the actual adoption level, the past adoption level and the future adoption level, resulting in the following: *Farmers who currently use drones and plan to use them in the future as well*, *Farmers who do not currently use drones but plan to use them in the future*, *Farmers who currently use drones but have no plans to use them in the future*, and *Farmers who currently do not use drones and who have no plan to use them in the future as well*. Then, reasons behind the choice of the different farmers to start or dismiss drone adoption were explored.

3 Empirical Analysis

In this chapter the main findings derived from the analysis done are presented. First, an overview of the main area of applications of drones, with a specific focus on agriculture, considering Italian as well as the international context is provided. Second, the main results arisen from the survey issued to Italian farmers are showed.

3.1 Census

At the end of the work, 816 articles from newspapers, magazines, and blogs were collected. As expected, use cases were mainly gathered from specialist publications accounting for 81%. In particular, the main sources of information were Drone Blog News (21%), UAS Vision (21%), Dronezine (14%), Quadricottero News (7%), and Urban Air Mobility News (6%) (Figure 11).

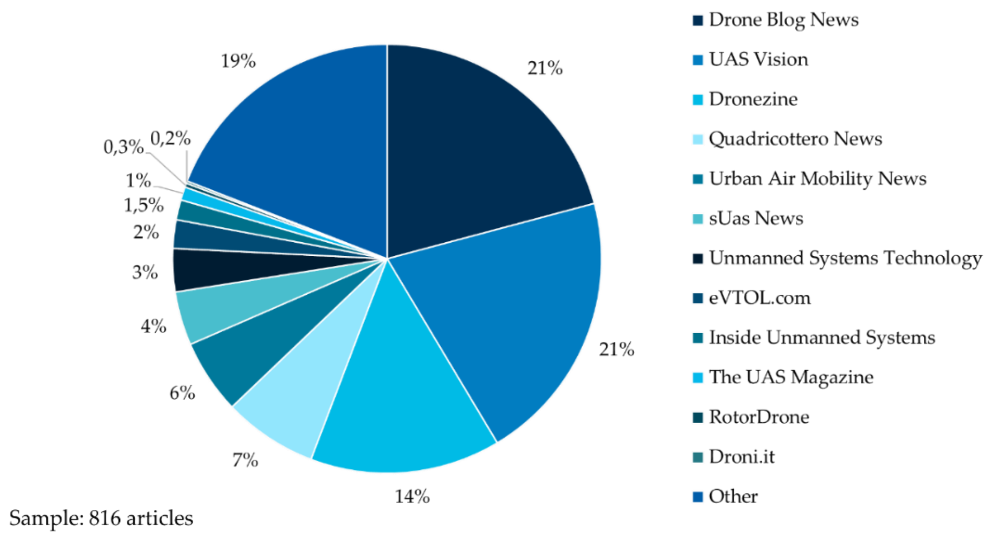

Figure 11. Sources of news in the drones industry

Looking at the industries, the applications of drones are not evenly distributed (Figure 12). The main areas of drones' adoption were Public Administration (31%), Logistics (13%), and Environmental Safeguard (13%) followed with less extent by Healthcare and Pharmaceutical (8%), Utility (7%), Agriculture (7%), Infrastructure (6%), and Entertainment and Media (6%). These are the most prominent sectors in which drone gave breakthrough. Mobility (3%), Mass Consumption (2%), Art and Culture (2%), Telecommunications (1%), Automotive (0,7%), and Insurance (0,3%) did not present a relevant number of applications. However, the mobility sector is expected to grow a lot in the next years with lot of projects where drones will be applied to the transportation of people in substitution of cars and moto.

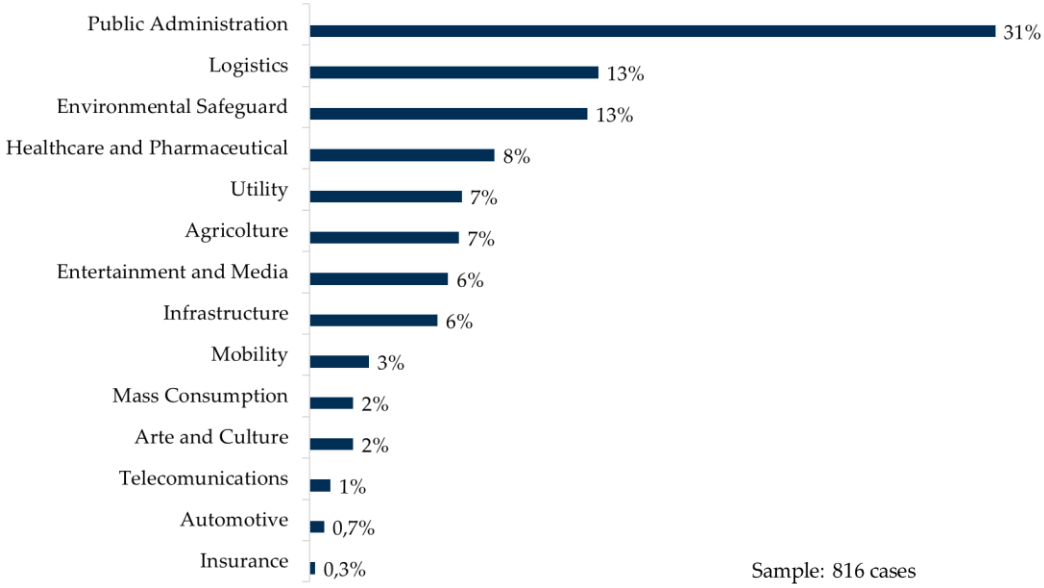

Figure 12. Application sectors

Considering the scope[16] of drones' applications, it is possible to see that Inspections (30%), Transportation (29%), and Security and Surveillance (14%) are the most diffused types of activity carried out by UAVs (Figure 13). With less extent it is possible to find also Dispensing (10%), Research and Rescue (9%), and Media, Art and Shows (5%). Whereas drones are very little used in Maintenance (2%) and Inventory (1%) activities.

[16] Scope 1.

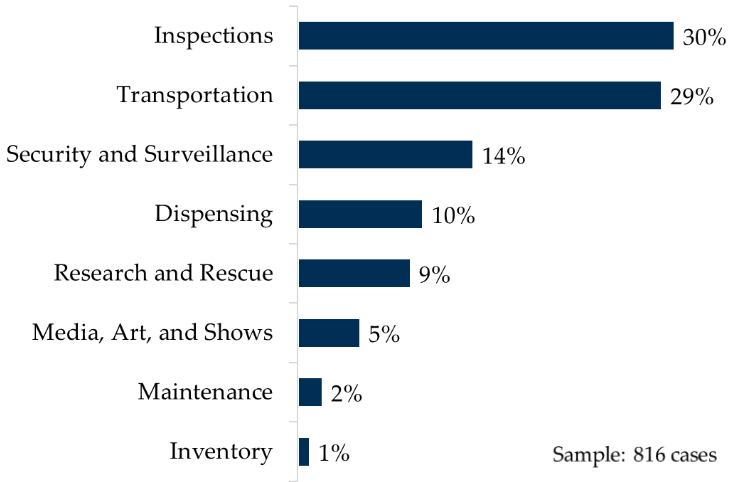

Figure 13. Scope 1

For what concern the type of operation, there was not relevant results, since it is a categorization only in force in Europe and furthermore it is something technical and recently introduced, hence, it is difficult that it is reported in those type of sources examined. Whereas is of great interest to see the state of drones' adoption. As it is possible to see in Figure 14, half the uses are either only announced or are in a state of experimentation (23% and 29% respectively), while 30% of the applications are in an operative state. This witnesses how drones still are not a well-established technology, but it is emergent and in the following years it is expected they will definitely "take off". Taking as reference the Rogers' curve (Rogers, 2003), the diffusion of drone technology is still in the early stages. It is the moment in which early adopters are trying for the first time to introduce drones in their activities. Then, few times the articles reported a case of UAVs used just once (18%). These latter are cases in which the intervention of drones was requested, but then it was not repeated anymore.

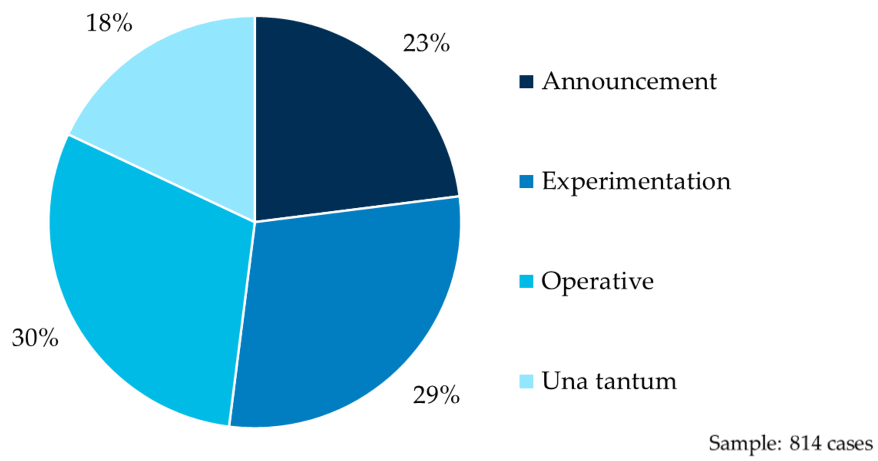

Figure 14. State of the applications

From a geographical perspective, it is possible to see that Europe, America, and Asia are the continents more active in the development and introduction of solutions based on drones, followed by Africa and Oceania (Figure 15). This is not surprising, since the first three are the continents more advanced from a technological point of view and they are leading ahead the drone's breakthrough. Then, the item Worldwide refers to all drone's applications either where the geographic location is not well specified or that are not confined in a define country but are spread worldwide. This latter is the case, for instance, of delivery service done by drones working in many countries. Just focusing on the most active continents – namely Europa, America, and Asia – it is possible to note that in Europe the countries that have stepped up the use of drones are Italy, United Kingdom, France, Spain, Germany, and Switzerland. In America, the leading country is United States of America (USA) accounting for almost all the evidence found. Finally, China, India, Japan, and South Korea are the most advanced countries in Asia from a drones' application perspective followed by Israeli and United Arab Emirates.

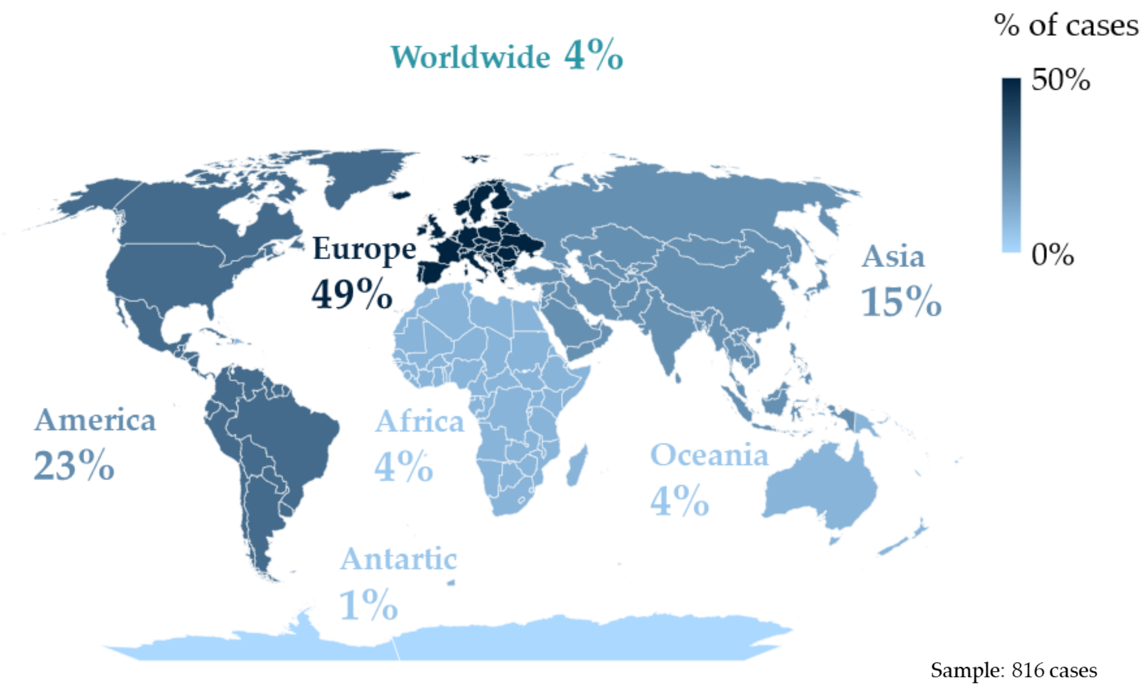

Figure 15. Continents

Moving to analyse the drone's typologies adopted to carry out the different activities, Figure 16 shows that the vast majority of applications are performed using multi-rotor wings drones and VTOL drones (45% and 38% respectively). Since multi-rotor wings models are capable to take off and land vertically, these two categories are a bit overlapped. While only in 12% of cases fixed-wing UAVs have been used and in 3% of cases rotor wing (conventional configuration) UAVs have been adopted. Multi-rotor wings drones are simpler to flight than helicopters, hence, they are becoming the dominant design in the generic rotor wing/s cluster. While, with respect to fixed wing drones, multi-rotor wings vehicles can perform hovering flight which is useful to do inspections, spraying liquids in specific points over crop fields, staging aerial shows, and many others. On the other hand, fixed wing UAVs requires an infrastructure to take-off and land, nevertheless, they can deliver higher speed and carry heavier payload. These latter features make them suitable for transportation of heavy payload for long distances, in fact, they are most used to deliver medicines, vaccines, and healthcare tools in remote areas of Africa which they do not have access to any medical facility. Indeed, many African local government and NGOs are collaborating to invest in this new technology in order to reach people living in remote villages providing them cares that curb the diffusion of infective diseases.

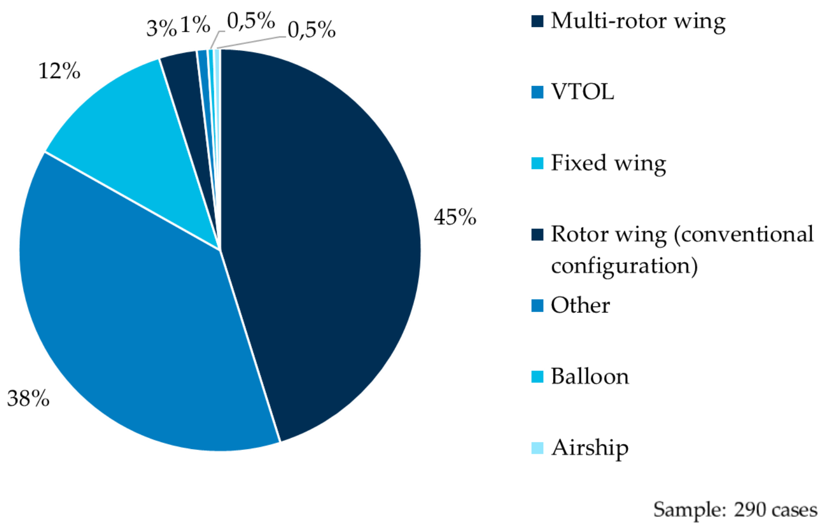

Figure 16. Drone's typologies

Considering the payload, the most diffused are camera RGB (20%) and distributor and other material transport systems (17%) followed by telecamera (12%), thermal camera (10%), other sensors (9%), dispenser of liquids, granulates, powders (7%), and photo camera (6%) (Figure 17). While concerning the other category, it includes tools and objects specific to the different cases. During these two years of pandemic, some local governments and Police adopted drones carrying a speaker to deliver warning messages to the people in street. Additionally, in almost all times drones were engaged in aerial shows they were endowed with bright LEDs to represent different figures. Moreover, there were case where the Coast Guard adopted UAVs to deliver life jackets to people at sea or farmers used drones endowed with a mechanical arm to harvest fruits from plants.

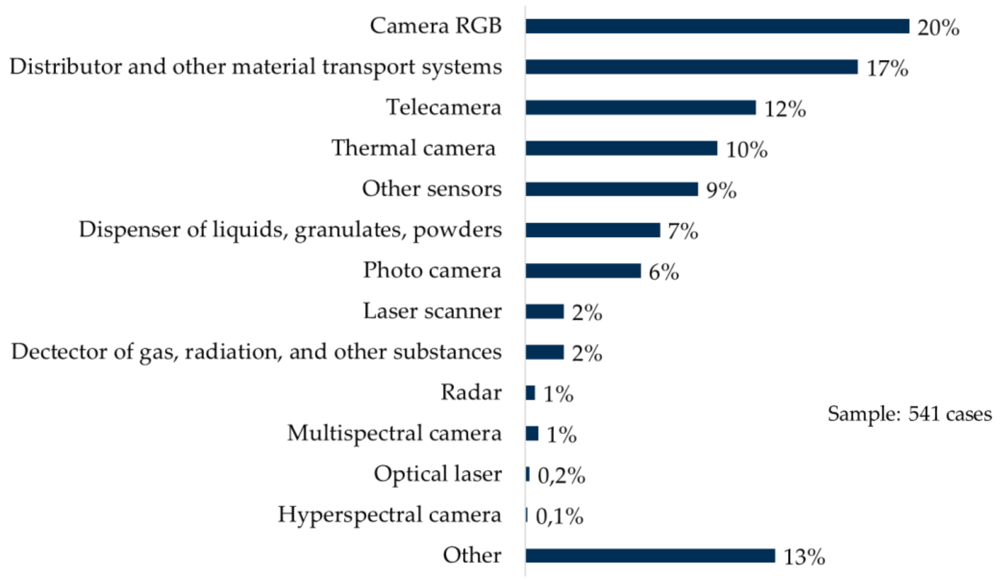

Figure 17. Payloads

Subsequently, an overview of the most common benefits sought is presented (Figure 18). Time reduction (37%) is for sure the most recurrent benefit adopters look for, followed by the possibility to achieve higher security in performing the activity (20%) and to reach uncomfortable places (18%). Drones flying in the air do not have any constraints in terms of traffic like other vehicles such as cars and they are faster than tractors to overlook crop fields and ships. Moreover, they do not need particular big infrastructure to take off and land like airplanes or helicopters, hence, they can reach remote zones like remote villages or island of a country faster than other transportation mode. Then, they can be used to perform inspections of unsafe places, spraying pesticides, or to perform other operations dangerous for humans like doing fireworks - substituting fireworks with drones allows to avoid unpleasant inconveniences. Then, just after, drones' adopters claim to want to enhance the quality/accuracy of data collected (13%), to reduce cost (12%) and to improve the environmental impact of their activities (11%). Drones are electric vehicles; hence, their emission is practically zero with respect to the other transportation mean like cars, ships, airplanes, and helicopters. Additionally, to run UAVs is cheaper with respect the other transportation means. Moreover, the time reduction is often linked with a cost reduction. Finally, increase yield is the least benefits drones' adopters look for.

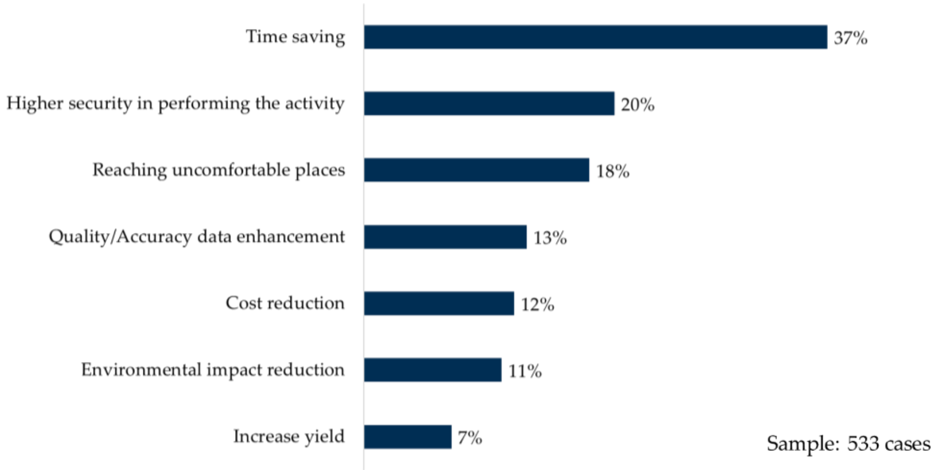

Figure 18. Benefits sought

Finally, Figure 19 shows an overview of the different application scopes divided per sector. Regarding the main areas of drones' application, it is possible to see that UAVs adopted in the logistics sector are almost all used for transportation of materials. In this field, an important trend related to the use of drones to perform last-mile deliveries is in place, in fact, lot of companies in the logistics industry are launching projects in this sense. Whereas the vast majority of drones' uses in environmental safeguard is mainly concentrated in the inspections. Indeed, UAVs are a precious tool that allows to map and survey the territory, including woods and forests, as well as monitoring animals. Likewise, in the infrastructure industry, drones are mainly adopted to carry out inspection to buildings, bridges, roads, and railways. Moreover, also companies working in the utility sector, mainly adopt drones to conduct inspection to electric lines or to infrastructure dedicated to the production of renewable energy like wind turbines. While the main purpose of UAVs' use in the healthcare and pharmaceutical sector is the transportation to deliver vaccines, medicines, blood sample, and organs to hospitals, medical centre, or even to populations living in remote areas like in Africa. Conversely, in the public administration there is not a scope which is the most popular, but there are three main types of applications: inspections, research and rescue, and security and surveillance. This is mainly due to the different actors included in the public sector. Police used to adopt drones to patrol the territory and perform inspections to find wrongdoing, whereas firefighters usually make use of UAVs to carry out on-the-spot investigations of buildings destroyed by fire or to look for missing people. Moreover, during these two years of pandemic, drones were heavily adopted by governments to control that people complied with regulations in force, to sanitize public spaces, and to announce alert messages via speakers mounted on drones in crowded places.

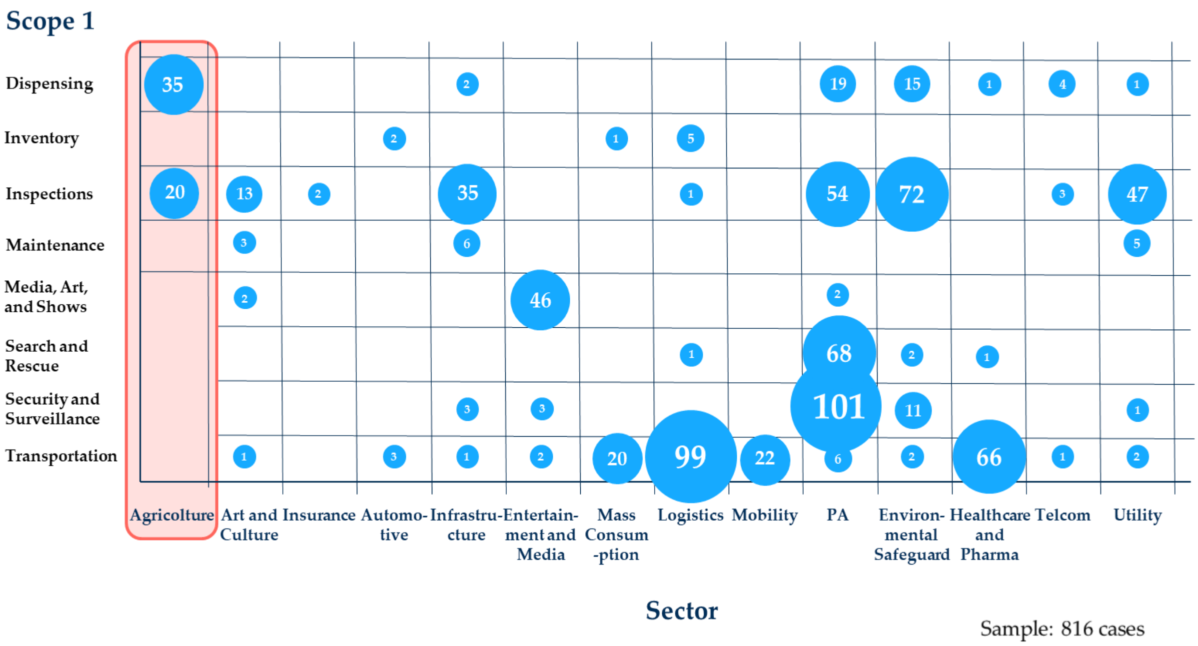

Figure 19. Application scopes divided per sector

3.1.1 Agricultural sector

Focusing on the agricultural sector, 55 evidences of adoption have been reported divided into dispensing (35 cases) and inspections (20 cases) activities (Figure 19). Regarding the detail item (Figure 20), the vast majority of cases are field/crops applications (58%), followed by aerial pesticides applications (25%) and plant protection (17%). This finding is not surprising since there are not common regulations among countries about the aerial spraying. Some countries, including Italy[17], forbid to deliver which ever liquids from an aerial vehicle for agricultural purpose, except under specific permission by the local government for some very peculiar scope. While other countries such as Asian countries like China and India along with USA and Australia it is allowed. For this reason, the aerial pesticides spraying operation is limited with respect to field application.

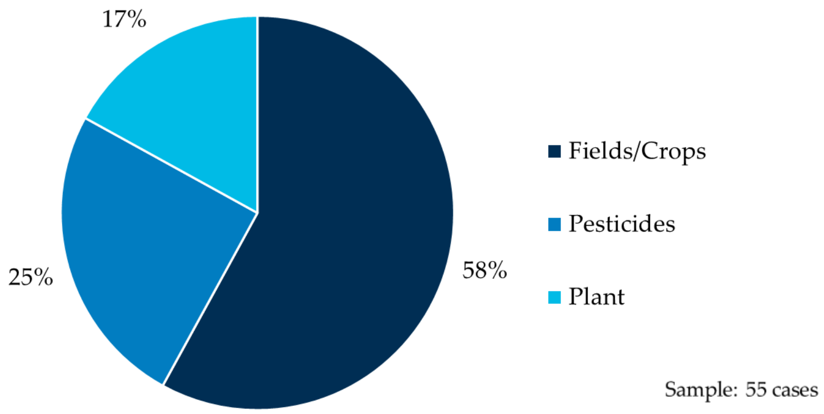

Figure 20. Agricultural applications divided per details

Whereas looking at Scope 2 (Figure 21), the main purpose of application is related to the release of materials (63%), followed with less extent by monitoring (30%) and

[17] Article 13 of D.Lgs. 150/2012.

surveys and mappings (7%). This result mirrors the previous finding about Scope 1 and detail. Actually, conversely to the finding about the detail, in this case dispensing overcome inspections since it includes not only aerial pesticides spraying, but also aerial watering and seeds shouting adopted to sow. While inspections encompass all activities regarding remote sensing like crop monitoring and farmland surveys and mappings.

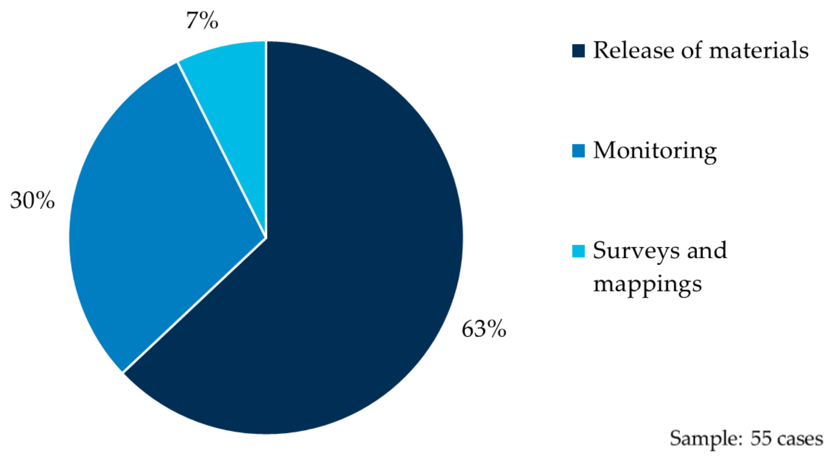

Figure 21. Agricultural applications divided per Scope 2

From a geographical perspective, things don't change much from the general context (Figure 22); Europe, America, and Asia still are the leading continents. However, Africa chases just after. While considering countries by countries, United States and Italy, followed by Australia and China are the most active countries in introducing drone-based solutions into the agricultural operations.

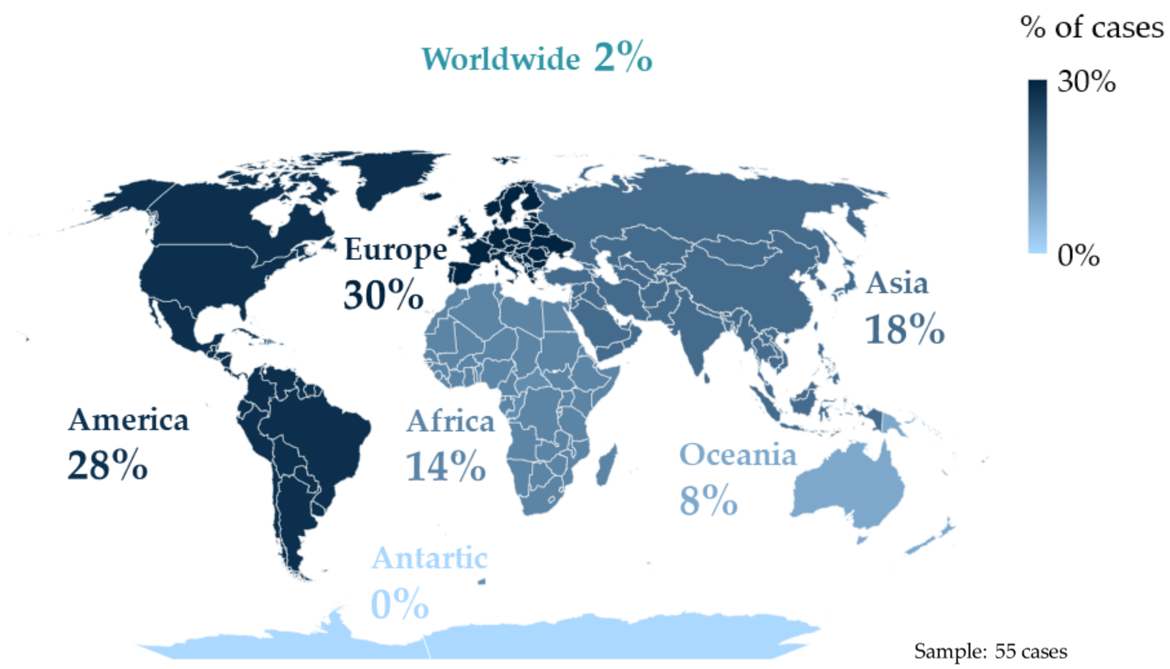

Figure 22. Application cases in agriculture divided per continents

Regarding the state of application, the agricultural sector mirrors what happens in the other industries (Figure 23). Farmers are getting know about UAVs and the most visionary and open-minded ones are starting to invest in UAVs and learning how to manage them. Moreover, many agricultural companies are not yet fully aware about the risk and benefits linked with UAVs. Therefore, more than half of cases are in a state of announcement or experimentation (20% and 41% respectively). While 39% of application is currently ongoing at fully power.

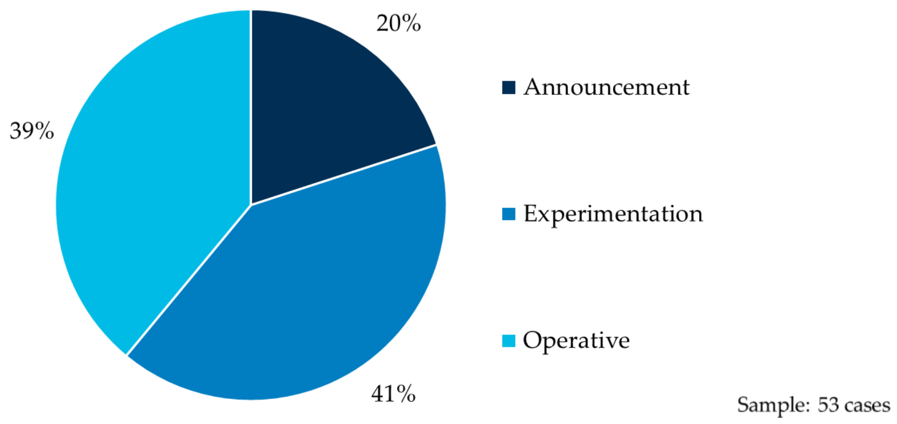

Figure 23. State of the applications in the agricultural sector

Based on the results obtained (Figure 24), only multi-rotor wings and VTOL drones were used in agriculture. This finding mirrors well both the general situation considering the other industries as well as what reported in the Chapter 1[18]. Multi-rotor wings typology is more flexible since it can be used in almost all the agricultural applications. Indeed, their ability to perform static flight allows to do inspections of the crops, to deliver liquids only in specific field points, to sow, and many other activities. Moreover, they are suitable both for farmers who own large cultivated land area and also small fields. Conversely, fixed wing UAVs cannot perform hovering flight, therefore they are mainly used to perform aerial spraying over long distances exploiting their capability to flight at higher speed and to carry heavier payloads, hence, they are more suitable for farmers that have huge crop fields in order to exploit their potentiality.

[18] See p. 24

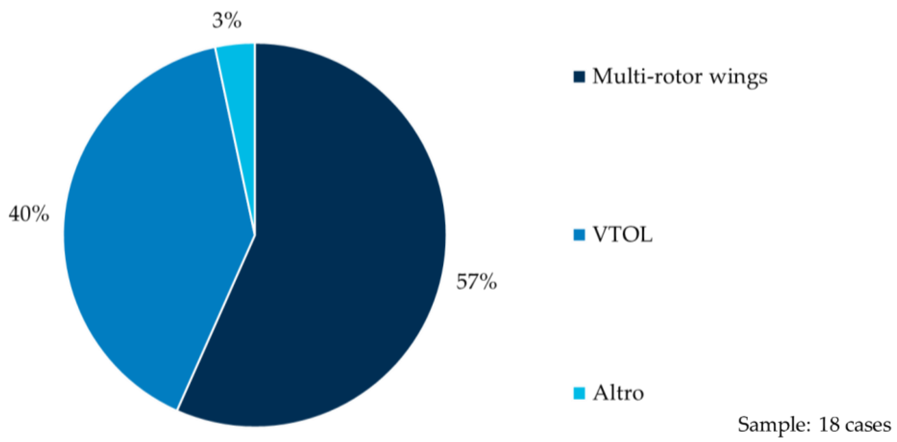

Figure 24. Drone's typologies in the agricultural sector

Considering the payloads, in the vast majority of the reported cases the ones most used are the dispenser of liquids, granules, powders (53%), followed by telecamera (47%), camera RGB (12%), other sensors (8%), and photo camera (8%) (Figure 25). This result reflects well the two most diffused applications of drones in agriculture. Aerial spraying was probably the first drone application in agriculture, and it attracts more and more farmers since it possible to rationalize phytosanitary treatments applying them only in specific points when needed. At the same time, growers can reduce production input and contribute to enhance the environment lowering emissions. Then, RGB camera can detect the degree of light reflection of the leaves and based on it famers can act in a targeted manner in specific crop's areas where a disease is coming up or where there is more need of water. Likewise, thermal camera and multi/hyperspectral camera have the same function detecting different parameters.

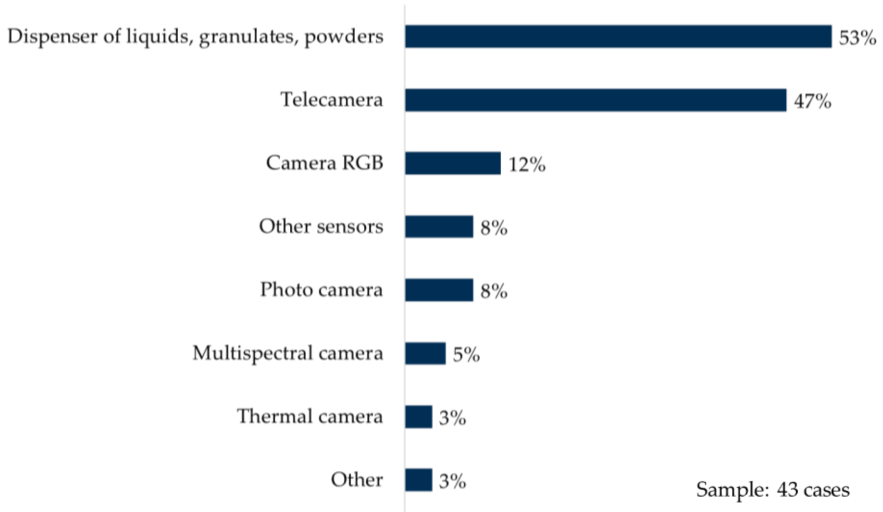

Figure 25. Payloads adopted in the agricultural sector

Focusing on benefits (Figure 26), time reduction is still the benefits most sought. Drones can fly over huge fields faster than humans by foot or driving a tractor. Moreover, drones can cover higher portion of crops when delivering pesticides and fertilizers in less time with higher precision. These advantages lead to the second benefits most sought, cost reduction. In this regard, if drones can cover higher portion of field in less time, farmers can lower the number of employees. Then, with a more precise spraying method, farmers can rationalize the production input in terms of water need, pesticides, and fertilizers. All these lead to a substantial reduction of costs. Consequently, with a more precise approach to the agriculture, farmers can raise the productivity of their crops without the need to enlarge their fields. In smart farming, delivering water or phytosanitary treatment only when and where needed, allows farmers not to waste water and to reduce the use of pesticides and fertilizers, that turns into a reduction of the NO_2 emissions that, everything being equal, are more pollutants of CO_2 emissions. Additionally, raising productivity there is no more the need to widen the farming fields to increase the output, with a consequently enhancement in the biodiversity safeguard. Finally, in few cases an enhancement of the quality/accuracy of the analyses was reported. Drones are more flexible with respect to satellites to gather information from fields since they can work also during cloudy days, and they have higher accessibility at a lower cost. Whereas few evidence was reported for increasing the security in performing farming activities and reaching uncomfortable places. However, some farmers are willing to start UAV-based projects to grow vineyards placed in sloping lands where it is difficult to come with other vehicles like tractors.

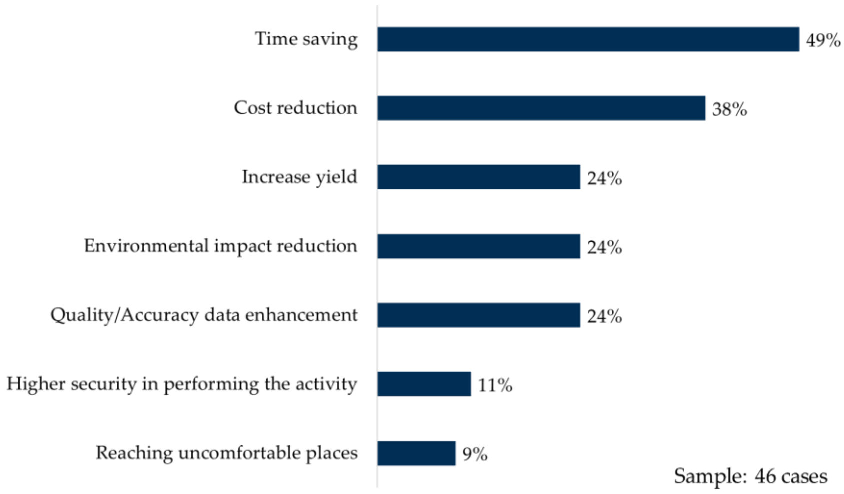

Figure 26. Benefits sought in the agricultural sector

In conclusion, it is worth to note that results obtained in the census are affected by the sources used. Indeed, most of publications refers to the Italian context, and the others are oriented on the European and North America landscape. Therefore, the figures of Asia, Africa, Oceania, and Latin America are a little downsized for this reason. Moreover, findings are affected by the content of the articles as well. Indeed, not in all news could be possible to find all the information needed. In fact, in some cases payloads, benefits sought, and drone typology were omitted. Anyway, the census provides a good overview of the state of the art at international level.

3.2 Survey to farmers

When the survey was closed, 360 farmers followed the invitation and answered the questions related to drones with a response rate of 22,6% over a total number of 1594 respondents. The result of the survey will be presented starting with a demographic description of the sample. Then, a descriptive statistic of the answers to the questions will be provided. Finally, cross-analyses between demographic information and result about the survey on UAVs will be done.

Starting with the farmers and farms characteristics, growers in the sample are 51 years old with 26 years of experience in farming activities on average (Figure 27, 28). With respect to education level, 44% of respondents achieved the high school diploma, while 36% also hold a university degree/diploma which lies above the Italian average of 8%[19] (Figure 29). Therefore, the education level of the sample can be considered medium-high. In the sample of 360 farmers, the average cultivated land area amount to 246 ha which is quite far from the national average of 11 ha[20]. However, 50% of respondents cultivate land no bigger than 25 ha (Figure 30). With respect to farm income, almost 60% of growers belonging to the sample have a revenue ranging from 30.000 € to 250.000 €, whereas 27% of farmers have a revenue lower than 30.000 € (Figure 31). Therefore, on average farmers surveyed have a medium-high income which is partially in line with the national context where the average income is of 45.000 €[21], and almost 60% of firms are very small – on average less than 8.000 €. For what concerns the crop typology (Figure 32), cereals are the most diffused crop

[19, 21] CREA - Centro di ricerca Politiche e Bioeconomia, 2020
[20] Coldiretti, 2020

typology grown by the 74% of farmers in the sample, followed by vineyards (46%), olive groves (42%), and leguminous plants (40%). Then, forage (34%), orchards (30% including stone fruits, pome fruits and citrus), and vegetables (26%) are a bit less diffused. Finally, a geographical description is provided in Figure 33. Most of farmers in the sample come from the northern Italy, particularly Emilia-Romagna (14%), Veneto (12%), Piedmont (10%) and Lombardy (10%), with the exception of Puglia (8%) and Sicily (8%) which partially reflect the Italian context.

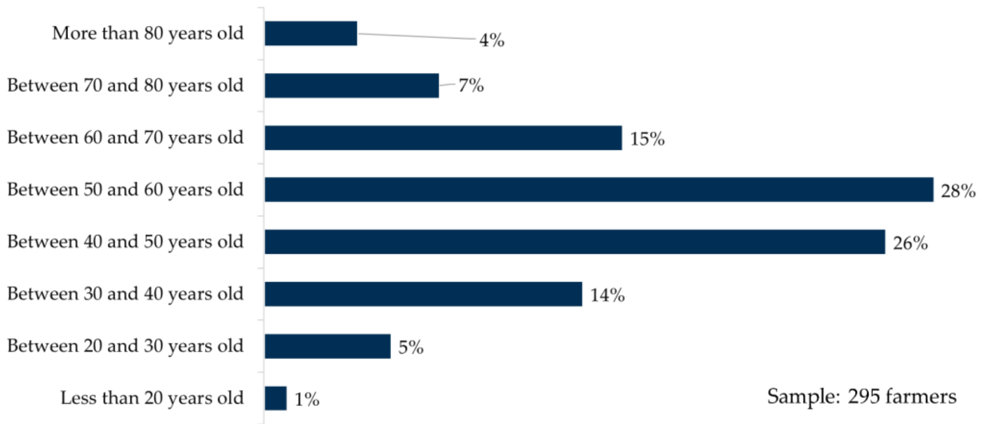

Figure 27. Farmers' age

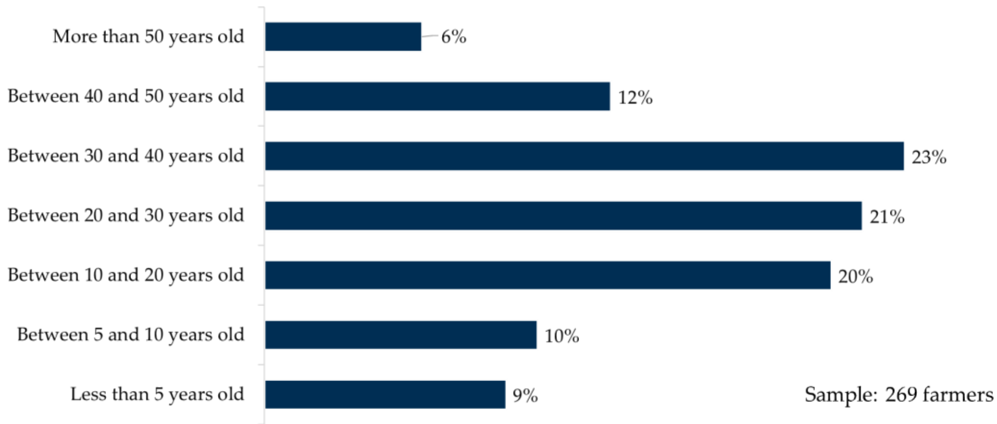

Figure 28. Years of experience in farming activities

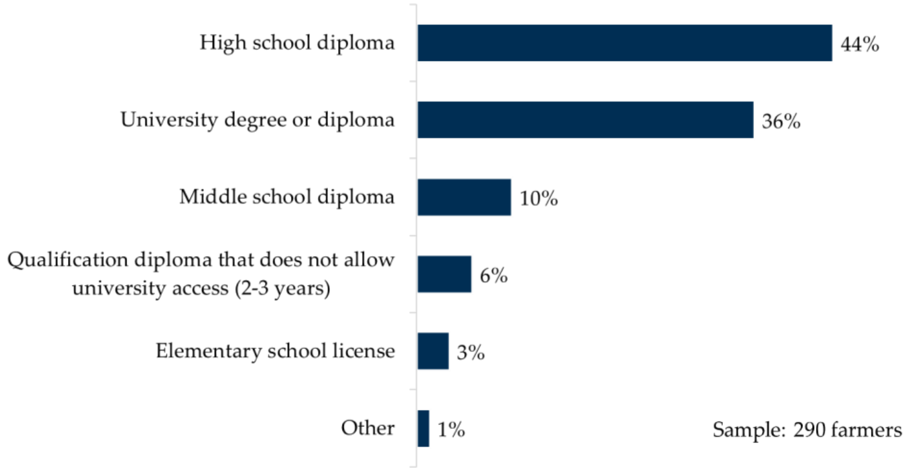

Figure 29. Education level

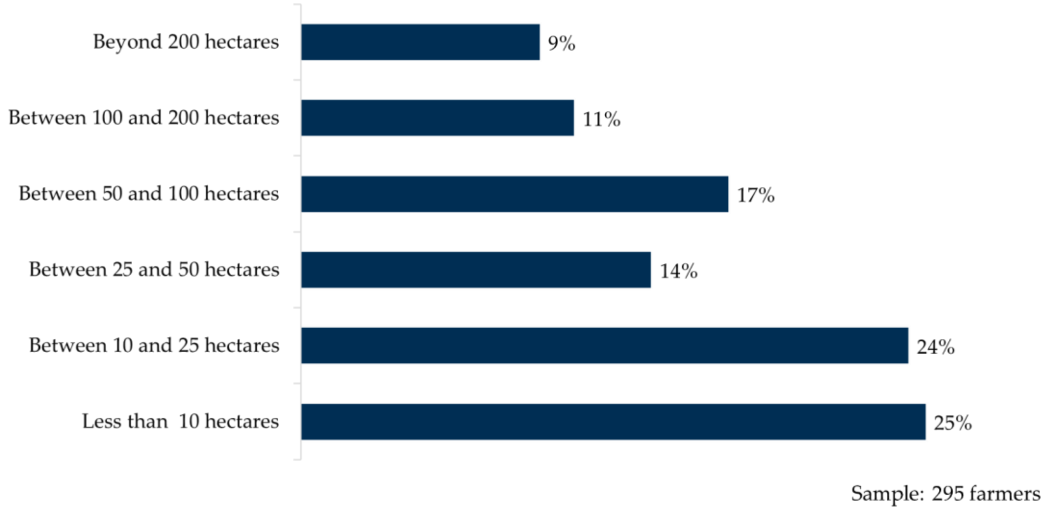

Figure 30. Cultivated land area

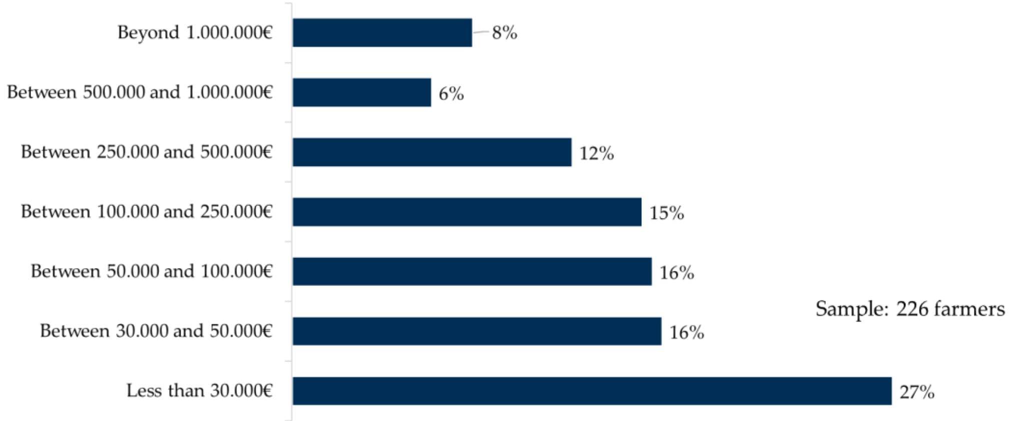

Figure 31. Farm income

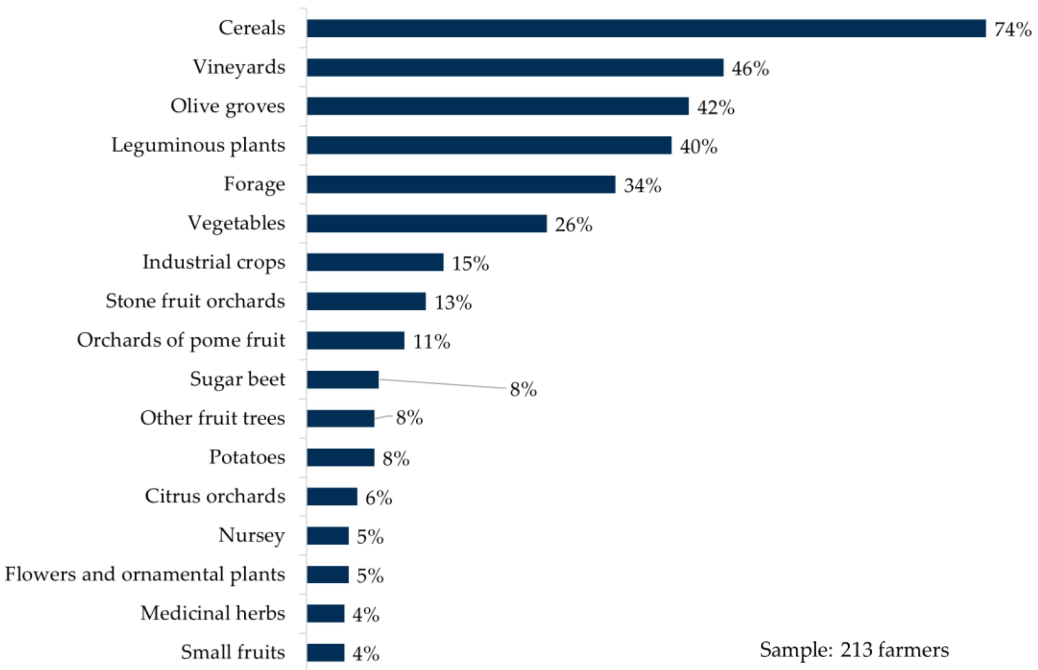

Figure 32. Types of crops

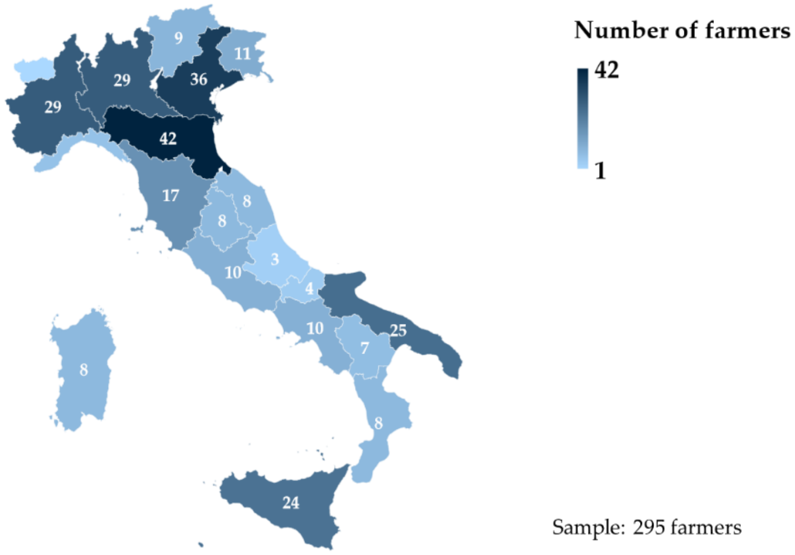

Figure 33. Geographical dispersion of Italian farmers

Moving to the descriptive result of the survey related to drones, in the sample of 360 respondents, 51% of farmers have an average knowledge of the technology, whereas only 18% of farmers have a high knowledge of drones (Figure 34). This is a first sign that generally agriculturists are not fully aware of UAVs, and it could be a first factor that is curbing the drones' diffusion. Farmers got to know about drones mainly through specialized media (49%) such as specialized press on agriculture, on new technologies followed by scientific magazines (32%), fairs or congress (30%), and general media (26%) such as national newspapers, local press (Figure 35). As expected, those with the highest level of knowledge tend to use specialist media and scientific journals more than others. Whereas "social networks" (Wachenheim *et al.*, 2021) seems not to play a relevant role in the diffusion of knowledge about drones. Indeed, only 14% respondents affirm to have become aware of drones from agricultural associations and 11% respondents from other farmers and provider of technical means.

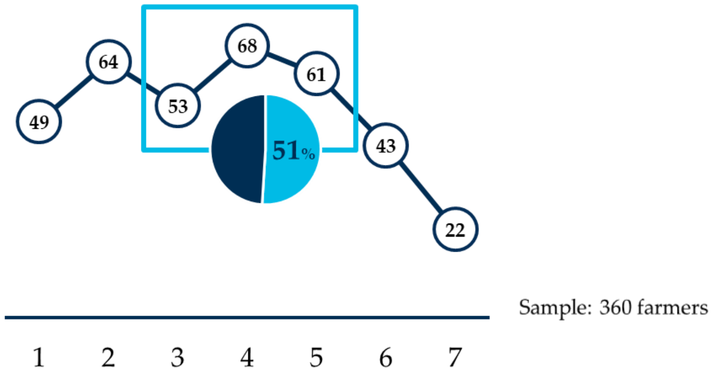

Figure 34. Knowledge level[22]

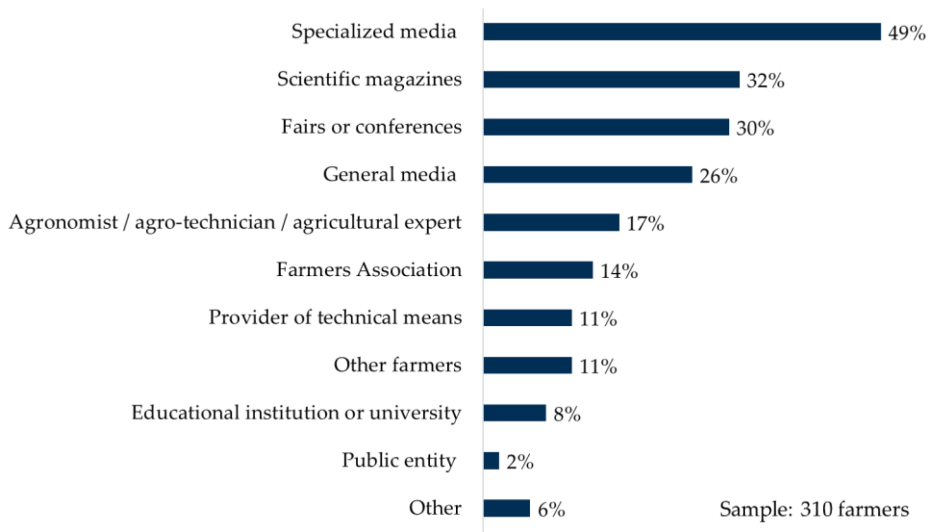

Figure 35. Means of knowledge

Subsequently, the survey on UAVs is composed of three sections, one related to the past use, another to the present use, and last one to the future use.

Starting to analyse the section referred to the past use, among the firms participating the survey about drones, 40 farmers (12%)[23] declared to have used drones in their

[22] 1 = "I do not know the topic"; 7 = "I perfectly know the topic"

[23] Total sample: 342 farmers.

farming operations in the past. They decided to invest in UAV technology mainly for an internal factor related to their curiosity in experimenting something new (Figure 36). Then, 20% of who answered the question declared to have used drones to improve efficiency in terms of cost and/or time reduction and 13% of respondents adopted UAVs to improve the environmental sustainability of their farming operations and to improve the effectiveness, i.e., increase the quality and speed of the processes. Nevertheless, they did not achieve the desired results and they stop using drones. Indeed, 23% of farmers did not encounter any benefits from the introduction of the new technology (Figure 37). Then, 20% of companies complains about a lack of internal skills, followed by 18% of respondents who report a limited return on investment and a lack of improvement in the activities carried out with drones. Moreover, some farmers blamed their suppliers who did not have a service level lived up to expectations (13%). Whereas few companies complain about the regulatory and bureaucratic complexity in obtaining authorization to use UAVs. Finally, some farmers highlighted other factors mainly related to a lack of economic resources and high cost to manage them.

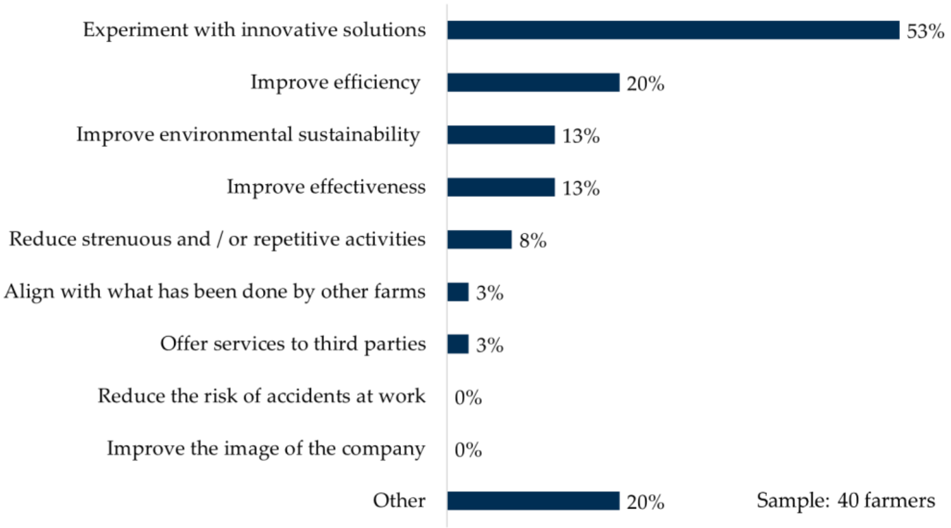

Figure 36. Benefits sought (past)

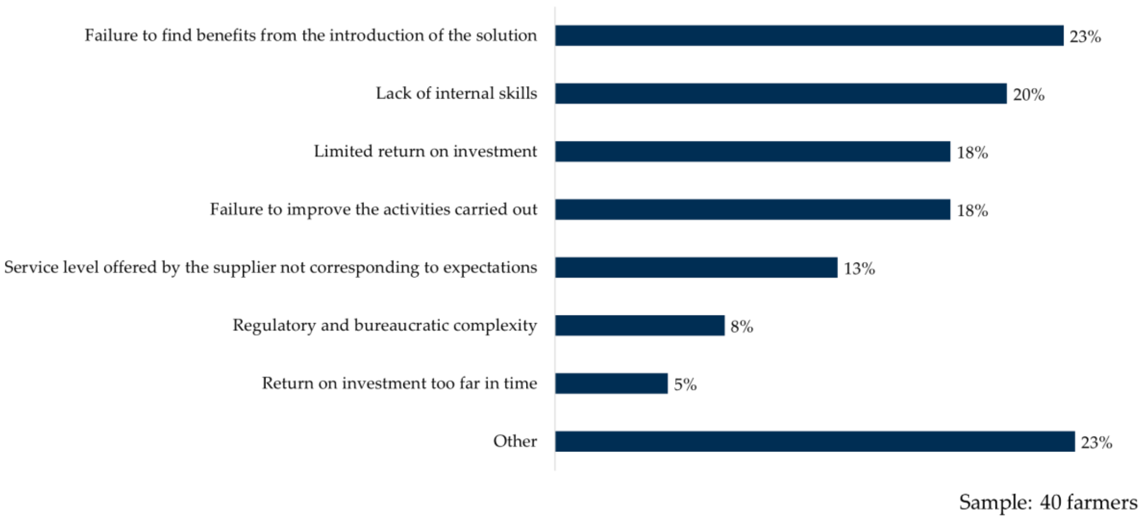

Figure 37. Reasons for abandonment

Moving to the present situation, results on the actual use of drones are not comforting; only 16 farmers (4,4%)[24] declared to currently make use of drones in their farms. Among these 16 farmers, half of them have a medium-high level of drones' adoption

[24] Total sample: 360 farmers.

(Figure 38). These findings witness that drone technology is not currently well diffused in the Italian agriculture landscape yet.

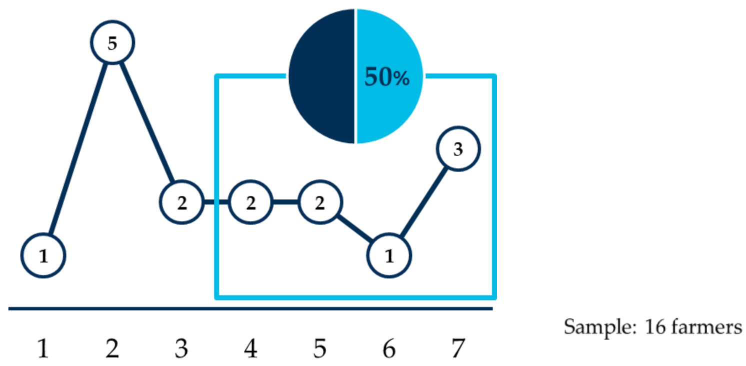

Figure 38. Actual level of drones' usage[25]

According to the results, the most diffused applications are the use of mapping services of crops and land through data collected by drones, such as maps showing the state of vigour of the crops, soil texture, yield maps (88%), spreading fertilizers (60%), crop monitoring without the production of maps (60%), and use of field treatment services with drones like integrated fight against the corn borer (33%). Then, there are applications a bit less diffused like transportation of material (20%), surveillance activity (20%), animal monitoring (20%), and sowing (20%) (Figure 39).

[25] 1 = "This technology is not used at all"; 7 = "This technology is heavily used"

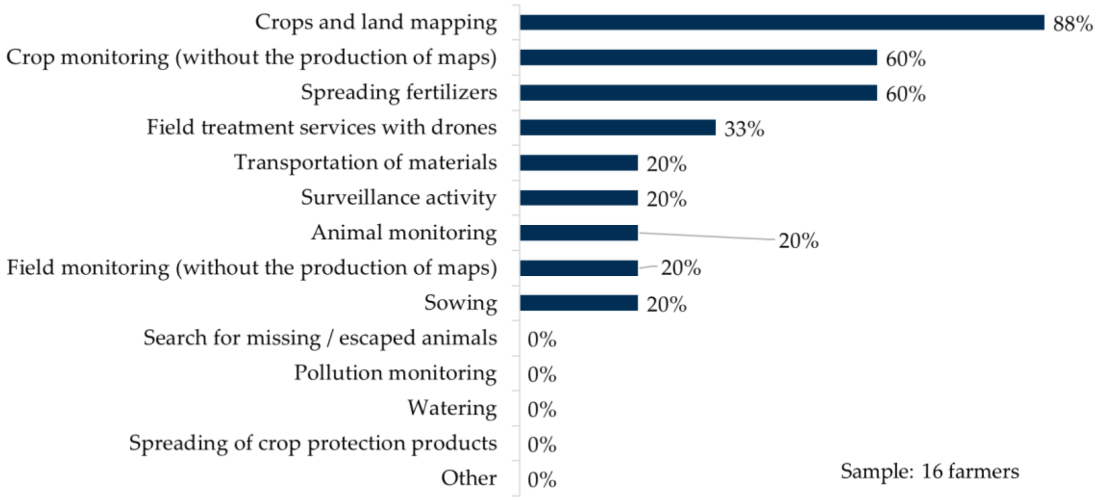

Figure 39. Drones' applications (present)

Farmers who are currently using UAVs in their farms, they did it for three main reasons (Figure 40). First, they wanted to improve environmental sustainability (56%) and they found in drones the best alliance to do that since they are alimented by electricity and with a precision approach to farming activities it is possible to decrease waste and pollution derived by the use of fertilizers, pesticides and other crop protection products. Second, farmers are currently using UAVs just to experiment new solutions (56%), i.e., what prompted them to introduce drones was not an economic, social, or environmental benefit, but rather an inner factor of the farmers themselves. Third, they hope to improve effectiveness (50%) enhancing the quality and speed of production processes. Then, with less extent, farmers hope to reduce repetitive and hard activities (13%) substituting the human workforce with UAVs or in combination with the extant workers, and to improve the image of the company as well (13%). In vast majority of the applications, companies want to integrate drones with solutions (workforce or other technologies) currently used to carry out internal activities (Figure 41). The benefits obtained are quite in line with the benefits sought. Indeed, the first benefit that farmers have been able to achieve adopting UAVs is the reduction of the environmental impact (56%), followed by an increase in the accuracy and/or quality of data collected (38%), an increase in the amount of data collected (38%), and a reduction of time in carrying out activities (25%) (Figure 42). While 13% of the current adopters do not report any improvement. In Figure 43 and Figure 44 are reported the typologies of drones used and payloads most adopted. Almost all farmers employed a multi-rotor wings UAV and as expected by the results on the applications, the most adopted payloads are the multispectral camera (67%) and telecamera (40%).

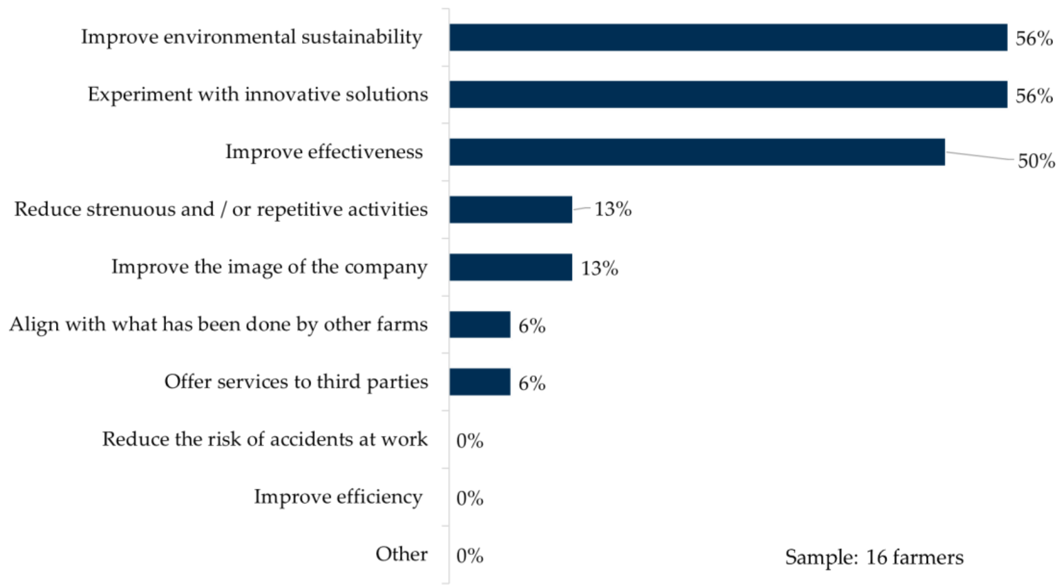

Figure 40. Benefits sought (present)

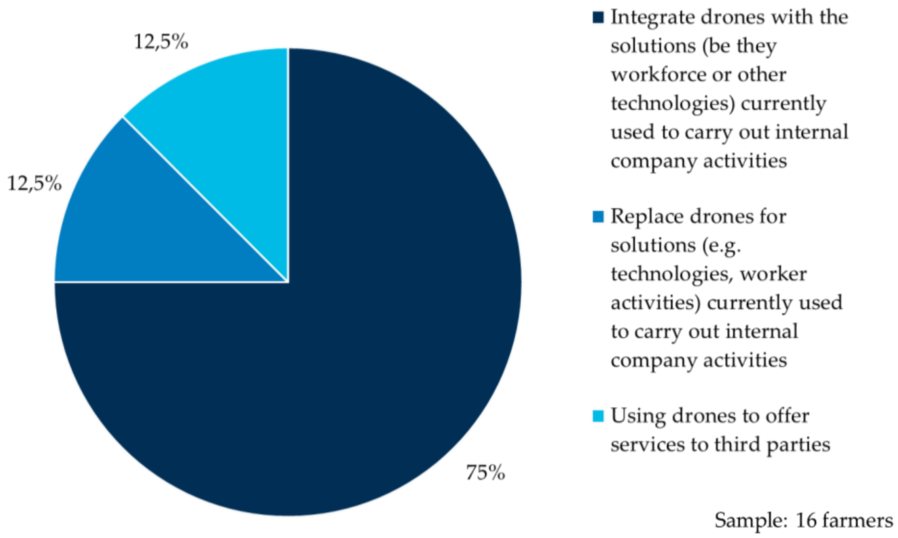

Figure 41. Drones' role (present)

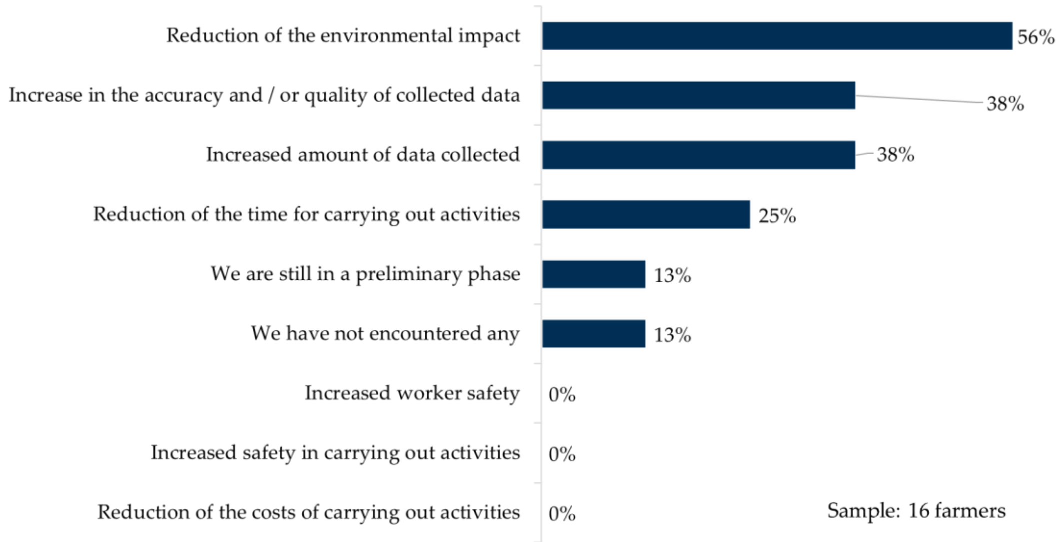

Figure 42. Benefits obtained

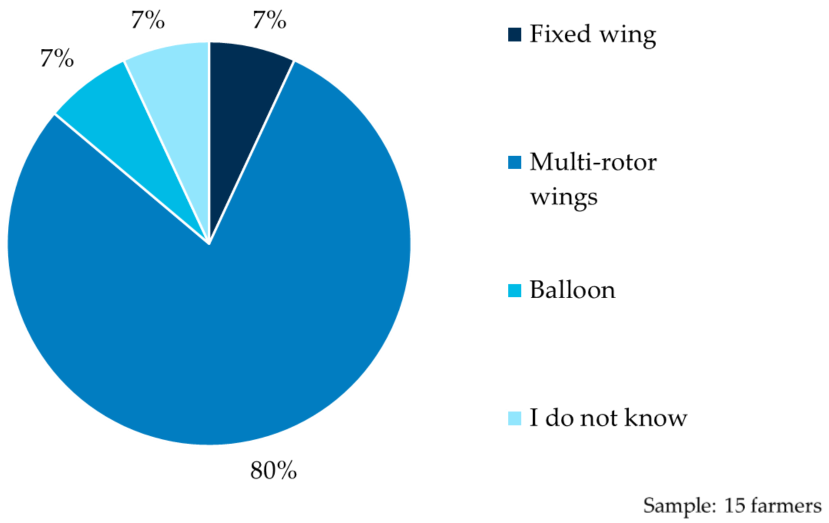

Figure 43. Drone's typologies

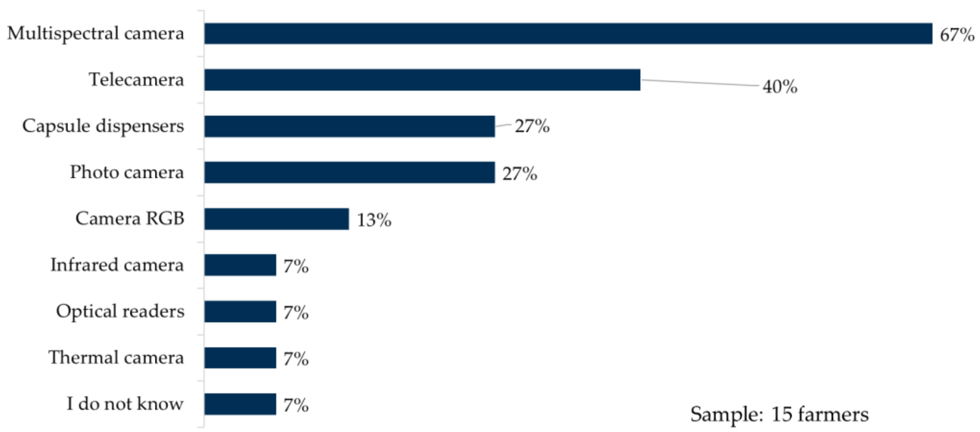

Figure 44. Payloads

Looking at the future, it is expected an important increase in the adoption of drones by farmers. Indeed, 68 farmers (19%)[26] stated that they are willing to invest in drone technology to support their farming operations in the next three years (2022 -2024), and 56% of them will have a medium high level of adoption (Figure 45). Apart from

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[26] Total sample: 360 farmers

the use of mapping services of crops and land through data collected by drones accounting for the 76%, which continuing to be the first scope of application also in the future; farmers will use drones also to perform crop and field monitoring without the production of maps (67% and 56% respectively) and spreading of crop protection products (53%) (Figure 46). Then, surveillance activity (47%), using field treatment services with drones (46%), and spreading fertilizers (33%) will be other relevant applications in future. If there will be some change in the Italian regulations about the delivering of liquids from aerial vehicles, the latter application will spread soon. In 64% of cases, UAVs do not substitute the existing resources (human and technology), but rather they will be integrated with them giving an important support (Figure 47). While 20% of respondents will introduce drones to replace the existing resources currently present in the farms. Moreover, 16% of firms intend to invest in drones not to improve internal operations but rather to provide a UAV-based service to third parties opening a new stream of revenues.

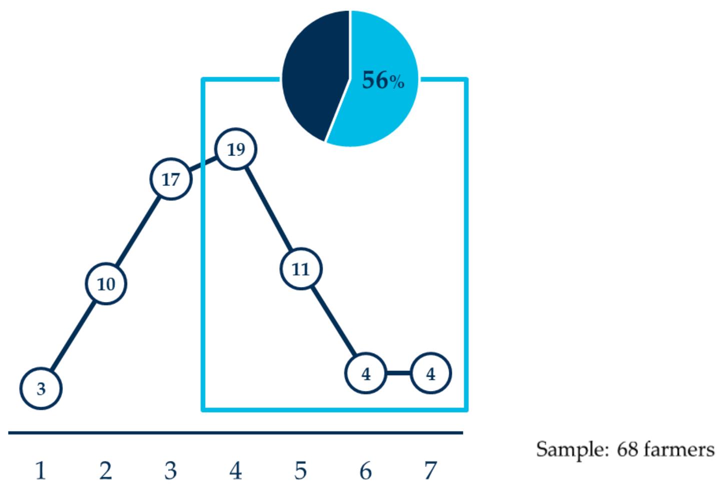

Figure 45. Future level of drones' adoption[27]

[27] 1 = "This technology will not be used"; 7 = "This technology will be heavily used"

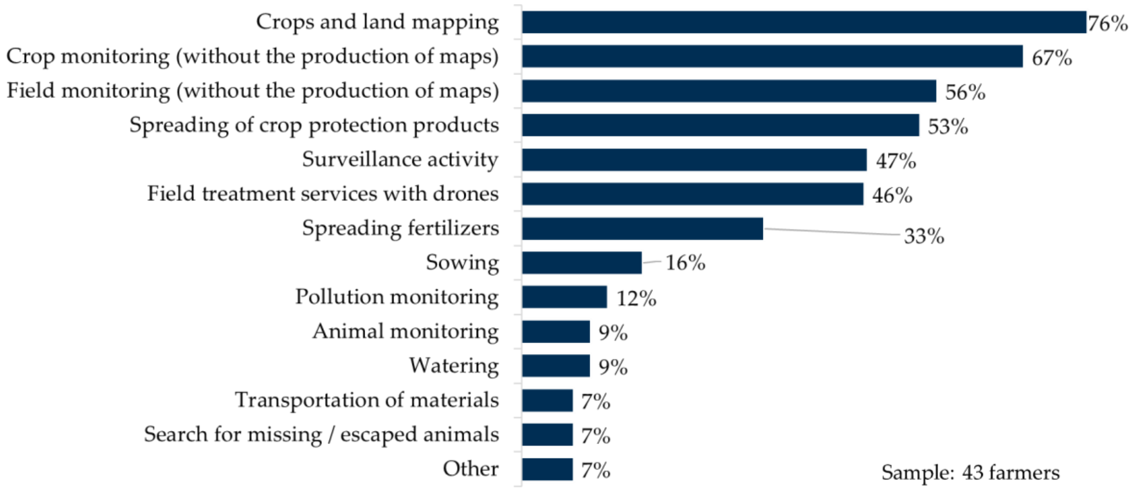

Figure 46. Drones' applications (future)

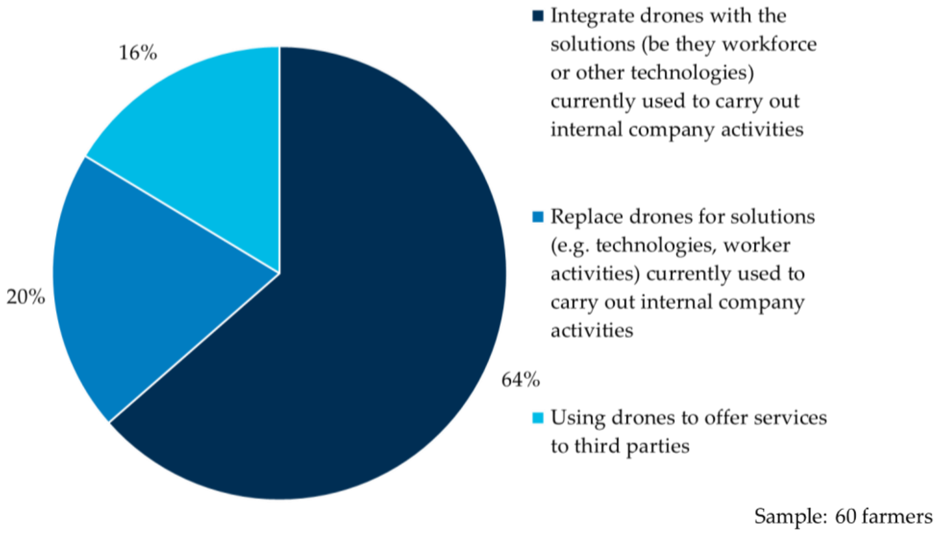

Figure 47. Drones' role (future)

The main benefits farmers look for is for sure to improve efficiency, hence, to reduce cost and/or time (75%) (Figure 48). Subsequently the internal factor component still plays a relevant role, in fact, 72% of respondents affirm they are willing to introduce drones just to try something new. Another relevant advantage firms hope to achieve is to increase not only the efficiency, but also to improve the effectiveness enhancing the quality and the speed of their internal processes. Then, environmental concern is still high within farmers, in fact, 62% of responding firms admit wanting to improve the environmental sustainability of their operations. Then, with less extent, respondents are looking to reduce the repetitive activities introducing drones to perform them (33%) and to improve the imagine of the company towards customers and final consumers (30%).

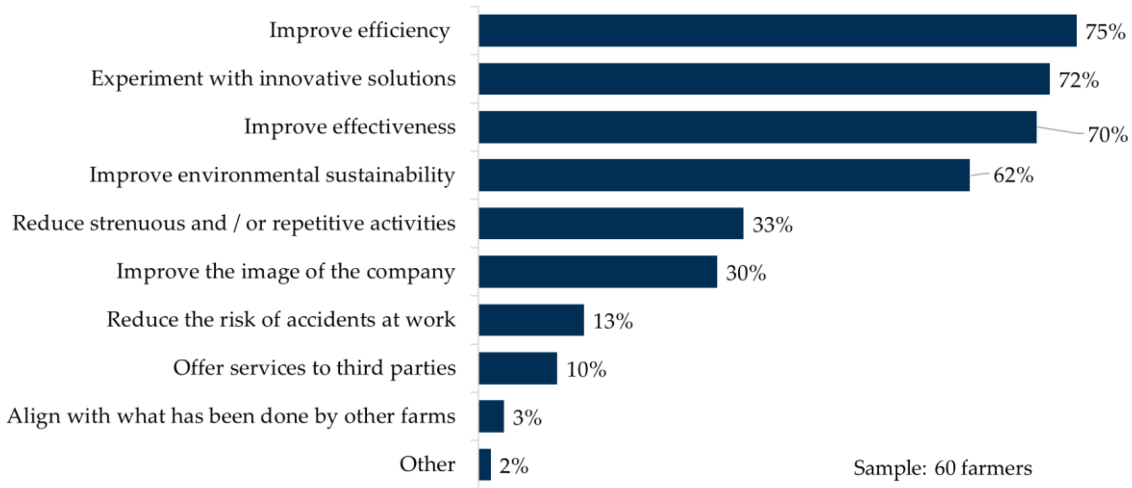

Figure 48. Benefits sought (future)

In the light of the previous findings and considering the low number of current adopters, anyhow it is possible to do a comparison on the evolution of benefits sought along the time (Figure 49). As highlighted many times, doing experiment with innovative solutions is a constant along the time. This is typical of new innovation, people (early adopters) not still fully aware of the potentiality of the technology try it to get know about it and learn. While the attention towards efficiency and effectiveness increased over time. Probably, farmers start to become more aware of the possible advantage that UAVs can bring in supporting farming activities and therefore farmers not only try drones just for doing experiment, but they begin to invest in this new technology with specific purposes. Then, it is possible to see how the environmental concern increased heavily in the last period following the general trend towards ecological transition. The latter is linked with an emergent trend related with the possibility to improve the image of the company. Finally, it is possible to note that the social factor, represented by the item "*Align with what has been done by other farms*", is not so relevant meaning that farmers are not so much influenced by neighbours' behaviours.

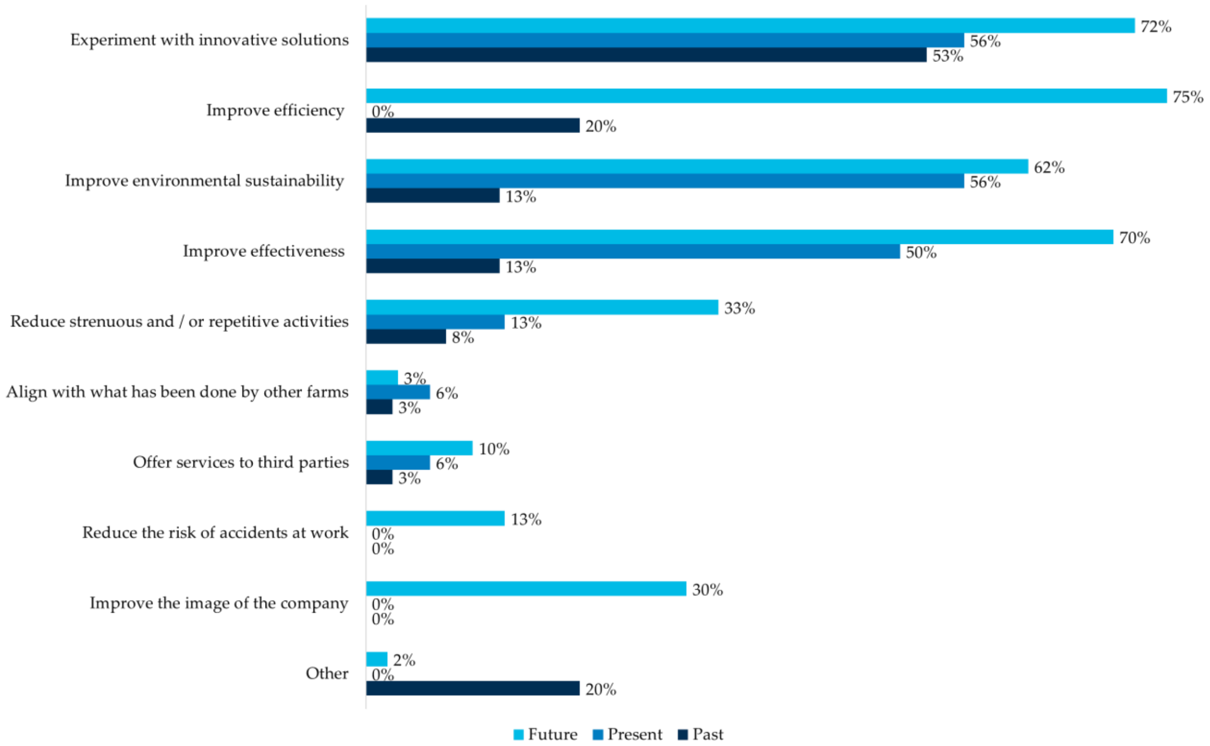

Figure 49. Comparison among the benefits sought in the past, present, and future

Following the analysis carried out in the literature and the data available, cross analyses between results from the survey about drones and demographic characteristics will be provide right away. Given the low evidence found regarding the actual use of drones (only 16 adopters), it is not worthy to deepen it with further analyses. Whereas analyses considering the past and future use can be more consistent given the higher number of evidence collected (40 past adopters and 67 future adopters). However, it is possible to notice that farmers who are currently using drones are those with medium-high level of education (high school diploma or university degree/diploma), owning large cultivated land area (> 50 hectares) and having medium-high turnover (> 100.000 €).

Looking at the level of knowledge about drones, it seems to be quite homogeneous among the different age groups with a slight tendency towards younger farmers. Whereas, as expected, those farmers with a higher education level (high school diploma, university degree/diploma or even doctorate) show a higher knowledge about drones.

Regarding the past projects, farmers who made use of UAVs present prevalently a medium-high education level (high school diploma or university degree/diploma), they own medium-large cultivated land area (> 25 hectares) and have a medium-high income (> 100.000 €).

Considering the future adoption, companies who report to want to invest in the new technology are middle age – 58% of farmers is between 40 and 60 years old – and they show a middle-high education level (high school diploma, university degree/diploma or even doctorate). Whereas considering cultivated land area and farm's income, also small-medium enterprises (SMEs) with medium-small crop fields starts to look at drones to improve their farming activities. However, medium-large farms reported higher level of adoption with respect to SMEs.

Table 3. Crossed analyses among age, level of knowledge, actual level of drones' use, and future level of drones' use.

Age	**Knowledge**	**Present**		**Future [3 years]**	
	Level of knoledge	Level of drones' use (average)	% respondents	Level of drones' use (average)	% respondents
Less than 20 years old	1	—	—	—	—
Between 20 and 30 years old	3,6	7,0	11%	4,5	7%
Between 30 and 40 years old	3,9	5,5	22%	3,9	15%
Between 40 and 50 years old	3,8	2,0	11%	3,7	22%
Between 50 and 60 years old	3,9	3,4	56%	4,0	36%
Between 60 and 70 years old	3,5	—	—	3,4	14%
Between 70 and 80 years old	3,8	—	—	2,7	5%
More than 80 years old	2,6	—	—	3,0	2%

Table 4. Comparison among education level, level of knowledge, actual level of drones' use, and future level of drones' use.

Title of study	**Knowledge**	**Past**	**Present**		**Future [3 years]**	
	Level of knowledge (average)	% respondents	Level of drones' use (average)	% respondents	Level of drones' use (average)	% respondents
Elementary school licence	3,3	3%	—		3,0	2%
Middle school diploma	3,0	6%	—		3,0	3%
High school diploma	3,9	41%	5,2	56%	4,3	38%
Qualification diploma that does not allow unive	3,1	6%	—		3,3	5%
University degree or diploma	3,9	44%	2,8	44%	3,6	50%
Other	4,5	—	—		3,0	2%

Table 5. Comparison between cultivated land area and actual level of drones' use and future level of drones' use.

Cultivated land area	**Past**	**Present**		**Future [3 years]**	
	% respondents	Level of drones' use (average)	% respondents	Level of drones' use (average)	% respondents
Less than 10 hectares	9%	—	—	3,1	14%
Between 10 and 25 hectares	9%	—	—	3,8	17%
Between 25 and 50 hectares	17%	—	—	3,5	22%
Between 50 and 100 hectares	23%	6	33%	4,2	20%
Between 100 and 200 hectares	17%	5,5	22%	3,8	15%
Beyond 200 hectares	26%	2	44%	4,1	12%

Table 6. Comparison among income, actual level of drones' use, and future level of drones' use.

Income	Past	Present		Future [3 years]	
	% respondents	Level of drones' use (average)	% respondents	Level of drones' use (average)	% respondents
Less than 30.000€	4%	–	–	3,2	25%
Between 30.000 and 50.000€	13%	–	–	4,0	16%
Between 50.000 and 100.000€	13%	–	–	4,0	9%
Between 100.000 and 250.000€	25%	5,7	43%	4,5	25%
Between 250.000 and 500.000€	21%	1	14%	3,3	9%
Between 500.000 and 1.000.000€	8%	–	–	3,5	5%
More than 1.000.000€	17%	4	43%	4,4	11%

Then, making a comparison between past and future drones' adoption with a geographical perspective, it is possible to note that if in the past companies relying on UAVs were mainly concentrated in the northern Italy with Lombardy, Emilia-Romagna and Veneto holding more than 40% of the companies, in the future perspective the gap between north and south will get thinner and thinner so much that if looking at the future level of adoption it is expected to be higher in the southern Italy.

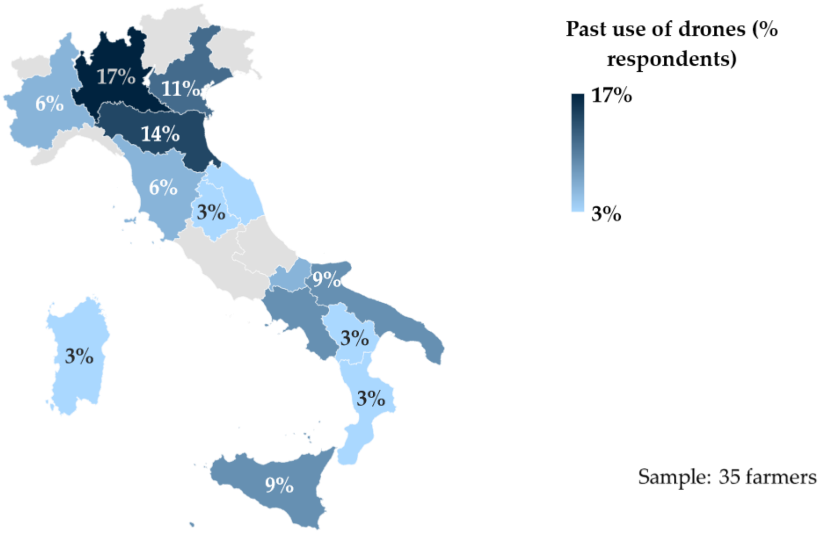

Figure 50. Geographical distribution of the past use of drones (% respondents)

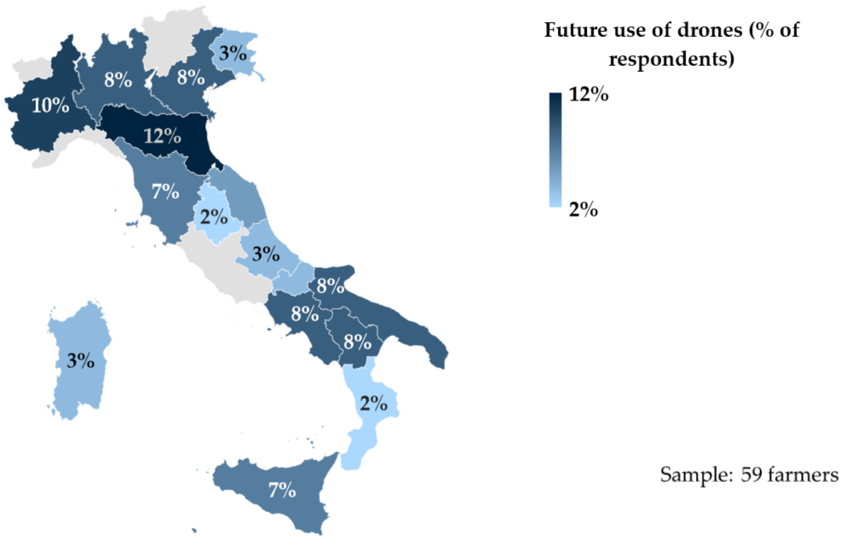

Figure 51. Geographical distribution of the future drones' adoption (% of respondents)

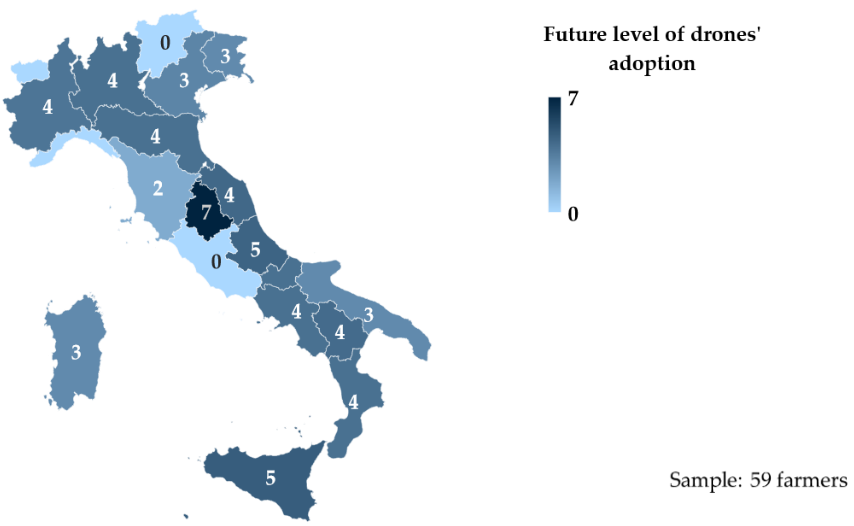

Figure 52. Geographical distribution of the future drones' adoption (level of use)

Considering the type of cultivation, Figure 53 shows the past, present, and future situation of drones' adoption divided per each type of crops grown by farmers. Overall, it is clear cereals crops are the ones in which drones are used most. Then, also leguminous plants, olive groves, forage, and vineyards seem that they lend themselves well to the use of drones. These types of crops are extensive cultivation, like cereal and leguminous plants where it is difficult to pass through with tractors or even by foot, or high value density cultivation like olive grove and vineyards. Whereas UAVs are less diffused in orchards. This maybe because fruits are a low value density product, and it is easier to pass through by tractors or by foot. Therefore, if farmers are not fully aware of the cost and benefits of the technology, they could be more reluctant to invest in drones. Then, drones are very little used in nursey, and to grow medicinal herbs and flowers and ornamental plants. This is mainly due to the fact that they are delicate, and the air displaced by the drone propellers could damage them.

However, this topic needs further insights, to better understand if it possible to define certain clusters of cultivations which are better suited for the use of drones exploiting better their features and potentiality.

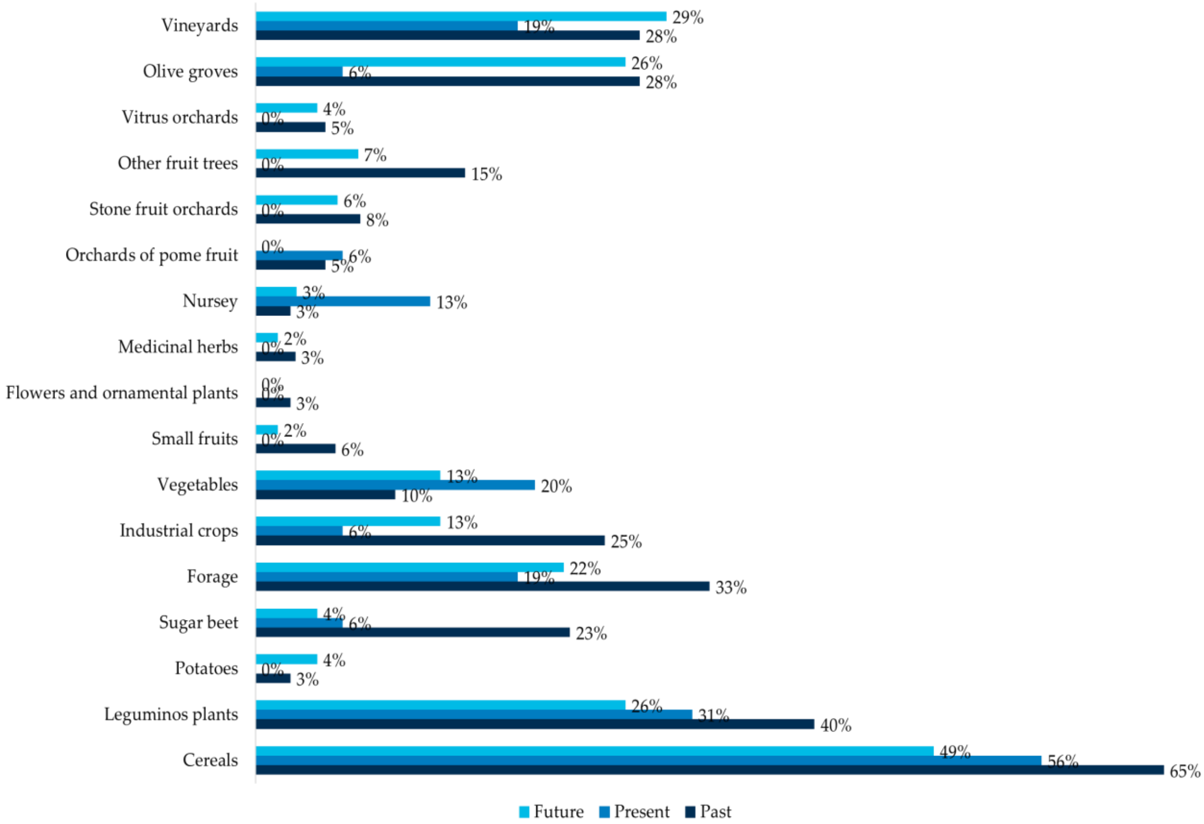

Figure 53. Past[28], ongoing[29], and future[30] drone-based projects divided per type of cultivation

Finally, by crossing evidence between the present and future projects, in Table 7 four main clusters of farmers have been identified: Companies that currently use drones and plan to use them is the future as well (1), Companies that do not currently use drones but plan to use them in the feature (2), Companies that currently use drones but have no plans to use them in the future (3), and Companies that currently do not use drones and have no plans to use them in the future as well (4). Given the low number of respondents concerning cluster 1 and cluster 2, only cluster 3 and cluster 4

[28] Total sample: 40 farmers.
[29] Total sample: 16 farmers.
[30] Total sample: 68 farmers.

have been taken into consideration for further analyses. More in detail, cluster 4, that encompasses 79% of the sample, is of particular relevance for the scope of the Thesis, since it is composed by farmers who are reluctant to invest in the drone technology. Therefore, it is interesting to study not only the benefits, but also the factors that may block the adoption (Figure 54). In particular, it emerged from the finding that farmers are particularly worried about the uncertainty of the return on investment (41%) followed by a lack of knowledge about the cost and benefits of drone technology (38%) and a lack of economic resources (35%). Then, with less extent, farmers claimed a lack of specific skills in managing drones (28%), regulatory and operational constraints (22% and 21% respectively), and a lack of concrete cases to take as example (20%).

Table 7. Clusters of farmers considering the present level of drones' adoption and future level of drones' adoption.[31]

Clusters		# respondents	% respondents
1	Companies that currently use drones and plan to use them in the future as well	7	2%
2	Companies that do not currently use drones but plan to use them in the future	61	17%
3	Companies that currently use drones but have no plans to use them in the future	9	3%
4	Companies that currently do not use drones and have no plans to use them in the future as well	283	79%

[31] Total sample: 360 farmers.

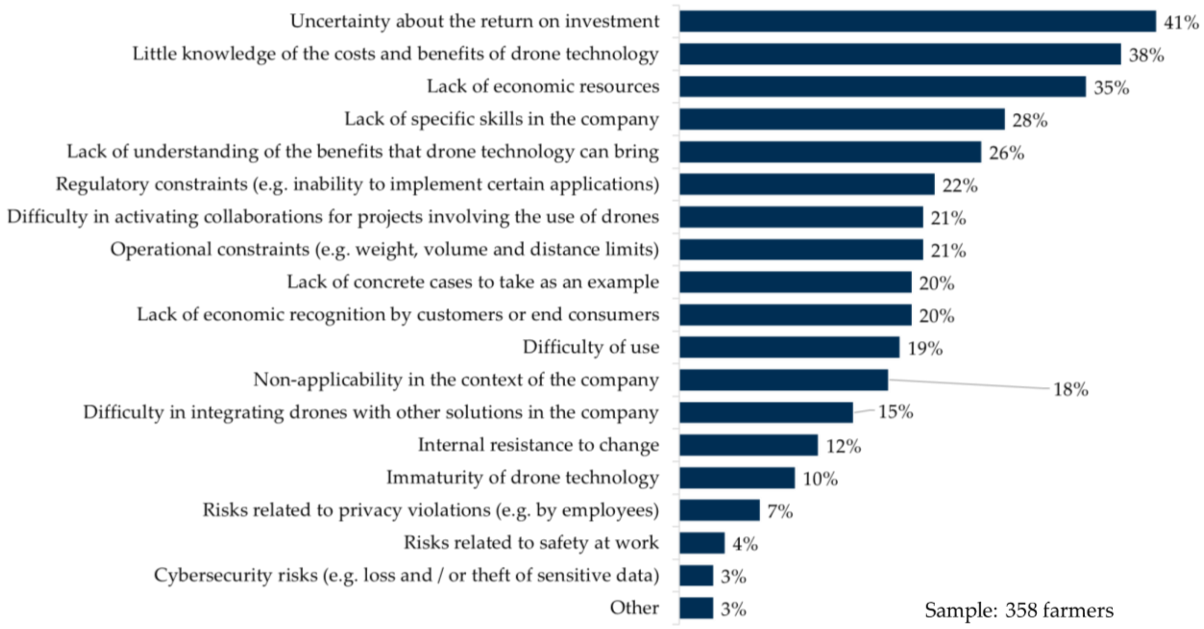

Figure 54. Blocking factors

4 Results Discussion

The numerical and statical results have been widely presented in previous sections. Now the goal is to underline the correlation between obtained results and the study purpose. Moreover, literature is presented as a support to the numerical findings.

The census results show how drones are becoming more and more a relevant technology that can be applied to different uses in different sectors. The sector main affected by this disruptive technology is for sure the public sector including, police, firefighters, governments, and civil protection. In this regard, the main application's scopes are inspections, search and rescue, and security and surveillance. UAV-based images allow governments to map the territory and speed up the process of land registry's updating. Police can perform inspections on the territory to monitor illegal actions and to patrol some specific area. Firefighters can inspect building destroyed by fire or they can employ drones to find missing people. Whereas civil protection can perform first aid operations. Then, other two main areas of drones' application are logistics and environmental safeguard. Excluding the public sector, logistics is the most prominent industry among the private sectors where drones can develop more. The main area of application is of course transportation accounting for the vast majority of cases. It varies from movement of materials and objects to the transportation of food, particularly drones are adopted to execute last mile deliveries. Indeed, big player in the logistics sector are starting project in order to introduce UAV-based solutions. Whereas, in the environmental safeguard domain, drones are a not invasive solution to monitor animals, trees, forests, and sea. Not by chance, inspection is the main relevant scope of use. Looking at the application scopes inspections, transportation, security and surveillance are, as expected, the most recurrent followed by research and rescue, dispensing, and media, art, and show. More than half of the use cases are either in state of experiments or have been just announced but are not yet operative. This witness how drones are an emergent technology not well widespread, but it is taking the attention of several actors in different industries including big players. The drone's typology most adopted is the VTOL multi-rotor wings thanks to its flexibility and versatility in being able to be applied in different situation and sectors. Regarding the payloads, as expected, the most adopted are camera – including RGB camera, telecamera, and thermal camera –, distributor and other material transport systems, and dispensing of liquids, granulates, powders. In almost all cases of transportation, drones were endowed with a sort of box responsible for containing the object to move. It could be a simple box, but also thermally insulated to maintain the desired temperature, for instance, in case of organs transportation. While camera is widely used to do inspections and survey. Based on what the user wants to achieve it is possible to choose among a vast range of cameras characterized by different features according to their functions. The diffusion of UAVs is not equally spread around the world, but the three continents most technological advanced – namely America, Asia, and Europe – are the leaders in the drones' sector. Indeed, most of use cases, drones' manufacturers, and service providers are concentrated there. Finally, UAVs can provide several benefits. For sure, in most of cases adopters looked for increasing efficiency in terms of time reduction. Moreover, drones are used also to reach uncomfortable places and to raise the security when performing activities. Then, with less extent, adopters wanted to perceive environmental impact and cost reduction.

Agriculture results the sixth sector in terms of number of applications and in many things well reflect trends that are in place worldwide considering the other industries. UAVs are mainly applied to monitor crops, to map and survey field, and to deliver liquids (pesticides, fertilizer, and water) and seeds. Drones equipped with RGB, multispectral, and hyperspectral camera can scan crops and field, and to assess the health of the plants. Thus, farmers can detect water stress points and areas where there is more need of pesticides because a disease is coming up exactly there. Growers, once detected all the deficiencies, can intervene with agricultural drones endowed with tanks to deliver water, pesticides and fertilizers with a precision farming approach. More than half of the cases are experiments or applications that have been only announced but they are not still ongoing, while the remaining are represented by operative applications. In the vast majority of cases, the type of drone adopted was a VTOL multi-rotor wings typology. Multi-rotor wings UAVs have some advantages with respect to fixed wing and single-rotor wing drones that make it the most diffused drone's typology. It can perform static flight which allows farmers to really adopt a precision approach to farming since it can stop on specific areas of interest and survey the crop or deliver liquids/seeds otherwise impossible to do with a fixed wing UAV that keeps moving. Likewise, it is easier to manage, and it has a higher manoeuvrability. Probably, the biggest lack concerns the payload, since multi-rotor wings models cannot be endowed with too heavier payloads, and this is critical when we have to deliver big quantities of liquids over a large crop. However, agriculture is characterized on average by many farmers owning small fields and R&D department of UAVs manufacturers are day by day improving the loading capacity of multi-rotor wings drones. About payloads, the most used is the dispenser of liquids, granulates, powders which is used to apply phytosanitary treatment and to water crops. While the other big cluster of payloads entails camera of different features from the simple photo camera to the multispectral camera passing through thermal camera. This mainly reflect what stated in the Chapter 1[32], the major drones' applications are aerial spraying and remote sensing. Finally, results showed that who adopted drones in agricultural domain first looked for increasing efficiency both in terms of time and cost, and second, for increasing the crop yield. Then also a concern about environmental impact emerged. Drones can heavily reduce the time to carry out some routine operations. Farmers instead of surveying their fields by foot or by tractors can flight UAV and survey crops easily in less time reducing the operations time. As a consequence, by doing this it is possible to reduce the costs as well. Moreover, applying water and phytosanitary treatment only in those points where really needed allows to reduce the input cost but also to increase crops productivity and the quality of the output. Finally, drones are mainly powered by electricity – using batteries – therefore are far less polluting than tractors which are powered by fuels. Moreover, having a precision approach to agriculture allows to reduce the use of water, pesticides, and fertilizers lowering the wastes and NO_2 emissions which are one of the main causes of pollution in agriculture.

Once having described the situation at international level and having provided with a focus on the agricultural sectors, let's look at the Italian agriculture landscape. The level of knowledge of drones is medium and the main sources of information are specialized media, scientific journals, fairs or conferences, and generalist media. As expected, those with the highest level of knowledge tend to use specialist media and scientific journals more than others. Conversely to Skevas and Kalaitzandonakes

[32] See pp. 26-29

(2020), “social networks” did not play a relevant role. Indeed, few respondents report to get know about drones from farmers’ associations or other neighbouring farmers.

Those who have used drones in past projects are farmers mainly concentrated in the northern Italy with a medium-high education level and having a medium-large farm and a medium-high turnover. They invested in UAVs to a large extent with the aim of experimenting innovative solutions, and minimally to improve efficiency and effectiveness, and to reduce the environmental impact of their farming operations. However, many of them have abandoned these projects because they have not obtained the desired improvements/benefits, mainly due to a lack of internal skills that did not make it possible to manage projects in the best possible way and due to a limited return on investment.

The current level of drones’ adoption is low. The ongoing projects essentially concern crop monitoring and the spreading of fertilizers. In these projects the drones are integrated with solutions already used in the company with the aim of making experiment with innovative solutions, improve environmental sustainability, and improve effectiveness. The main benefits that farmers obtained were a reduction in the environmental impact followed by an increase of the quantity and quality of data collected form fields and crops. However, the response rate to the section related to the present is so low that it did not allow further analysis. Nevertheless, also in this case, farmers with a high level of use are those with medium-high education level, large cultivated land area and medium-high income.

The future level of drones’ adoption is medium. Companies who are willing to invest more in drones in the future are particularly concentrated in the southern Italy and islands. Interestingly, even small farms – in terms both of farm size and farm income – want to start using drones in the future. Unfortunately, it was not possible to work on adoption profiles by crossing future use with current level of use because very few companies answered both questions. However, who intends for the first time to start projects with drones in the future, would use them essentially integrating with already existing solutions and above all for spreading crop protection products or fertilizers, monitoring fields and crops, and carrying out surveillance activities. The benefits sought through these projects are to achieve effectiveness improvements, do experiment with innovative solutions, and improve environmental sustainability.

Farmers who do not use drones and have no plans to introduce them in the future as well, report that the main factors blocking UAVs' adoption are uncertainty about return on investment, little knowledge of costs/benefits, lack of economic resources, and lack of specific skills in the company.

Overall, it is possible to state that the education level plays a relevant role in the adoption technology, since in all the three scenario adopters are far those with a medium-high education level. This is in line with Zuo *et al*. (2021) who found statistical evidence of a positive correlation between education level and drones' adoption rate.

Farm size and farm income are relevant factors in the technology adoption process as well. Looking at the past and ongoing projects, farmers with larger farm size and higher farm income were more likely to adopt drones. While, looking at the future it is expected that also farmers with smaller farm size and lower farm income are willing to invest drones. However, those with higher future adoption level are still companies with medium-high turnover and medium-large cultivated land area. This finding is quiet in line with the other studies in the literature that report a clear positive correlation of both farm size and farm income with the farmers' adoption process (Michels *et al*., 2020; Skevas and Kalaitzandonakes, 2020; Skevas *et al*., 2022; Wachenheim *et al*., 2021; and Zuo *et al*., 2021). Only Zheng *et al*. (2019) was not able to find statistical evidence about a possible correlation between farm size and farmers' willingness to adopt drones.

Whereas farmers' age seems not to play a relevant role since growers are on average middle age. This result is perfectly in line with Zheng *et al*. (2019) and Zuo *et al*. (2021) who in their studies on Chinese and Australian farmers did not find any correlation between farmers' age and the willingness to adopt drones.

Regarding the benefits sought slightly changed among past, ongoing, and future projects. However, the curiosity to experiment a new innovative technology is always one of the main reasons highlighted by farmers to adopt drones followed by the possibility to increase efficiency and effectiveness as well as to reduce the environmental impact. In this case the "peer influence" is almost null. Conversely to Skevas *et al*. (2022), very few farmers reported that they want to adopt drones in order to be aligned with what has been done by neighbour farmers.

Regarding drone's typology, payload, and application fields, results obtained in the Italian context well reflect those showed at international level. Multi-rotor wings drones are the typology most widespread in all application fields, and this holds true also in agriculture considering both international context as well as the Italian landscape. The payloads most used by Italian farmers adopting UAVs are cameras and dispenser of liquids. The situation is exactly the same also at international level. Finally, crop monitoring and aerial spraying confirmed to be the drones' application field most selected by Italian farmers, and this holds true also looking at international level.

Finally, even though there is not sufficient data to define clusters of cultivation's types most suited for the use drones, for sure it is possible to conclude that high value density crops like olive groves and vineyards presents good characteristics to justify an investment in UAVs. Moreover, extensive cultivation like cereals present some difficulties to assess the health of the crops in the inner part of the cultivated field which can be overcome with a non-invasive aerial vehicles like drones. However, further details are necessary to give a more general judgment.

5 Conclusions

The aim of this Thesis was to investigate the relevant topic about drones' adoption in agriculture. In so doing, this Thesis focused on three main research questions:

> RQ1: "What are the areas and modality of application of drones at an international level with a specific focus on agriculture?"
>
> RQ2: "What is the state of use and diffusion of drones on farms in Italy?"
>
> RQ3: "What factors can foster or curb the adoption of drones by Italian farmers?"

In order to answer to these questions, a census of applicative cases at international level and a survey to Italian farmers were carried out. First, a census of 370 applicative cases regarding the use of drones was made by collecting data from articles of different publications, including specialist and generalist. The insights on drones' use in different sectors, one for all agriculture, generated by this phase provided an answer to the first research question. Second, a survey to 360 Italian farmers was performed. Data about diffusion of drones in the Italian agriculture landscape have been analysed as well as data about factors that may curb or facilitate the diffusion of drones among Italian farmers. Particularly, cross analyses have been done comparing the past, ongoing and future projects and combining demographic characteristics of Italian farms and farmers with the UAVs' adoption rate. The survey with the consequent analyses provided an answer to the second and third research questions.

Overall, it was showed that the Italian agriculture well reflect what happens at international level. In particular, the two main drones' application in the agricultural domain are remote sensing – including crop and field monitoring, mapping, and surveying – and aerial spraying – including water and phytosanitary treatment. The most used type of UAV is the VTOL multi-rotors wings. While the most adopted payloads are, as expected, camera – from thermal to multi/hyperspectral passing through simple telecamera – and dispenser of liquids, granulates (seeds), and powders.

This Thesis is of interest both for drones' manufacturers/service providers and policy makers. Drones' manufacturers and service providers can get ideas from the results highlighted in this Thesis to better design marketing campaign choosing the best farmer type to address. Farmers with a medium-high education are more likely to adopt drones. Whereas, in the future not only larger farms with high income will be more likely to adopt drones, but it is expected that also SMEs are willing to start new drone-based projects. Therefore, this should be considered. Moreover, an important issue emerged. Many farmers reported to have little knowledge about the cost and benefits of drone technology. Therefore, dealers have to better display that information through a better marketing campaign or event with demonstration directly to the farms. Until farmers will not be fully aware of the potentiality and risk about the use of UAVs, their adoption will be always limited.

Then, an issue of lack of economic resources came out. In this regard, policy maker and governments can play a crucial role giving grants and facilitating the access to funding, especially for SMEs that has limited resources and struggle to reach economies of scale to absorbs an important investment as the one in drone technology. In this context, the Piano Nazionale di Ripresa e Resilienza (PNRR) is a great opportunity to bring economic resources to invest in digitization for the innovation and mechanization of the agricultural sector, for example with Agriculture 4.0 tools including drones, necessary to ensure environmental economic sustainability thanks to greater efficiency and production volumes. Furthermore, regulations about the use of drones in agriculture should be revised. In particular, Italy should adapt to those countries that allow aerial spraying. Nowadays, in Italy can be performed only under particular authorizations. For sure, the "legalization" of aerial spraying will help the diffusion of drones among Italian farmers.

5.1 Limitations of the research and future developments

Research is not a linear process and, as such, it bears some limitations and restrictions that could be areas for future research development. The census of articles about drones was based mainly on Italian, European and American (mainly USA and Canada) newspapers and specialist magazine. Therefore, use cases is mainly concentrated in Europe and North America as resulted by the geographic representation in Figure 15. Future research can consider further publications also closer to other continents like Asia, Africa, Australia, and South America. Moreover, not all the articles reported all the information desired, hence, some statistics are not based on the full number of articles collected. Finally, this work could be done in a more specific approach to each of the relevant sectors of application, looking at specialist magazine specific to the sector of reference. Thus, it could be possible to have a higher amount and a more comprehensive view of the different application cases.

Regarding the survey, the first limitations was the number of farmers that followed the invitations to the section about drones compared to the total number of respondents. Moreover, very few companies reported to currently use drones. This low number did not allow to further analyses, otherwise meaningless. Starting from these two limitations, future research may repeat the survey hoping in a better success.

Subsequently, econometric models and cluster analyses may be adopted to outline more precise adoption profiles. Moreover, information about demographic characteristics of the sample was not available for every farmer or even absent like the gender. Therefore, some results may be affected by this limitation. Finally, in future research may be of interest to deepen the correlation between the type of cultivation and their characteristics and the drones' adoption rate. In this research work, few data were available, hence, it was not possible to further investigate the topic.

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