POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

TECHNOLOGY SUBSTITUTION WITH DRONES FOR INSPECTIONS IN THE UTILITY SECTOR: QUANTITATIVE AND QUALITATIVE BENEFITS

TESI DI LAUREA MAGISTRALE IN
MANAGEMENT ENGINEERING-INGEGNERIA GESTIONALE

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Academic Year: 2022-23

Abstract

The phenomenon of technology substitution is continuously growing, thanks to the emergence of advanced technologies that provide more advantages compared to traditional ones. One of these innovative technologies are drones.

The existing literature analyzes the factors influencing the implementation of UAVs in different sectors, from environmental protection to logistics, from infrastructure and major works to arts and media, from utilities to telecommunications, from agriculture to public administration. Moreover, not all sectors of interest are equally studied, but there are areas that are poorly covered, such as utilities. In addition, the literature focuses on identifying the advantages and disadvantages in the individual cases and does not provide an overview of the overall benefits and critical issues of the technology.

This study addresses these gaps by providing an overview of the distribution of application cases using drones in terms of time, geographic space, macro sectors, and activities performed, with an additional analysis on the utility sector.

In addition, it is conducted an empirical analysis of ten Italian companies that use drone to inspect different infrastructures: power grids, pipelines, solar panels and wind turbines was turned. Through semi-structured interviews, the benefits and criticalities are defined. It is possible to divide the analysis into intangible factors, i.e., those that could not be expressed quantitatively, and tangible factors, i.e., time and cost. With the former, it is possible to create a framework of advantages and disadvantages and assess their impact according to the type of infrastructure inspected. With the latter, it is possible to create, for each type of infrastructure, a generic cost model for both the AS-IS case, i.e., the one in which inspections are carried out with traditional methodologies, and the TO-BE case, i.e., the one in which the previous technologies are replaced with drones.

Finally, the results are used to present theoretical and managerial implications of the research. In addition, limitations are highlighted, and future directions of study suggested.

Key-words: drones, technology substitution, benefits, criticalities, case studies

Abstract in lingua italiana

Il fenomeno della sostituzione tecnologica è in continua crescita, grazie all'emergere di nuove e avanzate tecnologie che offrono maggiori vantaggi rispetto a quelle convenzionali. Una di queste tecnologie innovative sono i droni.
La letteratura esistente analizza i fattori che influenzano l'implementazione degli UAVs in differenti settori, dalla salvaguardi ambientale alla logistica, dalle infrastrutture e grandi opere ad arte e media, dalle utility alle telecomunicazioni, dall'agricoltura alla pubblica amministrazione. Inoltre, non tutti i settori di interesse sono equamente studiati, ma ci sono dalle aree che sono poco trattate, come quella delle utility. Inoltre, la letteratura si focalizza sull'identificazione dei vantaggi e degli svantaggi nei singoli casi e non fornisce un overview di quelli che possono essere i benefici e le criticità generali della tecnologia.
Il presente studio affronta queste lacune fornendo una panoramica sulla distribuzione dei casi applicativi che utilizzano i droni in termini di tempo, spazio geografico, macrosettori e attività svolte con un ulteriore analisi per il settore utility.
Inoltre, è stata volta un'analisi empirica di dieci aziende italiane che utilizzano i droni per l'ispezione di diverse infrastrutture: reti elettriche, condotte, pannelli solari e turbine eoliche. Tramite interviste semi-strutturate vengono definiti i benefici e le criticità dell'introduzione degli UAV. È stato possibile dividere l'analisi in base ai fattori intangibili, ovvero quelli che non è stato possibile esprimere in modo quantitativo, e ai fattori tangibili, ovvero tempi e costi. Con i primi è stato possibile creare un quadro dei vantaggi e degli svantaggi per ogni azienda e valutarne l'impatto in base al tipo di infrastruttura. Con i secondi, invece, è stato creato, per ogni tipologia di infrastruttura, un modello di costo generico sia per il caso AS-IS, ovvero quello in cui le ispezioni vengono svolte con metodologie tradizionali, sia per il caso TO-BE, ovvero quello in cui le precedenti tecnologie vengono sostituite con i droni. Questo modello permette di analizzare in termini quantitativi il beneficio monetario che caratterizza questa tecnologia in questa attività.
Infine, i risultati sono stati utilizzati per presentare implicazioni teoriche e manageriali della ricerca. Inoltre, sono state evidenziate le limitazioni e suggerite future direzioni di studio.

Parole chiave: droni, sostituzione tecnologica, benefici, criticità, casi studio

Contents

Acronyms

UAV(s): Unmanned Aerial Vehicle(s)

UAS: Unmanned Aircraft System(s)

RPA(s): Remotely Piloted Aircraft(s)

FAA: Federal Aviation Administration

PMG: Petrel Macronectes Giganteus

BL: beached litter

FL: floating litter

LNC: leaf nitrogen content

ROI: Return Of Investment

PPE: personal protective equipment

VLOS: Visual Line Od Sight

EVLOS: Enhanced Visual Line Of Sight

BVLOS: Beyond Visual Line Of Sight

IoRT: Internet of Remote Things

LiDAR(s): Light Detection and Ranging(s)

EASA: European Union Aviation Safety Agency

ENAC: Ente Nazionale per l'Aviazione Civile

FMCG: Fast Moving Consumer Goods

Introduction

Nowadays, technology substitution is a phenomenon that is expanding in a growing number of professional fields as a result of the development of new technologies that bring advantages over traditional ones.

The driver of this phenomenon has been the 4th Industrial Revolution, based on the employment of digital technologies, such as Internet of Things, Big Data, Blockchain, Artificial Intelligence, Robot, and Drones, to which are attributed the ability to generate optimized performance. In addition, in the past two years, the disruptive event represented by the Covid-19 pandemic underlined the importance of new technologies even further.

This thesis will explore the phenomenon of technology substitution through an in-depth look at an emerging and cutting-edge technology, namely drones. This technology has been introduced within a variety of sectors from agriculture to telecommunications, from environmental protection to logistics, from infrastructure and major works to arts and culture, from health care and pharmaceuticals to entertainment and media, from utilities to public administration. In addition, there are various application domains in which drones are used, such as inspection and survey, security and surveillance, transportation, search and rescue, entertainment, maintenance etc. The introduction of drones derives from the significant benefits that allow companies to improve and streamline their processes and activities. In particular, drones have gone to fill a role that was previously performed with other technologies or entirely manually. This new technology does not always completely replace the previous technologies employed or human labor, but in many cases presents itself as an integrative and complementary solution to them.

Drones are unmanned aircraft more formally known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS). Unmanned Aerial Vehicles (UAVs) are flying machines that can be remotely piloted (RPAs) or autonomous. The Unmanned Aircraft System (UAS) is considered a complete system, including unmanned aircraft, remote control station and ground support, communication links, air traffic control, and all elements of the launch and recovery system [1, 2, 3].

This technology is not completely new. Its origins are recent only in terms of commercial applications, while the beginning of the history of drones in the military dates back to the mid-1800s.

The first use of drones in the military goes back to the First Italian War of Independence in 1849, when unmanned hot air balloons were designed by the Austrian Empire that dropped bombs on Venice.

In contrast, the use of UAVs in civilian settings took several years and dates back to 2006 when Frank Wang founded DJI Technology, which is currently considered a leader in commercial and civilian drones. DJI was the first company to introduce commercial and personal drones, that are easily accessible to the public, and has continued to develop various applications of this technology. In 2010, the French company Parrot launched the first drone that can be controlled via smartphone. In 2012, the U.S. Congress asked the Federal Aviation Administration (FAA), which works with various industries and communities to advance drone operations, to integrate small drones into the airspace. In 2013, the first corporate interest also emerged; in fact, Amazon announced its intent to introduce drones for product delivery [4]. Since that time, interest in the technology has continued to grow, and the use of drones has expanded to different sectors and application areas (Figure 0.1).

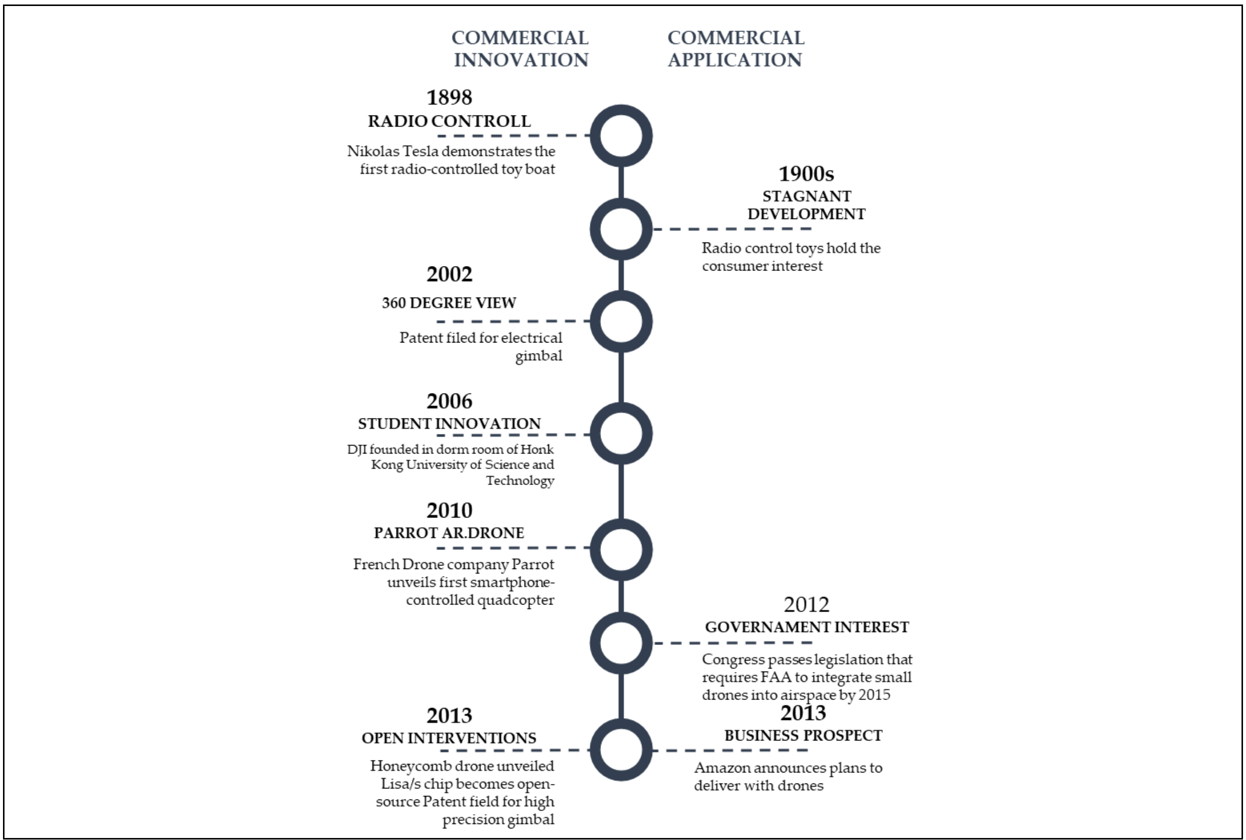


Figure 0.1: *History of drones in civil field* [4]

The objective of this thesis is to give an overview of the potential and critical issues of drones through an in-depth analysis of the advantages and disadvantages associated with their use. The analysis of advantages helps to explain why drones are used to replace other technologies or humans. While the criticality analysis, in addition to being conducted for completeness and objectivity of the research, helps to understand why the drone does not completely replace previous methodologies, but is adopted as a supplementary/complementary technology or as a support to humans. This analysis will then turn in more detail to the various application areas highlighting those are specific benefits and critical issues for them and for the activities they are replacing. Thereafter, the focus of the thesis will concentrate on the macro sector of utility as it turns out to be one of the areas least studied by scientists in literature and which needs to be investigated in order to fill the present gap. The objective is therefore to identify the qualitative and quantitative benefits and criticalities that technology can bring to this area. The study focuses on the area of infrastructure inspections as it turns out to be the major area of application in the utility sector thus obtaining solid and consistent information regarding technology substitution with drones.

The first chapter, Literature review, will consider a large amount of research from the literature that treat the argument of technological substitution of traditional methodologies with drones. The literature is divided into different macro sectors in order to highlight benefits and criticalities within every area. Then, based on the content of the paper, an analysis is carried out in order to understand benefits and criticalities of drones in general term. This is also useful to understand the main macro sectors where drones are used, traditional technologies that they replace or support and the activities where they are exploited. In the end, different gaps of the literature are identified.

The second chapter, Objective and methodology, starting from the different gaps identified in the Literature review, explains the objective of the research and two different research questions that are identified:

RQ1: *What are the main areas of application of drone technology in different sectors and in the utility field?*

RQ2: *What are the benefits and criticalities of using drones to replace or flank a traditional technology for inspection activity in the utility sector?*

After the identification of the RQs, an explanation of the different methodologies used to answer the questions is carry out.

To answer the first question, a census was developed which takes into account news articles covering the utilization of drones in various contexts. Each article was evaluated based on a number of factors to create the survey data.

To tackle the RQ2, a multi-case studies approach was chosen. The study is focused on ten cases within the utility sector, encompassing four different types of infrastructure (electric grid, pipelines, solar panels, and wind turbines), and is analysed in-depth through semi-structured interviews.

The results of these research questions are explained in the third chapter, Analysis. At the beginning of this section, a general overview of the distribution of different related application cases using drone technology is described. Macro-sectors, areas, years coverage, geographic spread, and different activities performed are considered. Also reported in this section is the analysis of the intangible benefits and critical issues that emerged from the interviews. Then there is the analysis of tangible factors, in terms of time and cost, and subsequently the creation of the model for each type of infrastructure.

In the fourth chapter, Conclusion, there is an overview of the results achieved in the previous sections and the theoretical and managerial implications of this research are analysed. On a theoretical level, the proposed framework serves as a systematic guide for identifying benefits and criticalities, with a specific emphasis on the uncharted field of utilities. From a managerial standpoint, the most significant implications arise from the qualitative and quantitative model designed for companies conducting inspections in the utility industry. Finally, limitation of this study and future research are discussed.

1. Literature review

In this chapter will be examined scientific papers that have covered the topic of technology substitution using drones in various sectors and application areas. In particular, the advantages and disadvantages of using this technology compared to previous approaches will be highlighted.

The chapter on the literature review is divided into three sections: methodology, content of the literature review, and gap identification. The first part describes the methodology by which the various scientific articles were screened and selected. These will then be analyzed in the second section to highlight the macro areas where the experimental use of drones has been most investigated. After that, the main benefits and criticalities of the use of drones in different fields will be explored. Finally, in the third section, the gaps in the literature will be investigated, providing the basis for the subsequent developments of this thesis work.

1.1 Methodology

The method used to select the scientific articles that will make up the corpus of the "literature review" is a systematic approach divided into five main phases: Scopus Research, Technical Screening, Abstract Screening, Article Screening, and Article Completion.

1. Scopus Research: after defining the topic of interest, the first step begins with searching for articles using the "Scopus" site[1]. First of all, to identify papers relevant to the proposed theme, several queries containing different topic keyword combinations were defined (Table 1.1). In the keywords definition, all terms were truncated and concluded with a wildcard symbol (*) in order to take all the various final combinations of the words (e.g. tech* to account

[1] Scopus is a database of abstract and citation that links scientific articles across a high variety of disciplines.

technology, technologic, technological etc.). In addition, the combinations of keywords with AND connector search all the results presenting the words in the query according to different sequences (e.g., Tech* AND Replac* AND Drone* is a query that selects all the results that present the word "tech", "replace" and "drone" in their various final combinations). At this stage, 1,211 papers were identified.

QUERY	
Tech* AND Replac* AND Drone*	Tech* AND Replac* AND UAV*
Tech* AND Substitut* AND Drone*	Tech* AND Substitut* AND UAV*
Human* AND Substitut* AND Drone*	Human* AND Substitut* AND UAV*
Human* AND Replac* AND Drone*	Human* AND Replac* AND UAV*

Table 1.1: *Queries containing different keywords combinations*

2. Technical Screening: in the second step, the list of articles found was downloaded in Excel highlighting different items, i.e., author, document title, year, source title, volume, issue, pages, citation account, source & documentation type, publication stage, abstract, author keywords. Then the list underwent an initial screening. Initially, all duplicates were eliminated, and then different criteria were applied to give more evidence to the research. Subsequently, the elimination of all articles that were published before 2012 was conducted in order to consider a time horizon that includes the last 10 years. Earlier publication may present outdate information that does not reflect the current state of the topic due to the fact that the technology is in continuous evolution. At the end, the papers that had a "document type" of "Article" or "Review" and a "Publication stage" of "Final" type were selected.
   This initial screening resulted in a selection of 414 articles.
3. Abstract Screening: For the remaining articles, a more thorough analysis was carried out by examining the papers one by one. In particular, titles, keywords, and abstracts were examined to obtain a second screening. At this stage, all articles dealing with the phenomenon of technology substitution through drones in the civil sector were retained. This is because the objective of this research is to investigate the benefits and criticalities of professional drone use in industrial and utility sectors, with a focus on the Utility sector. In addition, the Department of Drones and Advanced Air Mobility Observatory of the Politecnico di Milano, with whose collaboration the research work is being conducted, excludes the military market from the scope of analysis, focusing exclusively on the professional market.
   After this screening, 144 papers were identified.

4. Relevance identification: the various papers were then selected based on the relevance of the journal of reference. SCImago journal rank, an indicator that measures the degree of scholarly influence of academic journals, was used. Specifically, the relevance quartile for each paper was identified, and those with the Q1 and Q2 quartiles indicating "best case" and "acceptable case" respectively were selected to consider those from solid and celebrated sources. Then were identified 131 scientific articles.
5. Article Screening: Then the fifth and final screening resulting from the complete reading of the remaining papers was carried out. At this stage, all articles that present only a mention of technology substitution and do not go into the depth of the topic and those articles for which the technology being replaced could not be identified were eliminated.
   After this stage, the 72 articles were identified.
6. Article Completion: Also additional papers, that were cited in the selected ones, were included. These articles brought added value in the literature review and were therefore added to give a complete overview of the research.
   Finally, the 98 articles that are to be included in the "literature review" were identified.

1.2 Content of literature review

In this chapter the scientific papers analysed are divided into macro-areas. The macro-areas analysed concern environmental protection, logistics, agriculture, infrastructure and large-scale works, utilities, telecommunications, public administration and art and media. In particular, in each section it is reported a list of benefits and criticalities that were present in the scientific papers refer to that particular area. As, it can be seen there are specific advantages and disadvantages for different sectors due to the different types of activities that the drones can substitute.

This can be useful in order to highlight those that are the main characteristics of drones.

1.2.1 Environmental protection

Drones have brought important positive aspects within the environmental sector. It has been found that they are able to monitor and census both animal and plant species, improving the effectiveness of the activity due to the possibility of continuous monitoring and the increase of the frequency of observations [5, 6]. Furthermore, UAVs have also been introduced to keep track on the environmental disasters such as landslides, volcanic events, fires, [7] and marine and land pollution etc [8].

1.2.1.1 Plants

Inspection, soil survey, plants monitoring, and plant species census are activities that before the advent of unmanned aerial vehicles were carried out either by direct field observations, satellites or by manned aircraft.

UAVs are known because of the high spatial resolution of the images that they take thanks to the payloads that are installed on them. These payloads enable to achieve an accuracy and control of image resolution that satellites, and manned aircraft have not currently achieved [5, 9, 10, 11]. In fact, there are studies that have demonstrated that the high spatial resolution, achieved with this new technology, provides an accurate and objective way of acquiring data and quantifying plant populations [12]. Moreover, during the acquisition of images of costal areas, the high spatial resolution and the easy use of the drones are benefits that can expand existing mapping methods and the databases providing information on changes and migrations in the coastal area [10].

Unmanned aircraft, compared to the other methods used, allow to collect data in real time. For that reason, observers can make faster decisions by analysing the images that they receive and can better plan drone routes [5]. In addition, information can be acquired more frequently compared to other monitoring systems (manned aircraft and human observations). This is one of the most important advantages in this field since people can map changes in the soil in real time and thus assess and verify any possible problems. In fact, after a deforestation in Sabah, it was possible to understand, with greater efficiency, the impact that deforestation of soil has on human populations and disease vectors [5].

The use of this new technology permits to reduce costs and maintain a high quality of the activity compared to ground-based observations [13, 14, 15, 16]. This is because some inspection activities can be carried out with drones that are not so expensive and, in addition, the possibility of monitoring in automatic mode also brings a significant reduction in manpower, which further reduces costs [14, 15, 17, 18]. Although the introduction of UAVs is advantageous on an economic level, it must also be considered that in the case of unplanned incidents this solution can become disadvantageous, therefore, in these cases a good level of knowledge of this technology would be the most appropriate solution to the problem [15]. If monitoring, or censuses are carried out by using satellite images, in those cases, the economic component does not differ significantly if a company decides to use drones or the previous methodology [5].

Compared to direct measurements, another advantage is the possibility of significantly decreasing the time required to carry out the task, which is very important when diseases of the flora must be identified quickly [5, 15]. The possibility of reaching remote locations or places that would take a very long time to collect data is another positive aspect. This also reduces the risks associated with carrying out the activity for researchers or those that are collecting the data [15, 18].

The use of UAVs is also advantageous because they are not invasive to the ground surface, as opposed to ground-based observations, in which the investigator is expected to step on the ground [19].

The introduction of these unmanned aircraft does not only have positive aspects, but there are also some disadvantages that can arise. Drones cannot fly in all weather conditions. The UAV used to study epidemiological conditions in Malaysia and Philippines, cannot fly when the winds exceed 45 km/h. Moreover, even with high temperatures, it was noted that the drone overheated [5].

Another problem arising from weather conditions concerns data collection. Cloud coverage or the presence of significant wind gusts can compromise continuous data acquisition and image quality by causing blurring and darker images [5, 12]. In addition, the presence of weather sub-optimal conditions may also compromise the recognition of the species under consideration and in the case of census results in misclassification [12, 20]. In some cases, the problem of bad weather conditions can increase time due to the reorganization of the pre-flight phase and the computational work of image processing in the post-flight phase [12].

Different from direct monitoring, it can happen that the observations of new technology are less precise. For example, as a result of image collection, it is more complex to see small branches than direct observations. Furthermore, the perception of small distances is not always easy to define, and it can also happen that UAV images overestimate vegetation heights compared to field surveys [20]. The same situation occurred when collecting data on the diameters of trees in the savannah. In fact, the inhomogeneous ground led to greater difficulties during the research and substantial differences with direct observations [21].

For this reason, field surveys will remain an important methodology to distinguish those features that UAVs are currently unable to pick up and will therefore complement the work of drones. This flanking is justified by the fact that drones in any case bring an important advantage in terms of sampling efficiency in landscape locations. On the other hand, species-specific definition is a task that is much more efficient when carried out using ground-based techniques [13, 19, 22, 23].

1.2.1.2 Animals

The study of wildlife has, like other areas, taken advantage of the advent of UAVs, especially for monitoring, inspection, and census. These activities were previously carried out by aerial vehicles with operators in charge of data collection or through field observations. With the introduction of this new technology, researchers or companies can decide whether to maintain a fully automated system using drones or to apply a semi-automated method with human support [24, 6].

One of the main advantages for scientists using drones is certainly the possibility of carrying out their observations over larger areas than can be achieved with human observations [25, 6]. Following the evaluation carried out on images taken over national parks in Tsavo and the Laikipia-Samburu ecosystem, it was noted that UAVs manage to increase the spatial area analysed by 23% compared to field observation [6]. This can also be attributed to the fact that UAVs can reach remote locations that could endanger the researchers' lives or are even able to reach places that are inaccessible to humans. In addition, the acquisition of information is also carried out in a very short time, which is an added value, especially when monitoring animal populations, as in the case of Petrel Macronectes Giganteus (PMG) [25].

A further advantage comes from the installation of cameras on these aircrafts. These technologies allow researchers and scholars to improve the quality of their work due to the high quality of the images that are captured and the ability to maintain constant and sharp supervision. During the population census of urban gulls in North America, this advantage allowed the counting of gull nests and a better visualisation of this species in their habitats [26].

In addition, the presence of these payloads on unmanned aircraft allows for greater continuity of monitoring or census activity [6].

The substitution of UAVs to previous methods also brings an economic advantage. They allow a significant decrease in the costs associated with the activity they are going to perform. In particular, it has been calculated, following the census carried out in Kenya, that the actual saving on a kilometre sampled in semi-automatic mode compared to a manual aerial count can be between 160% and 1,050% [6]. Furthermore, the cost of inspecting or monitoring terrestrial animals is lower than in the other modes. The terrestrial surveys performed by Parshin et al. [27] were found to be between two and three times more cost-effective than previously performed terrestrial surveys [27].

Finally, as a result of the presence of some of these advantages, it can be seen that scholars can refer to a greater amount of information [28, 6, 24]**.** During geological surveys using UAS, scholars were able to observe anomalies and details that they had not been able to visualise with previous surveys using other methodologies [27]. In environments that are not completely open, such as savannah ecosystems, where trees and grass are present, the information that drones can obtain are less. This constraint, however, can be overcome due to reduced costs and thus the possibility of extending the observation area, which allows researchers to make more accurate census estimates of an animal species [6]. On the other hand, in environments where there is visibility, the problem of underestimation does not exist. The study conducted on seabird colonies in South Australia shows that much more accurate estimates are obtained following the use of RPAs. Counts using UAVs images have a 43% to 96% chance of improvement depending on the heights at which observations are made compared to field observations [24]. Therefore, when dealing with open area environments, an automatic method will be used [24] while in more complex cases, a semi-automatic method is preferred [6].

Regarding the problems associated with drones, the most significant one to be addressed concerns the disturbance of animal species. It can be observed that there are studies in which the disturbance of the technology on the animal species is highlighted, others in which the presence of drones do not cause disturbance and, others where are less invasive than other methods [26, 25, 29]. During observations that were made on seagulls in America, it was noted that the animals have continued to incubate during surveillance and that therefore the presence of the drone did not cause any problems. The researchers support that the drones were certainly much less disruptive than a previous census in which they accessed the site directly [26]. Observations made on PMGs do not show alarming behaviour when a drone approaches. On the other hand, the presence of humans and thus a direct observation has a very invasive consequence for this breed as very high mortality rates are collected [25]. It has been observed that inspections requiring the proximity of wildlife, such as nest inspection and animal control cause disturbances to the species. On the other hand, census, surveillance, and mapping studies do not cause major disturbances to the species as they can fly over greater distances [30]. Moreover, it must be considered that a no response of animals doesn't mean that they are not disturbed by the presence of drones. There is a study that highlight that black bears are disturbed by the presence of drones, but they do not have any visible reaction, they show an increase of the heart rate [29, 31].

Another element to be considered is the noise resulting from the drone's flight, which could disturb wildlife. In this case, the use of an electric rather than a fuel-powered motor has been suggested as they are acoustically less intrusive. In addition to the noise of UAS, also the size can alarm wildlife, as the larger the size of the drones, the greater the perceived threat to the animal species [30]. Finally, reactions also depend on the species being studied. Birds were found to be the most sensitive, followed by land mammals and finally aquatic animals [30].

Finally, it must be considered that there are certain environmental conditions that are not ideal for monitoring animals using drones. Research was carried out in which animal species in the Arctic area were studied using UAS. It was found that long-range UAS surveys can provide good information, but on the other hand they can be more costly and logistically more complex than observations by manned aircraft. The research states that in the Arctic area, the use of this technology is still at an early stage. Therefore, it appears that in some areas of the Earth, the use of drones deserves further investigation as advantages that would favour their use do not occur in the presence of particular weather conditions [32].

1.2.1.3 Environmental disaster

UAVs have been used to carry out analysis and monitoring during very dangerous events such as earthquakes, volcanic activity, landslides, etc. In these situations, previously manned aircraft [7] or road vehicles were used [33]. Drones can also be utilised during the periods following these events. For example, they have been exploited, complementary with ground-based observations, to study how the vegetation recovery process occurred following fires [22]. The use of this new technology has proven to be cost-effective not only in terms of its cost effectiveness, but especially in terms of risk management [34].

The main advantage that UAVs have brought within this field certainly concerns the possibility of keeping scientists and researchers at a safe distance from the dangers to which they would otherwise be exposed. Therefore, this allows to increase safety while carrying out work and the possibility of reaching remote locations [34, 7, 33]. In Japan, for example, the compositions of the volcanic plumes of the Kirishima volcano during a degassing phase were analysed. Since part of the volcano was not accessible to manned aircraft, the use of UAVs to gather the necessary information was crucial [7]. Furthermore, the measurements carried out on Mount Ontake were also facilitated by the presence of the UAVs as they made it possible to reach areas that were previously inaccessible as there are no road routes within 10 km of the main mouths [33]. Regarding earthquakes, UAVs are used for post-earthquake research and work. They have proven to be particularly advantageous when it comes to dangerous infrastructures that are more difficult to approach with traditional methods [35, 34]. This is also due to the greater flexibility of the technology, since differently from cars, unmanned aircraft allow for less rigid flight paths and closer to places that are not easily accessible [33]. In addition, the possibility of approaching more dangerous areas has made it possible to expand the collection of information and thus the possibility of being able to define increasingly precise estimates [34, 33, 7].

Drones are also advantageous in terms of timing. They are, for example, used during events such as landslides, in particular, when very large areas need to be inspected, this technology is particularly convenient because a ground-based inspection would take excessive time [36].

In order to limit the disadvantages of UAVs, a conceptual framework analysing the use of a swarm of drones to extinguish a fire was studied in the context of environmental disasters. The swarm of drones would be able to extinguish the fire without having battery charging problems and without requiring the need to draw on a water source during the entire operation. Moreover, it would be able to intervene at any time of day or night and even under low visibility conditions unlike aircraft. Finally, unmanned aircraft are able to reach areas that are difficult for humans to access, and it is a very flexible system as drone routes can be changed in real time depending on the evolution of the fire. On the other hand, there are few disadvantages that may arise. In particular, the amount of water that an unmanned aircraft can carry is less than that of aircraft, and furthermore, the economic benefits of using drones compared to aircraft have not been verified, so it is not known which solution is the best in these terms [37].

Regarding the study of post-fire vegetation, the human-drone combination allows for an accurate overview of population growth after fires. Therefore, it seems that this approach will provide a more comprehensible status of vegetation regrowth [22].

1.2.1.4 Pollution

The use of drones in the environmental field is also exploited with regard to pollution and thus the observation of waste on land and at sea.

One advantage that is brought in this area concerns the reduction of labour requirements and of the logistical effort [8, 38]. The use of drones requires the presence of significantly fewer operators. The research by Andriolo et al., [8] reveals that the search for beached litter (BL) required the presence of only one operator, while the search for floating litter (FL) required the presence of two operators, because the collection of FL requires the presence of a boat. Thanks to these advantages, it was possible to increase the frequency of monitoring and to extend the observation area [8, 38]. Another example related to the acquisition of pollution information was studied by Horricks, et al., [39]. They compared two methods, one using drones and the other carried out on a vessel by operators, to acquire information about bacterial count in the water. They found that drones are able to decrease costs and decrease the riskiness of the activity. Moreover, the possibility to increase the duration of batteries will allow scientists to collect more data and better influence the decisional process in real time [39].

Another positive aspect concerns the monitoring of waste in real time, which was not possible with the previous methods. The image acquisition process provides the possibility of accurately detecting waste, analysing it, and finally transmitting the information to a remote site. This also makes it possible to improve waste cleaning operations [40, 8].

Among the problems arising from the use of drones, also in this sector, there are the limitations related to environmental conditions [8, 41, 38]. The search for FL and in BL involved the use of drones that could not fly if the winds were moving at speeds greater than 19 km/h, and scientists also had to take tides into account. In low tide conditions, data collection allowed larger areas to be studied with greater precision. Another problem arises from the sun's rays as they could have a strong influence on the detection of BL [8]. Therefore, it can be seen that the problem of environmental conditions in this area is very important and greatly influences the organisation of drone flight planning.

Another problem relates to the limited battery life of drones; in fact, it has been found that the observation of waste by drones is more feasible in small environments such as rivers and lagoon environments [8].

1.2.2 Logistics

Unmanned aircraft technology has also become part of the logistics sector. In particular, they will partially or totally replace all those vehicles and equipment that are used for delivery [42].

In the field of logistics, in order to better analyse the benefits that derive from the use of this technology, deliveries of general goods will be highlighted first [42] and then those additional benefits that can be derived in the medical and pharmaceutical fields will be discussed more in detail [43].

1.2.2.1 Logistics of goods

The delivery of general cargo via UAVs succeeds in bringing very significant advantages, but also brings with it some disadvantages.

One of the main advantages for a company to improve its market position is time related. Autonomous drone delivery manages to eliminate the traffic-related time wastage that a vehicle on the road can encounter. In fact, whereas a traditional system used to take a day to deliver parcels, with this new mode it has been estimated that it can take two to three hours. The fully autonomous solution is particularly efficient if the load to be transported is relatively small and the distances to be covered are short. In other cases, the use of drones is still advantageous, but a hybrid truck-drone solution is preferred [42]. Furthermore, Nielsen claims that in 2035, with the help of drones, self-driving cars and robotics, a delivery can be achieved within 35-45 minutes from receipt of the order. These timeframes are also a target for the company Amazon, which has currently introduced this technology into its own process for the many advantages it brings [44].

A second key advantage is at the economic level. For big companies with high demand, investing in a logistics system based on unmanned vehicles is the best solution because it brings a long-term benefit. In fact, costs associated with truck capital costs such as insurance, fuel, maintenance, etc. could be reduced. On the other hand, for those companies with a more limited demand, the hybrid system would be the most appropriate delivery mode [42, 45].

As it can be seen from Figure 1.1, the most impactful costs for a logistics company are related to drivers and loading and unloading equipment. The presence of drones can reduce costs by 66% in the case of a fully automated solution, otherwise companies will incur a smaller decrease [45].

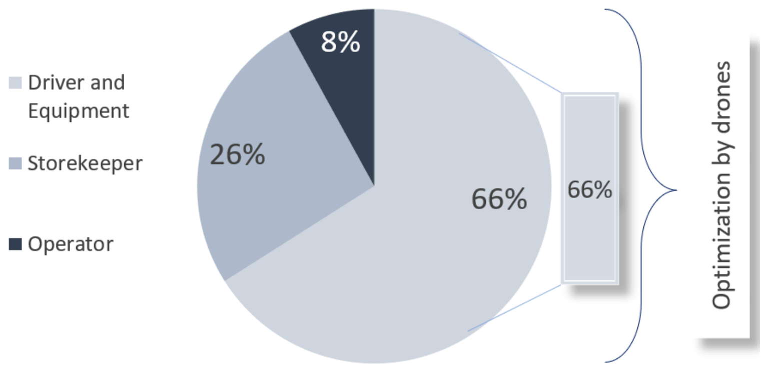


Figure 1.1: *The different costs of a logistic company* [45]

It also addresses the problem of manpower lack. The automated system only requires manpower for maintenance and air traffic control [42].

The use of UAVs is also important because it allows for almost zero pollution that is produced when using road vehicles. In fact, following a study in Thailand on the environmental impact of an online delivery system, it was concluded that the drone system is more environmentally friendly than other systems [46].

On the other hand, the use of this new technology brings with it disadvantages that are not present when using vehicles on the road. Indeed, in bad weather conditions drones are not always allowed to perform the required task. In this case, the most optimal solution to deal with this problem is the hybrid one [42].

The second problem is related to the limited battery capacity of the drone, which reduces the ability to transport the cargo. In addition, if the customer needs to return goods that have just been delivered to him, it may happen that the drone on its way back to the starting point, with an unexpected load, does not have enough battery power. Even in this case, the hybrid solution might be more advantageous as the driver of the vehicle could go and collect the return [42].

1.2.2.2 Logistic of medical and pharmaceutical goods

In the healthcare sector, this technology has been introduced much more slowly as it is a more sensitive area due to the critical nature of the material being transported [47]. In particular, drones are currently being used to transport drugs, medical supplies, and medical devices. In addition, the logistics of medical material plays a crucial role in emergency situations, given the time reductions and therefore as an auxiliary for rescue. Of course, in this case, they will not replace manpower but perform an additional function [47].

The presence of drones in this field allows companies to reduce costs. In particular, it was studied how costly the transport of vaccines is by using UAS. The results show that, thanks to this technology, it is possible to decrease logistics costs by 20% and increase the frequency of transport compared to traditional methods. The increase in frequency depends on the fact that thanks to automatic delivery, drones manage to eliminate the bottlenecks that occur when working with vehicles, thus reducing delivery times [43]. The reduction in time in some cases can also be a key benefit as the rapid delivery of drugs or first aid equipment can be crucial in saving someone's life [45].

A special type of drone, called medical drone, has been developed. The medical drone can transport oxygen and drugs needed for a rescue intervention on a seriously ill person. It takes about 10 minutes for the ambulance car to arrive at the scene, and so, thanks to the possibility of reducing the time, first aid can begin in the meantime. In addition, the drone, thanks to the presence of sensors and cameras, is also useful for sharing information in real time to doctors and hospitals, allowing for a more accurate intervention [47].

One of the problems to be addressed in this context is the storage of medical material, particularly blood. In fact, a large majority of deliveries are unfit for use. The Smart Capsule does not currently make it possible to claim to overcome this major limitation, but thanks to its combined use with AI, it allows the technology to be managed directly at the hospital and guarantees the safety of operations [48]. In Italy there is a start-up, ABZERO[2], which has invented a smart capsule for transporting easily perishable health care materials such as blood, organs, tissues, biological specimens, and drugs, that need to be preserved during their transport [49].

1.2.3 Agriculture

The use of drones has also been found to be particularly significant in the area of agriculture, and several studies have been done on the subject. Indeed, in this macro sector, there is increasing talk about precision agriculture, digital agriculture, and agriculture 4.0, i.e., the efficient and sustainable ways of practicing agriculture, where drones find great scope for action in order to increase productivity [50].

One of the areas that agriculture interfaces with is definitely remote sensing to obtain useful information. This is done through different platforms that can be divided into orbital (satellites), aerial (airplanes and UAVs), and terrestrial (including those carried or towed by agricultural machinery) [51, 52]. However, it is important to point out that the images captured by UAVs are better than those obtained by satellite sensing [50]. In fact, two viticultural areas in Italy are studied with different technologies, including satellites and drones, and it was possible to observe that in the case of vineyards characterized by strong gradients and large clusters of vegetation, the two technologies report similar results. In contrast, in vineyards

[2] Home - ABzero

characterized by small gradients and high irregularity of vegetation, low-resolution satellite images are less detailed [53].

The main advantage of remote sensing by drones concerns the ability to obtain more information due in part to the sensors used by this technology. Relevant information relates to the assessment of water stress, detection of vigour and nutrition of the plants, biophysical assessment and monitoring of biological of targets [50].

In two regions of Greece, UAVs with short-wave infrared bands have been used to map water stress in vineyards at the canopy level for entire parcels, and this has resulted in a high level of detail [54].

In China, on the other hand, UAV-based hyperspectral data were used to calculate the nutritional status of plants and specifically to conduct leaf nitrogen content (LNC) nutritional spectral diagnosis on winter wheat at several growth stages [55].

Thus, UAVs allow the calculation of various vegetation indices related to the physiological state of plants.

There have also been several studies investigating the use of UAS in the field of biophysical assessment. In particular, 3D modelling and point clouds are used to estimate surface biomass, model tree structure, crop canopies, and detect weeds. The advantage here is high spatial resolution due in part to the sensors that are used [56]. In particular, a study was conducted in Indonesia that aims to detect Sago palms based on their physical morphology from images of an unmanned aerial vehicle (UAV). this allows local farmers to identify the time of harvest by identifying the flower bloom to replace human inspection [57].

Monitoring of biological of targets, on the other hand, involves detecting agents that cause damage to agricultural production in order to ensure crop productivity [50]. They make it possible, for example, to reveal soil and fungal infestations that are not visible to the naked eye [58]. In China, a study using UAVs, combined with deep learning technology, was conducted to automatically detect plants infected by a corn pest, *Spodoptera frugiperda*, through its gnawing holes on leaves that causes extensive damage to these plants [59]. Also in China, remote sensing via UAV is being used for the identification of the *banana Fusarium* that wilts banana crops and threatens their productivity. Image resolutions by UAV have resulted in good accuracy in identifying the disease [60]. A study in Slovakia dealt with the monitoring of invasive plant species and in particular *Solidago canadensis and Solidago gigantea* (Solidago spp.) to investigate its spread also as a result of climate change. To do so required the use of state-of-the-art geospatial technologies, such as drones, which can provide high spatial resolution multispectral imagery that yields rich spectral information.

In many cases, in fact, the images that are captured by drone are more precise than those made by humans. This is the case of the research conducted in Saskatoon on fababean in which Duddu, et al., [61]discover that UAV can be a potential solution to replace human ratings, especially when it is a repetitive activity that can lead to human, such as In the con- text of high-throughput phenotyping due to the fact that requires the observation oh high number of plants in a short period of time [61]. Also another study in Turkey take in consideration the same topic. In particular, the scientists use the high-resolution Unmanned Air Vehicles (UAV) images and an algorithm to detect and count the citrus trees and discover that the degree of precision is very high, about 95% [62]. The accuracy of the analysis was also improved by optical and radar sensors. In this way, remote sensing using UAVs is established as a viable alternative to satellite imagery [63].

An important factor to monitor when discussing technology substitution is productivity. In fact, several studies have been conducted to evaluate the effectiveness of drones when used to replace knapsack applicators in the application of plant protection products [64]. Zhang et al., [65] found that the different methods of herbicide application do not allow for different numbers of ears and grains per ear, as, it was not directly affected by the different spraying methods, but on the contrary allow for an increase in grain mass by achieving a 14.6% increase in grain yield [65]. The effectiveness of this method, however, also depends on the soil characteristics, in fact, this is particularly good when there is adequately moist soil so that the herbicide can be activated, since it is carried out with a low volume of water [66].

Certainly, traditional techniques in agriculture to obtain relevant information involve a long and laborious process that relies on manual sampling. For this reason, UAVs have been introduced to acquire data in less time [59]. Raghu [67], reports that the introduction of drones in palm oil plantation sites allows for a significant reduction in labour dependence. In fact, this allows for data collection that is about 500 times more than manpower, and with an AI-based system, image processing would go from 14 days with the intervention of 20 people to 4 hours [67]. Time reduction was also found in another study of peanut plants in China in which the use of UAVs combined with specialized algorithms took only one-fifth of the time required for human detection [68].

Another significant advantage of the use of UAVs in agriculture is definitely the reduction of costs when substituting this technology for traditional agricultural techniques. In fact, this technology can be applied to greenhouse surveillance so as to increase crop yields and minimize labour and travel costs over very large areas. In this way, production costs are reduced, but product quality and integrity are maintained [58]. Using traditional techniques, there is also a high cost in pesticide application as it requires a large amount of manual labour and the cost of pesticides itself would increase due to indiscriminate spraying [59].

In the field of agriculture, comparing UAVs with other imaging technologies, such as satellite remote sensing and to aerial remote sensing, it can be seen that unmanned aircraft also find cost advantages in this case due to lower investment costs 13]. Indeed, Leroy et al. [69] found that when comparing the operating costs of manned and unmanned vehicles, drones lend lower operating costs [69]. A study considering the Return Of Investment (ROI) and budget of different technologies in palm oil agriculture was conducted in Malaysia. Taking into consideration the application of pesticides in this field, it can be seen that the use of the drone sprayer, compared to the knapsack sprayer, not only allows for a significant reduction in manpower, but also yields a positive ROI of 39.9 (higher than other technologies such as the tractor sprayer which is about 19.2) and, at the same time, meets the budget [70].

Another important factor to consider in agriculture, as is reported by Hunter III et al., [71], is that drones allow the application of pesticides and other products even in areas that are difficult to access and have irregular topography and complex geometries [71, 70].

One particular situation is related to the COVID-19 pandemic, which included national lockdowns. During this period, all daily activities were halted, including agricultural activities. To cope with this problem, drones equipped with artificial intelligence could be used for soil management activities during the national lockdowns period or in industrial and mining areas where soil contamination can be found due to chemical leaks [72].

Using drones in agriculture also makes possible to achieve a greater degree of human safety. In this regard, it is possible to use this innovative technology for tick surveillance. In traditional practice, it is the man himself who, while walking, drags a flannel cloth over vegetation suspected to contain ticks, but this undoubtedly leads to greater human exposure to ticks, thereby increasing the risk of contracting tick-borne diseases. In addition, the use of personal protective equipment (PPE), such as encapsulating suits, causes humans to experience increased heat stress. Therefore, it is possible to use a drone to perform the same task and completely or partially replace manual labour. Comparing these two methods, it was found that the activity performed with the drone allows similar results to be achieved by going to reduce human health risks and also allows for increased surveillance [73]. In addition, another important task that drones can perform is the spraying of pesticides and fertilizers. This activity also permits to increase the safety of operators since with the new technology they would no longer be exposed to hazardous gases [74].

Switching to the use of UAV technology also allows for less waste and reduced environmental impact. For example, unmanned aircraft allow for less waste of pesticides, as a result of increased precision, while also reducing the environmental impact caused by pesticides [59]. In addition, weed mapping and site management using UAVs can also reduce pesticide use [71].

This cutting-edge technology, however, obviously has limitations. These include the fact that UAVs can only be used for local monitoring as they can only cover a few hectares of land [63]. This is because drones have limited battery life that does not allow them to cover long distances [56].

In addition, it is important to note that although the resolution of the images is particularly high, the detection is affected by several factors such as the phenological status of the flowering stages, community size, and adjacent plants exhibiting similar characteristics [75]. Weather conditions are also a limitation for drones as they are unable to fly in certain situations [56].

Regarding costs, it is useful to point out that reduction is not always a given, but rather there are some cases where drones may have higher costs than the replaced technology. In Malaysia, for example, a study found that in palm oil agriculture and particularly in monitoring tree health and fruit ripening, the use of drone as a substitute for traditional practices is not beneficial. Although the technology has a positive ROI, it does not allow for meeting the prepared budget due to high investment costs [70].

Although drones make it possible to reach even inconvenient places, it is necessary to keep in mind that in some particular situations there may be impediments. For example, when using drones for tick surveillance, it is necessary to keep in mind that the sheet dragged by the drone might get entangled with vegetation and in fact this assumes that the technology in this case is not suitable for flying in wooded areas [73].

1.2.4 Infrastructure and large-scale works

Drones are also used for monitoring and inspecting infrastructure and for construction site management and they can replace or complement direct observation on site or manned aircraft. Infrastructure, in order to always be a safe place, requires regular monitoring, which is most often carried out by an inspector through direct observation. Moreover, inspectors are not always able to catch all anomalies and these sites, often, present a high level of risk for human life [76].

The introduction of this new technology is justified to the possibility of introducing many and important advantages compared to traditional methods, i.e., direct observation and manned aircraft. In particular, advantages have been observed in terms of cost, quality of data collection, speed of operation and in particular for the safety of employees [77, 78, 76, 79].

With traditional methods, there were problems in detecting anomalies and cracks in places that were not easily accessible. Again, the advent of UAVs has allowed observers to get closer to more remote and difficult-to-access areas. Indeed, it is possible to monitor what is happening inside tunnels and buildings [80]. It has also enabled the acquisition of more and better-quality data and thus the possibility of noticing infrastructural aspects that the human eye can hardly identify [81, 77, 82].

As regards the monitoring of bridges, for example, the old technologies relied only on human observations. There were two problems that had to be faced: on the one hand, the risks associated with the activities, and on the other hand, the impossibility of access to dangerous areas for humans [81, 82]. Indeed, one of the most important advantages with the introduction of unmanned aircraft concerns the safety of operators [83, 81, 77]. The use of UAVs allows bridge monitoring activities to be carried out in a much more secure manner. In fact, bridge monitoring operations require low-altitude flights that are very dangerous for manned aircraft as there is a risk of collision with infrastructure and the bridge itself. In addition, the need to close the section to be inspected causes many dangers for operators, especially near busy sections. In these cases, the use of a drone would overcome the problem [83, 81]. Also for the observation of roofs, the introduction of drones makes it possible to reduce operator injuries on site [84].

The use of drones in this area is also limited by weather conditions. In particular, the use of drones for bridge inspections can cause damage when there are cold environmental conditions, such as those in Norway, for example. The conditions of the drones in this case can prove to be very damaging as they worsen the performance of the drones [81].

Another problem that arises with the use of this technology lies in the inability to recognise structural damage inside the inspected infrastructure, in fact but only allows the detection of external damage. The possibility of performing contact inspections is one of the challenges being focused on as this activity is currently carried out by operators using ladders or hoists and is very time and money consuming [85].

The duration of UAVs is another limitation for the inspection of bridges. During a mission, the flight times of drones usually used for these purposes vary between 20 and 30 minutes. This implies the need for several battery fields during a long-range inspection of a bridge and thus also an increase in the time required to complete the task [85]. Furthermore, the improvement of this aspect could lead to the expansion of activities that drones can perform, such as flying over key points near a bridge [76].

Another use in this area concerns the collection of information on the location of resources on the construction site. This activity was previously carried out by operators, through observations in which they filed location data, and was inefficient and subject to errors. The use of a UAV-based platform that integrates an RFID receiver allows a more facilitated management of tagged resources such as materials, heavy machinery and workers distributed around the site. On the other hand, this platform has limitations. In particular, although used at a distance that reduces interference with on-site activities, it could get in the way of tall equipment such as tower cranes, electric poles and cables. This would cause problems for the operation of the UAV-RFID platform itself [86].

1.2.5 Utility

In the field of utilities and thus mining, oil & gas, electricity, renewable energy etc., drones have been exploited especially for inspection and monitoring activities as they save time and costs compared to traditional technologies [87, 88].

It is remarkable that thanks to the use of drones, tasks can be performed in considerably less time. In particular, it has been verified that while it takes a human operator 15 to 30 minutes to inspect a turbine, a fully autonomous drone can perform the same task in 6 minutes [87].

This new technology brings advantages not only in terms of time but also economically. As far as the electrical industry is concerned, it has been found that the old systems are no longer appropriate in terms of cost and risk for the inspection, measurement, and operation of electrical networks. Aerial aircraft have become a necessity for the energy sector. In particular, the UAV solution among aircraft is also the most efficient [88, 89, 90]. As far as wind turbines are concerned, it has been proven that inspecting turbines with a drone can decrease costs by 90%. The main reason for this reduction is due to the decrease in inspection time that is expected with drones and thus the resulting reduction in lost revenue due to the interruption of the turbine's main activity. Khristopher et al., [87] conducted a study in which four methods for the inspection of wind turbines are considered. The Baseline case involves manual inspection while the other three methods involve the use of drones. Specifically, Case (i) uses one drone operated by an operator for inspection (Visual

Line Of Sight VLOS), Case (ii) uses multiple drones (Enhanced Visual Line Of Sight EVLOS) while Case(iii) uses a fleet (Beyond Visual Line Of Sight BVLOS). It can be seen that the baseline cost is not advantageous in terms of time and cost compared to the others, whereas the greater the automation, the greater the benefits found (Figure 1.2). This also allows a generation of 375 extra pounds per year per MWh installed [87].

A cost saving is also given by the fact that less manpower is required. In the case of wind blade monitoring, there is a need for drone operators instead of turbine technicians. Both jobs have similar wages, but the automated option requires fewer operators [87].

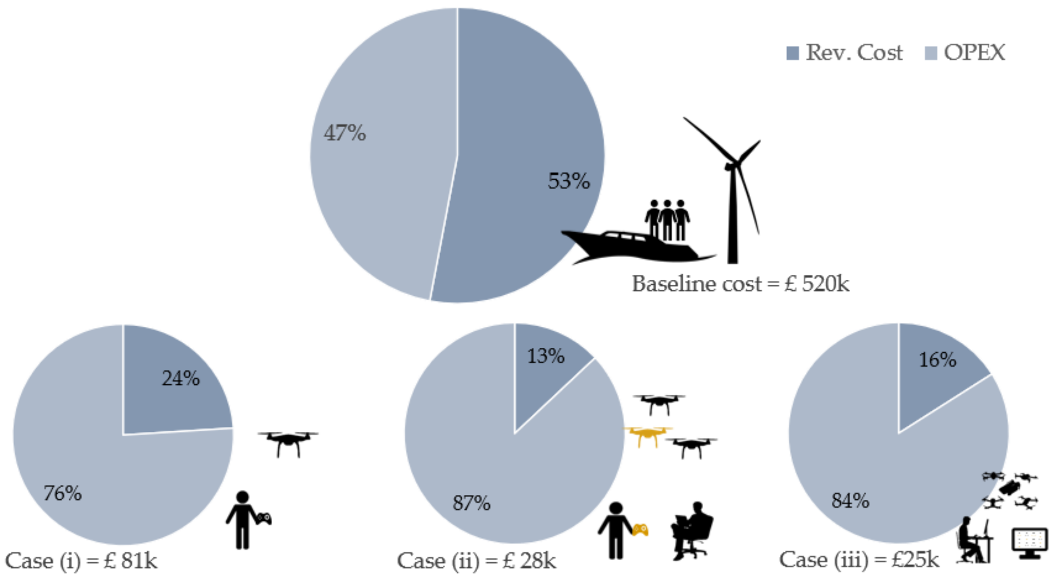


Figure 1.2: *Opex and rev. cost in different scenarios (Utility)* [87].

1.2.6 Telecommunication

The use of drones is also expanding into other areas, such as telecommunications. This technology makes it possible to cover very different areas whose purpose focuses more on improving communication and increased cellular coverage. Studies highlighting the advantages of drones over alternative technologies are shown below.

Xin He et al., [91] investigated the improved communication via UAV systems in both ordinary and emergency situations. Indeed, the technology provides better system robustness as it enables emergency communications in case the traditional infrastructure is destroyed, and the cellular system is blocked [91]. In routine situations, unmanned aerial vehicles allow for increased system effectiveness when base stations are overloaded as a result of population gatherings. They allow increased throughput as they have lower path losses that help improve channel conditions. In addition, they make it possible to improve the quality of communications for users at the edge of traditional cells. They can be used for business expansion as they have lower requirements for infrastructure construction than traditional communications. Another advantage concerns the ability to access more edge users or IoT devices. Finally, drones, due to the proximity characteristics of UAV communication, allow the realization of services and applications used for sharing among nearby users [91].

Therefore, it is possible to conclude that drone technology enables improved communication and increased cellular coverage. Two more specific cases related to the above advantages will be analyzed below.

UAVs can be an advantageous solution for uplink data transmission in IoRT networks (Internet of Remote Things). These networks in fact have limited power for transmission, and drones can act in support and be used to upload the data from smart devices to low earth orbit satellites. This technology replaces traditional ground communication systems, thus enabling better communication due in part to the high mobility of UAVs that allow additional system capacity to be achieved [92].

In some cases, however, this type of technology can provide poor quality of service because in geographic areas, such as deserts, oceans and forests, the implementation and maintenance costs are too high, and the benefit achieved would fail to justify the costs [92].

Furthermore, drones can be used to improve cellular coverage enhancement. Qin Yujie et al. [93] report that UAVs can be very helpful to TBSs (terrestrial BSs) to increase their effectiveness. They, in fact, can be used in dangerous situations, such as fires, because they allow more stable connectivity than TBSs that can be overloaded or damaged. In addition, UAVs are able to optimize their positions in real time, which is particularly useful when the spatial distribution of active users changes continuously over time. In addition, this technology supports TBSs to have adequate network coverage when providing hotspots to users by also generating additional capacity [93, 94].

Despite this, it is still possible to find a major limitation in the application of drones which is due to the power battery of the drones. The moment UAVs stop their activity to go to charging stations, the quality of service provided to customers, in terms of coverage, is lower [93].

1.2.7 Public administration

The areas in Public Administration where this technology is being extended range from security and surveillance to inspections and surveys, from search and rescue, to transportation, but also from delivery to entertainment.

Drones are often used in public administration to replace or enhance the workforce. This is especially important when disturbances or dangerous situations arise for citizens. Given, in fact, the increase in the frequency and scope of crimes and the overloading of the workforce, drones can be used for crime prevention and risk situation analysis. This is precisely why it is possible to say that one of the main fields in which public administration focuses on and uses drones is precisely security and surveillance [95, 96].

When drones are used in this context, there are several advantages. The distinguishing advantage of using this technology is increased security for citizens. In this regard, a model for crime prevention has been proposed that focuses mainly on domestic theft. It involves an integrated monitoring system through unmanned drones that can recognize crimes as they occur [95]. This certainly ensures an increase in timeliness of response, as the drones allow images to be captured in real time and, thanks to Bluetooth 5.0-based wireless communication systems, they are transmitted in a timely manner alerting the administration of the risk situation. This solution certainly allows for more efficient management of surveillance activities as it minimizes the blind spots of traditional patrolling and enables real-time monitoring. This, moreover, is presented as a low-cost model that requires less use of the workforce that is overburdened in many cases. In this way, it is assumed that it will be possible to reduce the crime rate in the areas most affected by these phenomena [95].

Another important case that aims to ensure greater citizen safety is dealt with by Xiao et al. [96]. This is a crowd monitoring system using a swarm of drones to identify antisocial and abnormal behaviours among them. This system has gained important relevance especially in times of pandemic or during social unrest. Crowd monitoring, in fact, allows real-time surveillance of what is happening, and even in this case a timelier response by the public administration is possible [96].

One of the disadvantages in these cases is the high vulnerability of the data during the transmission of them, and to limit this problem, the system is complemented by a Blockchain system that definitely allows for the uniqueness and veracity of the data itself. Again, this is a cost-effective solution that allows reducing the costs associated with technology and those related to manpower since it allows replacing, at least partially, the human factor while also reducing the risks associated with the activity [96].

1.2.8 Art and media

Drones are very versatile and, because of their highly mobility and adaptable characteristics, they can be used in a variety of fields, including entertainment and media and arts and culture.

1.2.8.1 Entertainment and media

Most of the applications in this area involve image and video capture using drones, an immersive and audience-oriented practice. An example of these applications is found in the field of journalism where drones equipped with cameras are used to produce images. This technology is definitely a viable alternative to motorized vehicles, such as helicopters, as the latter are only economically accessible to larger newspapers or media institutions. In fact, drones, given their limited cost, have made aerial photography accessible to a larger number of journalists and also have better image quality [97].

Despite this, in the media field, drones are not seen as a completely new and innovative practice, but more as a variation of existing technology. The initial interest in this technology was dictated by novelty, in fact, curiosity was often not related to the news event, but by the technology used. Once it became a common practice, however, the attention toward them declined [97].

Indeed, it is important to note that journalists have found several limitations in using this technology for their craft. The noise of drone propellers attracted attention during reporting, which clashed with the notion that the journalist must be invisible, and this could often interfere with other people's work. Another major concern certainly relates to safety as the drone could injure people with its propellers and thus this factor precludes the use of the technology near crowds. Also, although the quality of images captured via drones was better, this could result in images that were too aesthetic or abstract for ordinary breaking news coverage [97].

Despite these limitations, the use of drones in journalism can be useful for site detection to communicate its size and/or extent. This is made possible by the fact that drones make possible to reach places that are difficult to access [97].

1.2.8.2 Art and culture

The inspection capability of drones turns out to be an added value when talking about historical buildings, artworks, ruins and archaeological excavations. The following are two cases where drones bring significant advantages over previous technology.

Taking artworks into consideration, it is possible to note that inspection of the painting surface is often conducted manually. However, this technique has limitations, in fact, due to human error and individual experiences of observers it is very difficult to obtain a correct and objective judgment of the examined surface. To avoid this problem, therefore, a camera inspection is conducted, but even in this case there are weaknesses: the quality of the images that depends on the light intensity and the difficulty of judgment that is based on images alone. To overcome the pitfall arising from light, the use of the drone equipped with cameras is proposed which, by flying independently at the same height, allows for better image quality and consequently better inspection quality. On the other hand, regarding the difficulty of judgment, it is proposed to also use a deep learning algorithm to analyse the images reported by the drone so as to limit human errors as much as possible and improve performance. It is possible to conclude that the combination of these two technologies, drones and deep learning, represent a significant improvement in the identifying painting defects [98].

In the field of archaeological surveying, UAV-based photogrammetry is an important tool as it allows the planography of the studied sites to be updated. In particular, the use of this technology in the Valley of the Kings, in addition to previously studied objects, has allowed the discovery of a multitude of new archaeological items that had escaped previous field surveys. Despite this, however, the technology cannot be considered a complete substitute for human analysis as it may not reflect small or low objects, but it is a viable solution to detect areas of interest [99]. In addition, research by Vilbing et al. [100]argues that photogrammetric UAVs are a suitable substitute for LiDAR (Light Detection and Ranging) technology particularly in areas with low vegetation [100].

In general, it can be said that remote sensing of these two technologies has advantages for both over traditional archaeological methods that rely on excavation. In fact, the technologies presented allow not only to reduce costs and limit the possibility of permanently damaging archaeological sites, but also allow for more information and in-depth studies given their larger scale [100].

Increasingly, the attention of archaeologists shifted to LiDAR technology which allowed them to reduce the disadvantages of traditional surveying. This method is very effective, but it is not without weaknesses. One of them is definitely the cost as they present themselves as solutions that are not accessible to everyone because they require a high investment from archaeologists. In addition, LiDARs present very long times in terms of planning and data collection as it requires specific skills and resources. An alternative solution is photogrammetry using UAVs as they allow for very similar quality compared to the previous technology, especially in areas with low vegetation, and they have lower costs and reduced time since they can be implemented more easily. When archaeologists choose the type of technology to use, they should do a site analysis to understand whether indeed UAVs can be a beneficial solution [100].

From these two researches, it can be concluded that the drone, due to its flexibility and mobility characteristics, is a viable alternative to manual inspection as it allows for good image quality without incurring human error. In addition, UAVs can also be an advantageous option compared to other technologies as it is less expensive and requires less time due to its user-friendly characteristic.

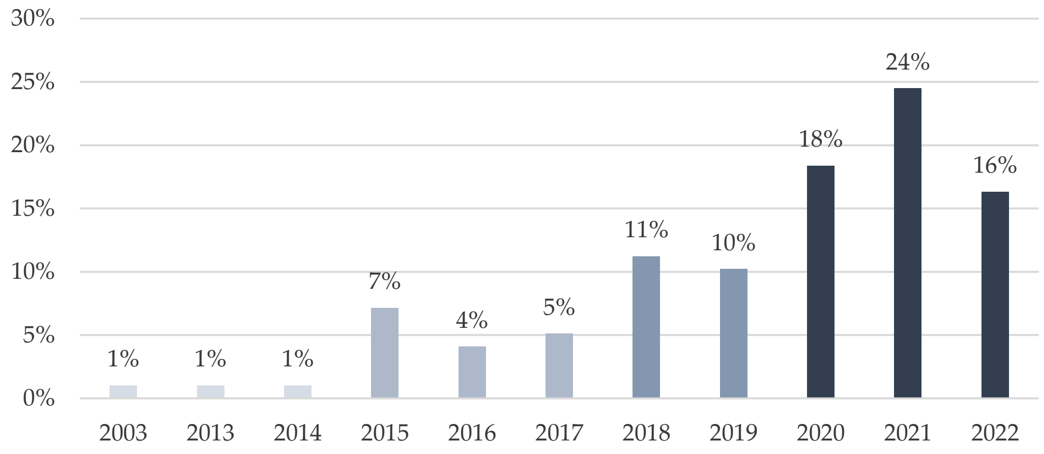
1.3 Analysis of literature review

After having selected and read the scientific documents, they were analysed in more detail. For each one, it was defined the area of interest, as well as the technology previously used, and the activities that the drone would replace.

This analysis is particularly interesting because it will help to understand which areas are less covered and, therefore, more interesting to analyse in order to better understand the benefits and criticalities that may be encountered.

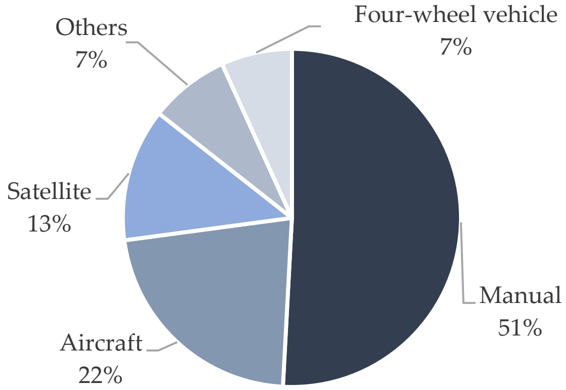
Before conducting this analysis, it is interesting to investigate the distribution of various scientific papers in the various years considered in the research, that is, from 2012 to 2022.

As it is possible to see from the Graph 1.1, the number of papers that could be found in the first years is rather low, standing at 1% until 2014. Thereafter it is possible to see a slight increase in the number of cases surveyed finding only a maximum percentage of 7% in 2015. In 2018 and 2019, on the other hand, this percentage is about 10%. Most of the papers are concentrated in the last three years of analysis, i.e., from 2020 to 2022. this increase certainly makes it clear that the interest and applications for this technology have continued to increase over time precisely because of its potential and the benefits that drones can bring in various areas.



Graph 1.1: *Scientific paper distribution by years*

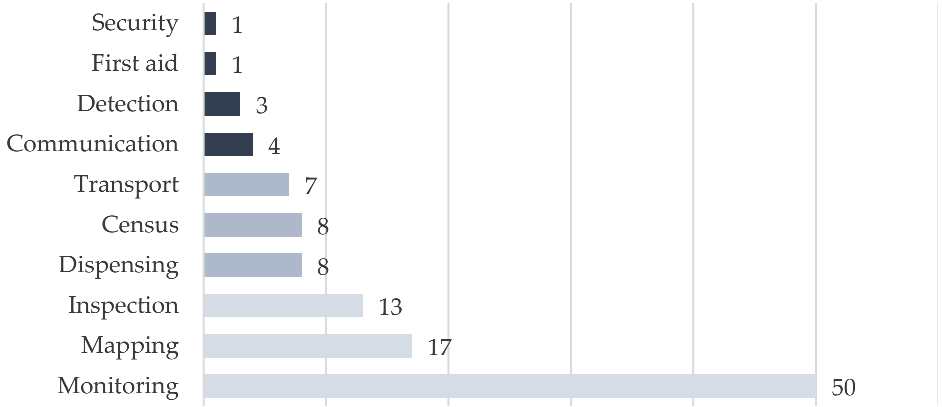
Unmanned aerial vehicle is a technology that was introduced to replace activities that were mainly performed manually by operators (Graph 1.2). In fact, as it can be seen before, they have also brought important benefits related to the dangerousness of certain tasks. This technology also made it possible to intervene in situations where there was a manpower lack that was undermining the efficiency and effectiveness of the operations being conducted.



Graph 1.2: *Distribution of scientific paper by traditional technology*

Drones have also replaced that equipment, such as satellites and aircraft, which, in many cases, have proven too expensive in relation to the activity performed. They were used to carry out data collection and activities such as monitoring, mapping, inspection, census, etc. It turns out, not surprisingly, that the main activity covered by this nascent technology is monitoring. Many of the other activities that can be seen in (Graph 1.3) are related to the main feature of the drone, data collection through images, but they are more specific to the various areas and, for this reason, are less covered.

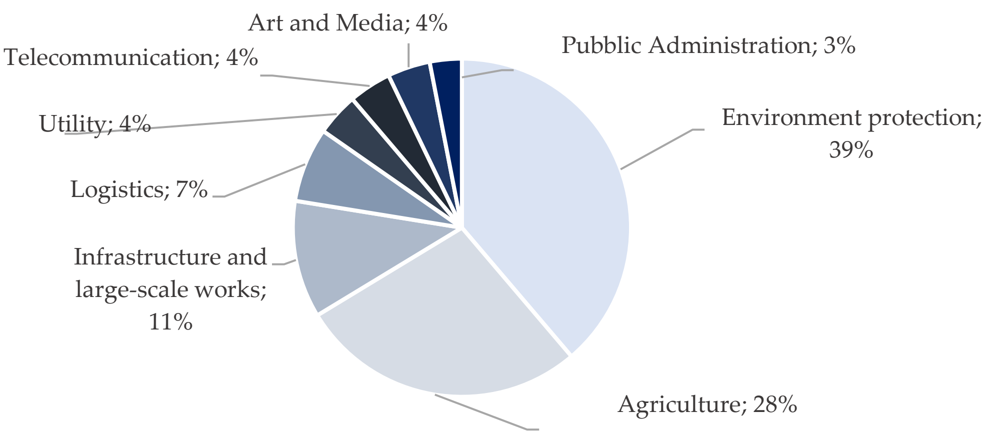
Another important aspect that has been found in the literature is related to the activity of transporting goods and therefore, in this case, refers almost exclusively to the logistics area (Graph 1.3). This area not only considers logistics with regard to goods, but also extends to the health care and pharmaceutical sector where cases of transportation can be highlighted relating to drugs, laboratory samples, medical supplies etc.



Graph 1.3: *Distribution of scientific paper by activities*

As far as the most studied areas are concerned, environmental protection and agriculture are the macro-areas with the most research in this field. Drones are therefore used in the case of environmental protection mainly for activities related to flora, fauna, environmental disasters, and pollution.

Among the other sectors, those related to logistics and infrastructure and major works also appear to have been fairly well researched and analyzed. As for the other macro-areas, these have been less analyzed and are probably areas where the introduction of drones is slower (Graph 1.4).



Graph 1.4: *Distribution of scientific paper by sectors*

Going into more detail, in the agricultural field, the main activities lie in the dispensing of materials on the fields, the monitoring of crops, and the mapping of territories. Activities, the latter two, that are also exploited in the environmental field with the difference that in this case they are also utilized for the census of plant and animal species (Table 1.2; Table 1.3) Previously, these tasks were all carried out manually with direct observations on the sites, using manned vehicles or through satellites (Table 1.4).

Furthermore, in the field of logistics, drones will eliminate or support the four-wheel vehicles that were used to transport goods or medical supplies (Table 1.4).

As far as inspections are concerned, it can be noted that this is an activity in which drones are mainly exploited in the field of utilities and in the infrastructural field since it mainly refers to the activity of inspecting infrastructures or dangerous and difficult-to-access places. Finally, it can be noted that satellites and aircraft are mainly replaced for those activities that involve land monitoring and thus in the macro-area of environmental protection and agriculture probably because they are sectors most in need of more precise, on-demand survey (Table 1.2; Table 1.3; Table 1.4).

	Agriculture	**Art and Media**	**Environment protection**	**Infrastructure and large-scale work**
Dispensing	8			
Monitoring	**15**	4	**27**	1
Inspection			1	9
Mapping	6		7	3
Detection	1		2	
Census			8	

Table 1.2: *Number of scientific papers divided by area and technological functionality*

	Logistics	**Public administration**	**Telecommunication**	**Utility**
Monitoring		3		
Inspection				3
Mapping				1
Transportation	7			
Communication			4	
First aid	1			
Security		1		

Table 1.3: *Number of scientific papers divided by area and technological functionality*

	Manual	Satellite	Aircraft	Four-wheel vehicle	Others
Agriculture	**20**	8	6		1
Art and media	2		1		1
Environment protection	**24**	6	**16**	1	
Infrastructure and large-scale works	7	1	2		3
Logistics				7	
Public administration	3				
Telecommunication					4
Utility	4	1	1		

Table 1.4: *Number of scientific papers divided by sectors and previous employed technologies*

After studying in detail the areas and activities described in the various scientific papers, the focus of the research shifted to benefits and critical issues.

Two analyses were carried out to investigate the typology of advantages or disadvantages resulting from the introduction of drones. The first analysis investigates the aspects that can be valid for all areas considered before, instead the second one classified benefits and criticalities in quantitative and qualitative.

As a result of the thorough screening process carried out, it was found that drones are a cutting-edge technology that can replace or integrate human factors and other traditional technologies. The latter ones can be divided into aerial (manned aircraft), orbital (satellites) and terrestrial (ground vehicles) [50]. The substitution or integration of the actual methodologies depends on the fact that drones can bring relevant benefits. These benefits that arise from UAVs are different depending on the area of use, but it is possible to outline some that cut across all application macro sectors.

One advantage that comes from the use of drones is first and foremost the reduction of manpower [101]. The ability to automate various tasks has made it possible to limit the human factor to only necessary operations [59, 102]. For activities that are not fully automated, where human presence is required, it has been found that human-drone integration still brings added value [42]. This is especially important in those regions and activities where there is little manpower [95].

Due to the reduction in man labour, users of this technology have also found a reduction at the cost level especially in replacing tasks that were previously done manually [13]. As autonomous systems often eliminate the need for humans to perform low-level skill-based tasks they also offer potentially lower training costs [103]. This economic benefit is also found when these go to replace other technologies. In fact, the drone itself has a relatively low investment cost and lower operating costs than other solutions [53, 69].

The use of drone technology to replace or support humans has also allowed for a reduction in the time involved in carrying out professional operations. Especially for tasks performed manually, technology has been able to reduce more than 50% of the time normally spent [87, 59].

UAVs also enable productivity gains, that is, an improvement in the output/input ratio of the process itself. This increase can be seen in various areas from monitoring to culture yield, from transportation of goods to inspection frequency, etc. [43, 5, 95, 65].

Drone technology has been proven to not only help reduce the time it takes to perform tasks but also to improve the quality of those tasks. An example of a drone-optimized activity is analysis by image acquisition [104, 91]. This allows obtaining information in real time [40, 47], having a high spatial resolution of the images, which is higher than that obtained through satellites, [5] and collecting more information [28]. One of the peculiar features of drones that is very important in this field is flying at low altitude compared to manned aircraft and satellites. In addition, they can fly at various speeds and check their position when they come in contact with obstacles and this can increase the precision [105, 106].

The characteristics of UAVs, such as high mobility, flexibility, and greater spatial extent, allow them to reach inconvenient places. They make it possible to reach remote and difficult to access areas by going to facilitate the performance of the task [71, 97].

The safety factor is certainly not to be underestimated when talking about drones. In fact, this technology allows for a reduction in risks to humans while carrying out activities that are particularly dangerous. This is especially relevant when it comes to activities in enclosed spaces [107], activities in which operators may come into contact with diseases [73] and when an environmental disaster occurs [34, 108].

UAVs also allow minimizing environmental impact. In some cases they allow minimizing the impact on flora, fauna and the survey site which means, for example, safeguarding public peace and reducing noise and physical disturbance on animals and plants [9, 25]. In addition, in the case of transportation, they allow reducing carbon emissions [42].

Drones are recognized not only with advantages but also with a number of limitations, which may be regulatory or purely operational in nature. There are multiple regulations governing the drone industry and therefore multiple regulatory entities as well. The use of drones may require local approval, and companies must refer to different regulatory entities depending on the country of use. Example of regulatory entities are the American FAA (Federal aviation Advimistration), the European EASA (European Union Aviation Safety Agency) and the Italian ENAC (Ente Nazionale per l'Avazione Civile). These authorities may also limit their scope [73]. In fact, the process for applying for flight approval may require the need to apply to several entities and thus lengthen the waiting time [5]. In addition, small UAVs are much easier to operate than large UAVs, such as those for passenger transport, that, on the contrary, need many more approvals to be operated [109].

Drone flight is also limited by weather conditions. Indeed, in case of unstable or stormy weather conditions, drones are also prevented from flying due to their small size, which makes them unsuitable for all kinds of situations [109, 38].

In addition, it is important to keep in mind that the battery of drones is limited, which affects the range of unmanned aerial vehicles. Therefore, their time in the air is not unlimited and it is possible that they may have to stop operation to recharge or limit their range of action [93, 38, 45, 104].

After highlighting the main benefits and criticalities associated with drone technology in general terms, i.e., regardless of fields and application areas, the same analysis was conducted by going in depth to study what the origins of these aspects are in qualitative and quantitative terms.

The classification of benefits and criticalities was made between quantitative and qualitative aspects. The first can be measured in monetary terms. In the case of technological replacement by drones, these are related to time and cost. Qualitative or intangible benefits/criticalities are gains/losses attributable to the current technology that cannot be reported for formal accounting purposes but have a significant business impact. In this case, the positive aspects related to the quality of the analysis, safety during operation, environmental impact, and the ability to reach remote locations were found. Instead, the criticalities are related to the regulations, batteries, and weather conditions (Table 1.5).

	Qualitative		**Quantitative**	
Benefits	Safety of the activity Reaching remote places	Quality of analysis Environmental	Costs	Time
Criticalities	Regulations Weather conditions	Batteries	Costs	Time

Table 1.5: *Classification of benefits and criticalities*

1.4 Gap identification

The purpose of this section is to identify the gaps in the literature with regard to technology substitution with drones.

First, the study of the papers consulted showed that, what can be found from the literature is that there is no paper in this research that considers the benefits and criticalities of using drone technology in a general scope considering all application areas. Scientific papers focus on a specific application area and very often to a single activity. In particular, most of these researches make only minor references to the benefits or critical issues that could arise as a result of replacing or integrating old methodologies with drones.

In addition, there is no direct comparison between the previous ways used to carry out the activity and the new technology. The articles analysed, in many cases, do not provide precise and tangible data on which an objective comparison can be made regarding the use of two different technologies in performing out an activity. Thus, these scientific papers were limited to describing the new method and mentioning in a non-exhaustive way what are advantages and disadvantages without going into too much detail. This makes it particularly difficult to be able to identify what are the benefits and criticalities of the technology even in application areas that have been less studied.

The areas that have received more attention from scientists are environmental protection and agriculture, with 39% and 28%, respectively. The focus on these fields may also be due to the fact that the introduction of drones occurred earlier than in other areas. Central, among the areas that have been less analysed, is the role of the utility sector. Here, in fact, the papers found that present a comparison of the use of drones compared to earlier technologies are very few. It is therefore more difficult to state with certainty what are the benefits and criticalities of the technology by separating them from the business cases analysed by the specific paper. It is therefore necessary to understand the advantages and disadvantages, both tangible and intangible, compared to traditional technologies of using drones in the utility field and those that are one-offs. To do this, the analysis will focus specifically on the utility infrastructure inspection activity as it appears to be the one of greatest application for this field so as to obtain solid and consistent information for technology substitution in this area.

In conclusion, the gaps that this research will focus on are:

- What are the various macro-fields of application in which drone technology is included or plays a complementary role to previous methodologies;

- What are the benefits and critical issues that drone technology can bring to the utility field for infrastructure inspection activities.

2. Objective and methodology

This chapter discusses the objectives of the thesis, the research questions related to the identified gaps, and the methodology used to answer them.

2.1 Objective of the thesis and research questions

Having identified the gaps emerging from the literature review, expressed in the previous chapter, it is important to define what the goals of the thesis are in order to fill them.

To this end, two main objectives have been identified:

1) To study the phenomenon of technology substitution through the introduction or flanking of drone technology in a variety of sectors and application areas.

2) To narrow the study of the same phenomenon to a specific sector and scope of application: utility sector infrastructure inspections, highlighting potential and criticalities of the technology.

Then, after identifying the gaps related to the literature and highlighting the objectives of the thesis, the research questions can be created based on these elements. The research questions are as follows:

RQ1: *What are the main areas of application of drone technology in different sectors and in the utility field?*

RQ2: *What are the benefits and criticalities of using drones to replace or flank a traditional technology for inspection activity in the utility sector?*

2.2 Methodology

In this section, the different approaches used to answer the different research questions will be explained in detail; in particular, two procedures were performed in parallel. The first, based on creating a census of application cases, was used for RQ1. The second, on the other hand, is based on interviews with medium- to large-sized companies operating within the utility sector; these were used to answer RQ2.

2.2.1 Research question 1 method

To answer the first research question, related to the study of the technological substitution of drones in various industries and the utility sector, a census based on news about drone applications in various fields was used.

2.2.1.1 Census definition and compilation

An Excel document that contained articles from 1 January 2019 to 31 January 2022 was updated and articles up to 31 December 2022 were introduced. The articles that were surveyed had to report on a drone application case within a particular area. During the selection process, military applications, articles related to the description of new drone models, new licenses, articles related to regulations, and articles dealing with non-aerial drones were not considered since they are news items that are not of interest to this research. In addition, both specialist and newspaper titles were consulted to complete the selection of articles (Table 2.1).

Specialists	Specialists from other sectors	Generalists
· Drone Blog News	· Transportonline	· La Stampa
· Urban Air Mobility News	· Trasporto Europa	· Il Corriere della sera
· Dronezine	· Il Giornale della Logistica	· Il Sole 24 ore
· RotoDrone	· Pharmacy Scanner	· La Repubblica
· Quadricottero news	· Cnet	· TGcom24
· UAS Vision	· Webnews	· Corriere Comunicazioni
· The UAS Magazine	· National Geographic	· Corriere del mezzogiorno
· sUAS News	· Sky Sport	· Il Resto del Carlino
· Unmanned Systems Technology	· Pharmacy Scanner	**Others**
· eVTOL.com		· CBI Insight
· Inside Unmanned Systems		· Key4Biz
· eVTOL Insights		· Tio 20 minuti
· Mirumir		· Quotidiano.net
· Droni.it		

Table 2.1: *List of newspapers used for census*

Following the reading of the articles, the creation of the database for the census of application cases considers aspects of a more general nature and others of a more specific nature of drone technology.

With regard to general aspects, the following information was considered:

- *Name of article;*
- *Link:* link to the article's website;
- *Description:* summary of the article;
- *Macro-Sector*: this section is related macro-areas previously covered in the Literature Review and thus agriculture, environmental protection, logistics, infrastructure and large-scale works, utilities, telecommunication, public administration, art and media with the addition of the macro-area related to mobility;
- *Micro-Sector:* based on the macro sector, it is possible to further detail the analysis. For example, for the case of utilities, it is possible to detail the analysis according to the type of source/energy used (electricity, renewable energy, nuclear energy, etc.)
- *Scope 1:* considers the scope of the technology and specifically 9 different scopes have been identified, including search and rescue, inspection and survey, security and surveillance, transportation, dispensing, entertainment, maintenance and gathering;
- *Scope 2 and Scope 3:* then based on the different scopes chosen, it is possible to go into more detail and identify different categories based on "action," "what," and "where."
- *Status:* it is possible to categorize the item according to the current type of use
  - Announcement: not yet used but there is an intention to integrate drones in the near future
  - Experimentation: operational study of a new field of application of drone technology
  - Una a tantum: non-routine use of drone technology for a particular service
  - Operational: established use of drone technology
- *Year:* year of publication of the article;
- *Date:* date of publication of the article;
- *Continent:* continent where the drone mentioned in the article is used;
- *Country (of use):* country where the drone mentioned in the article is used;
- *Company/Entity:* the entity or company that uses the drone mentioned in the article.
- *Service provider:* the company/entity that makes possible for the user to utilize the drone technology. Thus, these are those who provide the drone or the service for its rental;

- *Other actors involved:* other actors who have been relevant to the use of the technology;
- *Drone model:* drone model used by the company to provide the service.

The following information was considered with regard to the more specific aspects related to drone technology:

- *Type of drone:* the type can be distinguished between fixed wing, rotary wing, rotary wing, multirotor (multicopter), VTOL, aerostat, airship, and other.
- *Payload:* devices that are integrated with the technology to perform a certain type of task. They can be: camera, thermal camera, laser, liquid dispenser, etc.
- *Software*: particular types of software that are added to the technology to perform the task (AI, UTM, timing, navigation, etc.)
- *Type of flight*: the type of flight can be distinguished into Visual Une of Sight (VLOS) or Beyond Visual Line Of Sight (BVLOS). Flying in VLOS means that the drone cannot be lost sight by the pilot, while BVLOS allows for a flight in which the pilot does not have to maintain constant contact with the drone;
- *Scope of the project*: it is possible to distinguish between Covid-19, AAM, 5G, AI/Data Analysis;

Benefits achieved: highlights what types of benefits are mentioned in the article due to the use of drone technology. The benefits considered include reduced costs, reduced time, increased productivity, improved quality/accuracy of analysis, reduced environmental impact, increased safety in performing the task, and reaching inconvenient locations.

For further details, see Appendix A (

Census).

2.2.1.2 Census approach

At this point, an analysis of the census cases, found in the Analysis section, was done to answer the research question. Specifically, of these cases, only the information needed to respond to the research question was considered. To do this, only the columns of the Excel file needed for analysis were considered, and the "Conta.se" and "Conta.più.se" function was used to create the tables for analysis (Table 2.2).

Macro sectors	N° of case	%
Agriculture	=Conta.se(Censimento!$E$2:$E$1138; “Agriculture”)	xx%
Utility	=Conta.se(Censimento!$E$2:$E$1138; “Utility”)	xx%
Logistics	=Conta.se(Censimento!$E$2:$E$1138; “Logistics”)	xx%
…..	….	…

Table 2.2: *Function used for tables creation*

Total	1100	100%

At this point, two different paths were performed.

Specifically, to answer the first part of RQ1, tables were created on the Excel file of census considering all the news to examine the application cases present in the different sectors and the various areas of implementation of the technology. Then for each of these sectors it is possible to go into more detail based on the micro sector and the type of business conducted so as to have a complete overview of the distribution of interest in drone technology.

To answer the second part of RQ1, a second screening was performed, which involves eliminating all those news items that do not belong to the macro area of utilities. In fact, in this second phase, with the focus on the utilities macro-area, the distribution of the various application cases is analyzed in relation first to the micro sector, i.e., the type of energy, and then to the type of activity performed. In terms of activities, there will be a focus on the infrastructure inspection activity as it is the core of this research.

For this research question, data were analyzed by graphing in Excel. The analysis performed will be explained in more detail in the Analysis.

2.2.2 Research question 2 method

To answer the second question, several interviews were conducted with companies in the utility sector that use drones. Specifically, companies dealing with power grids, Oil&Gas and renewable energy for inspection of related infrastructure.

The methodology used to answer RQ2 is based on four stages: *company research, interview definition, data definition and validation*.

2.2.2.1 Company research

A In this first phase, the different companies to be contacted were identified. This process began through the use of the census referred to in Appendix A (

Census). Specifically, all cases were considered that had the content "Utility" within the *Macro-area* column and that *Scope* referred to "Inspections and inspection." In addition, cases where in the *Country (of use)* the content was "Italy" were identified because it is necessary to analyze a sample that was comparable and thus subjected to the same or similar conditions for all. After this screening, companies in the utility sector that plan to use the drone for infrastructure inspection activities were identified. It was possible to obtain a base of 8 possible companies to be interviewed.

In addition, in order to expand this base, internet searches were conducted to be able to find other companies that have introduced this technology in recent years. The searches were based on companies based in Italy, belonging to the utility sector, and that within their website referred to the use of drones for their activities. Therefore, 14 companies were informed of the research and following their feedback, 8 interviews were conducted.

Since 2 of interviewees referred to multiple Micro-sectors with which they operate with drones, it was possible to define 10 different Case Studies in order to consider the different fields of applications where significant differences emerge.

2.2.2.2 Interview definition

During this phase, the questions that were to be asked of the interviewees were defined in order to arrive at useful information to carry out an analysis of both tangible and intangible data. Semi-structured interviews were conducted as a direct source of information, and open-ended questions were defined to make respondents feel free to share their experiences.

Specifically, more general questions were first defined that covered the company's motivations for introducing this new technology, the different ways in which they conducted the business under consideration, and the type of drones and different payloads in which they invested.

Next, there were more specific questions regarding the macro-topics that were to be analyzed. This was done through the identification of the advantages and disadvantages divided by macro-area made during the literature review (Appendix B-Interviews).

The benefits that were to be addressed concerned:

- *time reduction*: the difference in time spent with the different methodologies and inspection frequency;
- *cost reduction*: the difference in costs regarding the technologies used and/or manpower required for the inspection activity;

- *reaching inconvenient places*: the possibility of reaching places that were previously inaccessible or difficult to reach, such as private places or remote locations;
- *personnel safety*: the possibility of increasing safety during the performance of the activity and reducing workplace accidents;
- *environmental impact reduction*: the possibility of bringing a positive impact on the environment, such as the possibility of reducing CO2 emissions and decreasing noise disturbance;
- *quality/accuracy of inspections*: the possibility of improving the quality and quantity of data that are collected during inspections and the way these are analyzed and processed.

On the critical issues, the questions addressed:

- *regulations*: the possibility that current regulations are a hindrance or that companies need constant involvement of authorities to get particular permits;
- *batteries*: the possibility of limited battery life being an obstacle to inspection activities;
- *weather conditions*: the possibility that adverse weather conditions, such as rain and wind, will not allow the use of drones and create problems;
- *personnel investment*: the need to invest in personnel in order to acquire the know-how needed to introduce this new technology or to be able to maintain and upgrade skills.

More specific questions were then defined for each of the benefits/critical issues to be addressed based also on the responses of the interviewees.

Finally, they were asked what they think are the aspects that drone technology is currently unable to bring within the business (Appendix B-Interviews).

2.2.2.3 Data definition

At this stage of the process, the different interviews were conducted, and all the data collected were subsequently summarized in different Excel files.

The different companies interviewed were classified according to micro-sector, type of infrastructure inspected, and the supply chain position (Table A.1).

Interviewers	Micro-Sector	Inspected infrastructure	Supply Chain position
Case A	Electrical energy	Electricity grid	Distribution
Case B	Electrical energy	Electricity grid	Distribution
Case C	Oil&Gas	Pipelines	Distribution
Case D	Renewable energy	Solar panels	Distribution

Case E	Renewable energy	Wind turbines	Distribution
Case F	Renewable energy	Solar panels	Production
Case G	Renewable energy	Wind turbines	Production
Case H	Oil&Gas	Pipelines	Transport and Storage
Case J	Renewable energy	Solar panels	Production and Distribution
Case K	Renewable energy	Solar panels	Production and Distribution

Table A.1: *Interviewers, micro-sectors, inspected infrastructure and Supply Chain position*

The interviews were conducted between October 2022 and January 2023 through the Microsoft Teams platform. The meetings were attended by the two authors, a researcher from the Department of Drones and Advanced Air Mobility Observatory of Politecnico di Milano, and one or two representatives of the interviewed company. The meetings lasted one hour each and were conducted following a series of questions that are previously explained and can be found in Appendix B (Interviews). All interviews were recorded and transcribed. Subsequently, additional questions were asked of the interviewees in order for them to complete the information they provided to us; in particular, additional data needed for the cost analysis were requested. This additional information was requested by email since it was simple data that did not require the need for an additional interview. The requested questions were summarized in Appendix B (Additional questions).

Once all the data were collected, they were summarized in two Excel files: one including all information regarding intangible benefits and critical issues (Appendix B-Information about intangible data), and another regarding tangible ones (Appendix B-Information about tangible data), thus time and cost information. It is important to note that some aspects have been included in the intangibles section that, although they are quantifiable, data about them have not been shared by the companies and therefore have not been defined quantitatively. Moreover, there are also some data that are included in both sections since they can influence in a qualitative and quantitative way the decisions of companies.

2.2.2.4 Intangible data

The first Excel file includes all the benefits and critical issues that were listed in the section Interview definition, so if the company encountered that benefit or critical issue an "X" would be marked in the box corresponding to that case study and that particular critical issue or benefit.

Based on the respondents' answers, during the analysis phase, each factor is rated from 1 (low) to 5 (high) based on the degree of impact that the introduction of the new technology had on the factor for that company. Specifically, value 1 will be assigned when that particular aspect has not been considered or has a completely marginal impact for that particular company. Value 5, on the other hand, has been assigned when the factor considered has a significant impact and could influence the decision to introduce the new technology or not (example Table A.2; Appendix B-Information about intangible data).

	Reaching uncomfortable places		**Security of personnel**		**Environmental impact**		**Quality/accuracy of inspections**	
	Rating	…	Rating		Rating	…	Rating	…
Case W	…	X			…	X	…	X
Case Y	…		…	X	…		…	X

Table A.2: *Example of the file Excel containing data about benefits and criticalities*

2.2.2.5 Tangible data

The second Excel file, on the other hand, concerns the quantitative benefits and criticalities of cost and time that will then be used to compare in monetary terms the cost-effectiveness of inspecting infrastructure using drones for each case.

This file will be used for all the cases analyzed with the relevant information given by the different companies. The files with detailed costs from the different companies will not be shared to keep the sensitive data in each Excel sheet confidential. In addition, it will also be useful to create the different generic models for each type of infrastructure that can be consulted by other companies willing to invest in drone technology to replace or supplement the traditional inspection methods they have in place. These general models will then be analyzed in the Analysis.

In order to compare the different case studies, it was defined clusters based on the type of assets that the drone inspects. In this case the clusters turn out to be four since the infrastructures inspected are: power grids, pipelines, solar panels, and wind turbines (Table A.3). Specifically, in the case of assets that span thousands of kilometers (power grids and pipelines), it was defined all cost items in km, while for the other assets (solar panels and wind turbines), which involve mostly vertical drone movement, it was defined all cost items in MW.

Within the clusters (Table A.3), it is possible to notice that two case studies were not considered, ones related to cases J and K. These two cases perform their asset inspection activities through external companies; therefore, they were unable to provide data in terms of time and cost that could be comparable with those of the other companies.

Inspected infrastructure	Cases
Electrical grid	Case A; Case B
Pipelines	Case C; Case H
Solar panels	Case D; Case F
Wind turbines	Case E; Case G

Table A.3*: The four macro clusters and the cases referring to each one*

Once the clusters and units were defined, two tables were created for each case and model: the first referring to the old methodology of inspection (AS-IS case) and the second to the new one using drones (TO-BE case). Within them, the various differential cost items that the company would incur by comparing the old method with the new one was identified.

Specifically for the AS-IS case, three macro cost items were considered: operational cost, cost for extraordinary inspections, and injuries cost. While for the TO-BE case the costs that were identified are: investment cost, battery cost, operative and extraordinary inspection cost with drone and injuries cost.

In calculating the total costs, those costs generated by the increased effectiveness of drone inspection were not taken into account. The total result of actual TO-BE costs for companies will be even lower than the proposed estimate because additional savings related to, for example, higher inspection quality and inspection improvement on damage prevention are expected.

In calculating total costs, three cases named Worst Case, Medium Case and Best Case have been defined. The Best Case will result as the case with the most cost-effective decisions, and the Worst Case as the least cost-effective. Notably, each table has within it boxes with fixed values that are repeated in all three cases presented. Despite this, it can be seen that some of these values are slightly different depending on the type of infrastructure inspected. The values that have been defined are the result of the information that was provided during the interviews with companies and two additional interviews with experts in the field of drone inspections.

2.2.2.6 Validation

After collecting data from the different companies using drones for inspection activities, a generic model was created for each type of infrastructure.

Following this, it was necessary to validate the created model and consequently confirm the information entered into the model.

To do this, two drone specialists were consulted, namely two startups focused on selling services for companies in this field. More specifically, the first business deals with the design and prototyping of multi-rotor UAV platforms and with an in-house laboratory for UAV flight testing. The second, on the other hand, provides autonomous drone inspection services of electrical transmission/distribution lines, renewable energy production sites, industrial facilities, and infrastructure.

Given the experience of these specialists, their competencies have been leveraged to define the characteristics that drones must have in this field, and in particular the models, payloads, and batteries. Of course, given their experience in infrastructure inspection, they were also important in defining the yields in different scenarios.

Subsequently, the generic model was also shown to two companies involved in infrastructure inspection in the utility field. The first company specializes in the inspection of electric grids and pipelines and confirmed the input data by sharing feedback especially regarding inspection times and drone operability, which were later implemented in the model. The second company, on the other hand, uses drones for the inspection activity of renewable energy infrastructure. This company confirmed the general overview of the models created for solar panels and wind turbines by giving a slightly different perspective on extraordinary inspections. This perspective was also integrated within the model to create an average case.

Feedback from drone specialists and companies was used to validate and confirm data used. As a result of these additional interviews, it is possible to claim with a good degree of confidence that the model has been validated.

3. Analysis

This chapter resorts to the results obtained through the analysis described in the methodology section in order to answer the three research questions.

Specifically, the first section and the second section will report the results, obtained through the census analysis, to answer the first part and the second of the first research questions below.

RQ1: *What are the main areas of application of drone technology in different sectors and in the utility field?*

Finally, the last section shows the findings obtained from the analysis of the interviews to answer the second research question below. In particular, this section displays the results divided into two sub-sections: intangible benefits and critical issues and tangible benefits and critical issues.

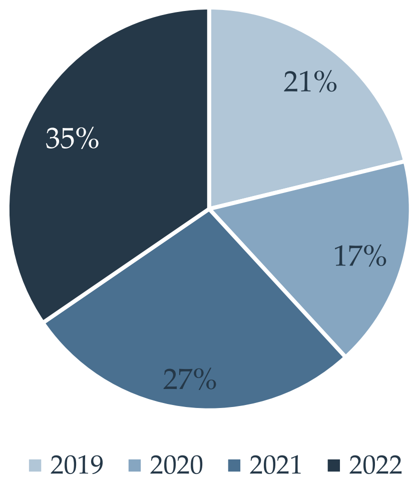
RQ2: *What are the benefits and criticalities of using drones to replace or flank a traditional technology for inspection activity in the utility sector?*

3.1 RQ1: Main sectors and application areas of drone technology

As anticipated in the Methodology section (1.1 Methodology), to answer the first research question, that is "What are the main areas of application of drone technology in different sectors and in the utility field?" a census was conducted. The census involves an analysis and categorization of all application cases in recent years from January 2019 to December 2022. In fact, once the application cases are identified, they are placed within the Excel file "census," found in the Appendix A (Census) and evaluated according to several clusters explained in the Methodology section. At the end of this selection and evaluation process, 1,137 application cases were surveyed.

First of all, it was investigated how these census cases were distributed over the different years, in particular, it can be observed from Graph 3.1 that the news during the first two years was pretty balanced. Subsequently, however, a rise in cases was seen in the last year to almost double in 2019 (Graph 3.1).

One of the meanings of these numbers could be the fact that there is growing interest in this technology at this time and therefore more and more experimentation is being done and also more and more bringing this technology as a common activity within the different realities (Graph 3.1).



Graph 3.1: *Distribution of census cases (1,137) by years*

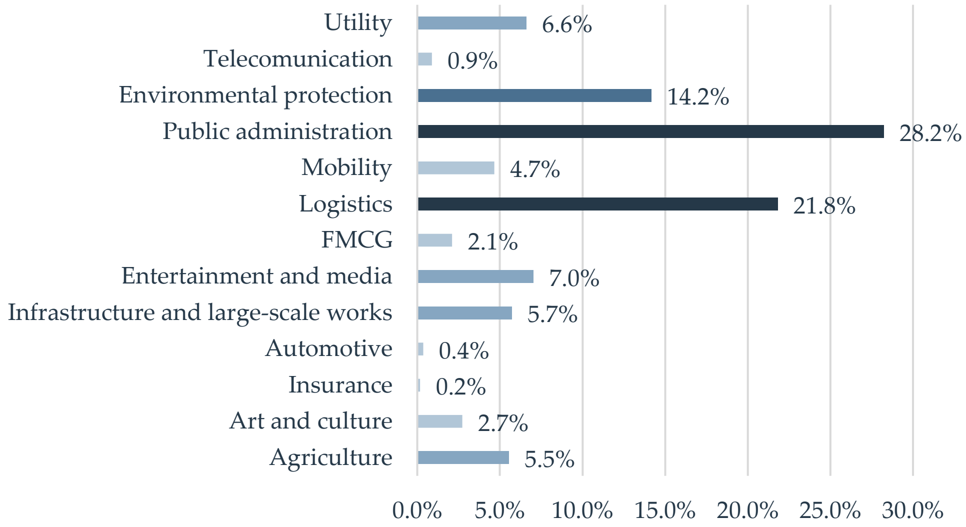
In particular, to answer this research question, it is necessary to focus on the sector to which the different cases belong. As can be seen from Graph 3.2, most of the cases surveyed in recent years are related to the public administration sector with 28%. Another highly studied area is logistics with 22% of cases and then environmental protection with 14%. All other sectors do not find much distribution in recent years, with a percentage of cases surveyed below 7%.

In particular, it is possible to confirm that, as seen in the Literature review (Analysis of literature review), interest in environmental protection is very high. In fact, although the percentage of cases surveyed is only 15% (compared to 39% found in the literature) it turns out to be the third most treated area as well. This is probably also attributable to the fact that this area encompasses several areas of study; in fact, environmental safeguarding includes plants, animals, pollution, and environmental disasters.

Moreover, in the news surveyed, the cases involving agriculture are only 6%, whereas they were widely covered in the literature, i.e., 28%. Probably the reason why the percentage of census cases is not so significant is that this area has been studied extensively in the years prior to it, with numerous applications in precision agriculture, and therefore, since the literature analysis considers a wider time space, it is possible that most of these are concentrated in the years prior to the compilation of the census.

Among the major areas of application in the census is also public administration, which, however, only finds 1% of the cases covered in the literature. A possible explanation for this is to be found from the fact that, it is true that most of the cases surveyed are from public administration, but as can be seen from Graph 3.2, most of these cases involve one-off uses, so drone technology is not used specifically for this sector, and probably because of these there are fewer scientific articles concerning the use of unmanned aerial vehicles in the field of public administration.

Finally, as far as automotive and insurance cases are concerned, these are around 0%, so very few news were found. This could mean that these two areas are new discoveries and researchers are trying to investigate how to introduce drones inside these areas (Graph 3.2).

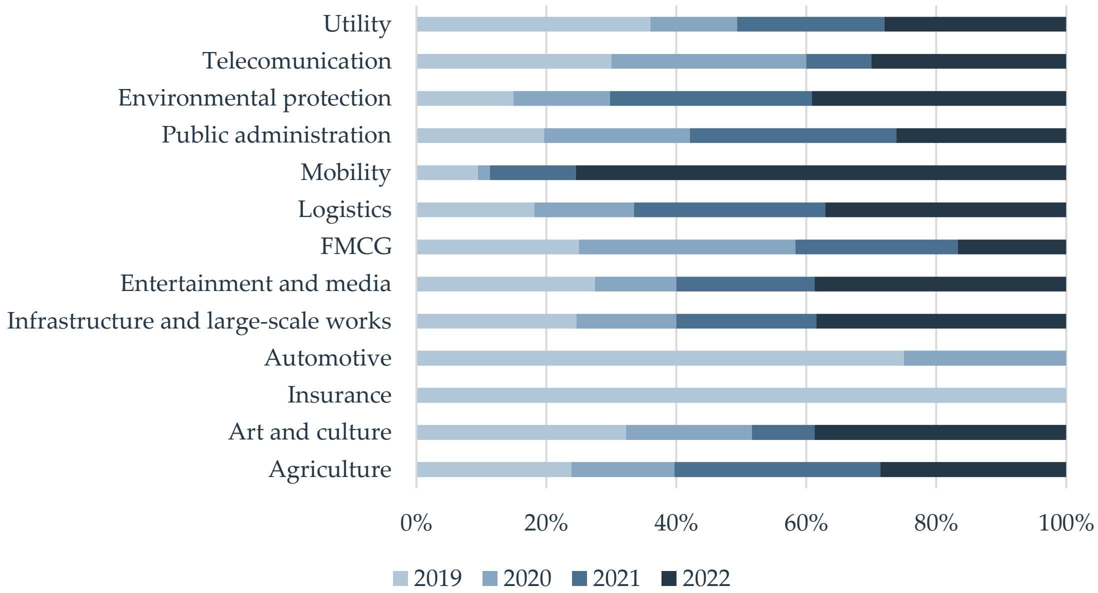


Graph 3.2: *Distribution of census cases (1,137) by macro sectors*

It is also possible to study the distribution of cases across years in relation to their sector. In particular, in most sectors the application cases are widely distributed in the year 2022, with percentages exceeding 30%. This means that interest in drone technology is increasing in all sectors (Graph 3.3).

In addition, cases related to the mobility sector have an even higher impact in 2022 with a percentage of about 75%. The potential for using drones for people's mobility is mainly concentrated in news dealing with the construction of vertiports, which are areas of land, water, or structures used or intended to be used for landing and take-off of VTOL (i.e., vertical take-off) aircraft[3] (Graph 3.3).

However, exceptions are present. These include the utilities sector in which most of the census cases refer to the year 2019 with a percentage of 36%, and then in subsequent years interest in the technology declined increasing again only in 2022 with a percentage of 28%. The telecommunications sector, on the other hand, has an even distribution across years, but with a particular decrease in the year 2021. Another exception refers to the automotive and insurance sectors where all the census cases refer to 2019 or 2020. One of the reasons for these declines in these sectors can also be traced to inadequate regulations and slow bureaucracy in obtaining permits[4] (Graph 3.3).



Graph 3.3: *Distribution of census cases (1,137) by macro sectors and years*

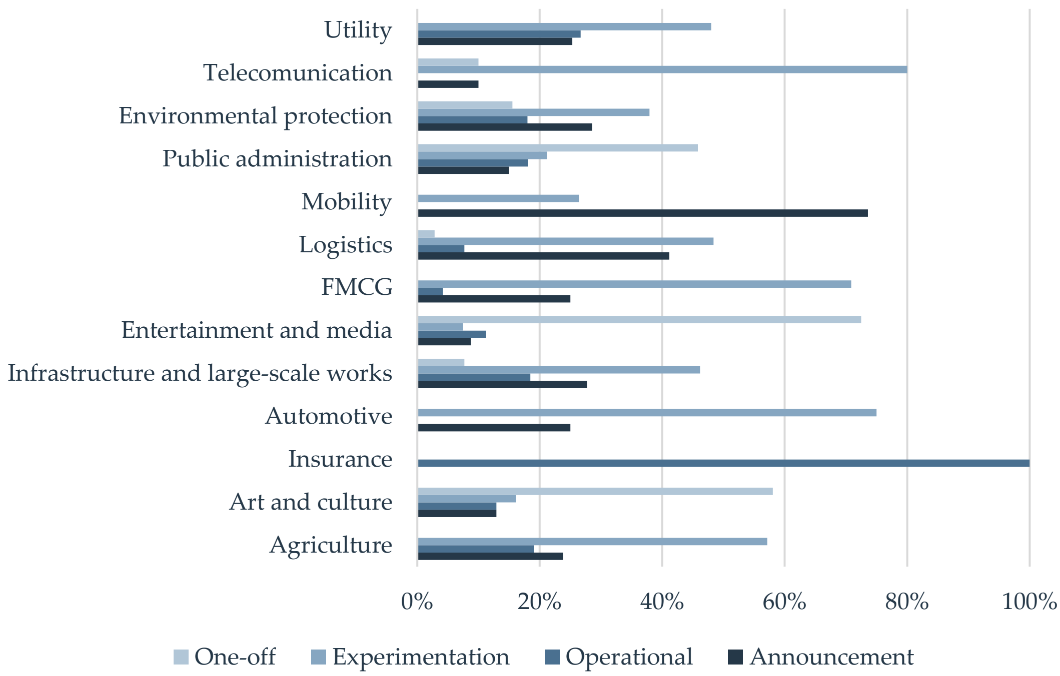
However, at this point it is also possible to proceed to study the status of the cases surveyed in the different sectors. In particular, from Graph 3.4 it is possible to see the distribution of them according to one-off, announcement, experimentation and operational.

[3] Vertiporto, cos'è: tutte le informazioni | Moveo
[4] Droni, 60mila operatori in Italia. Mercato in affanno ma il boom è alle ...

As can be seen from the Graph 3.4, most of the uses of drone technology can be accounted for by experimentation, this underscores the fact that in many sectors unmanned aerial vehicles are not yet fully operational but are still in the testing phase mainly because it is a new technology. In fact, most companies continue to invest in research related to the introduction of drones in various fields.

Exceptions are also present in this regard. The first among them concerns the mobility sector in which most of the cases are announcements, i.e., news in which different companies express their willingness to introduce drones in this field but experiments in this regard have not yet been initiated. This is probably related to the fact that the field itself is also unproven, but it is under development and the potential of it is growing, especially in combination with drone technology. In fact, this area is not very defined and most of the regulations and standards to be followed are still being defined since this is a very sensitive topic in terms of people's safety (Graph 3.4).

The other exceptions are in the public administration, entertainment, and media, automotive, and art and culture sectors where the cases involve one-off uses; thus, unmanned aerial vehicles are not fully allocated to the respective divisions. The true potential of this technology has probably not yet been fully investigated by these sectors and they are limited to sporadic use of it (Graph 3.4).



Graph 3.4: *Distribution of census cases (1,137) by macro sectors and status*

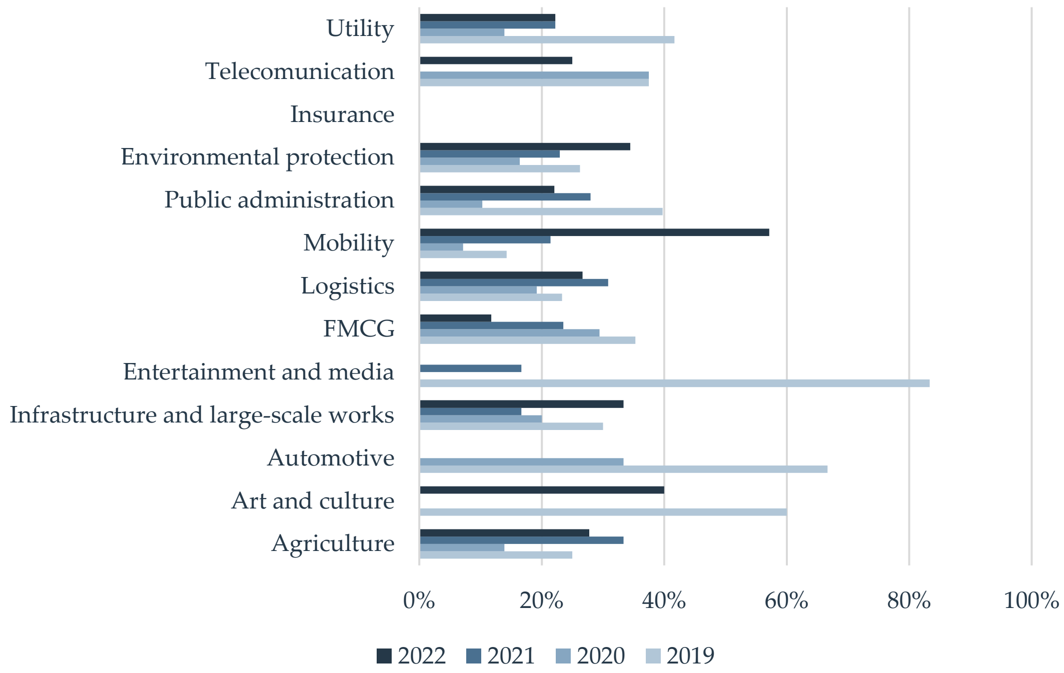
It is also interesting to see how these experimentations are distributed over the various years, so as to understand the trend related to this technology. In particular, in some areas most of the trials do not have a linear trend.

For infrastructure and major works, environmental protection and especially mobility, most of the experimentations were conducted in the year 2022, thus the last year of the analysis, suggesting that they are among the areas most affected by the innovation of the technology (Graph 3.5).

For agriculture and logistics, on the other hand, most of the trials focus on 2021, with a very slight decline in 2022. These sectors probably began to develop particular interest earlier than those mentioned above (Graph 3.5).

The remaining sectors, on the other hand, were conducting experiments on drone technology as early as 2019, with a particular concentration in the entertainment and media sector, art, and culture and automotive where almost all of the tests are referred to this year. However, these are special cases because the number of experiments is very low, and they are all concentrated in the first year (Graph 3.5).

In the end, as regard the insurance sector, no cases about experimentation were found. This probably depends on the fact that is not one of the main application areas where you can use this technology (Graph 3.5).



Graph 3.5: *Distribution of census cases (1,137) by macro sectors, experimentation, and years*

Another type of analysis that can be conducted concerns the distribution of cases with respect to the continents where the new technology is used. In general, it can be seen from the graph below (Figure 3.1) that most of the cases come from Europe (about 51%). Thereafter, the distribution of the census news is about 24% in America, 15% in Asia, and the remainder between Oceania, Africa and Antarctica.

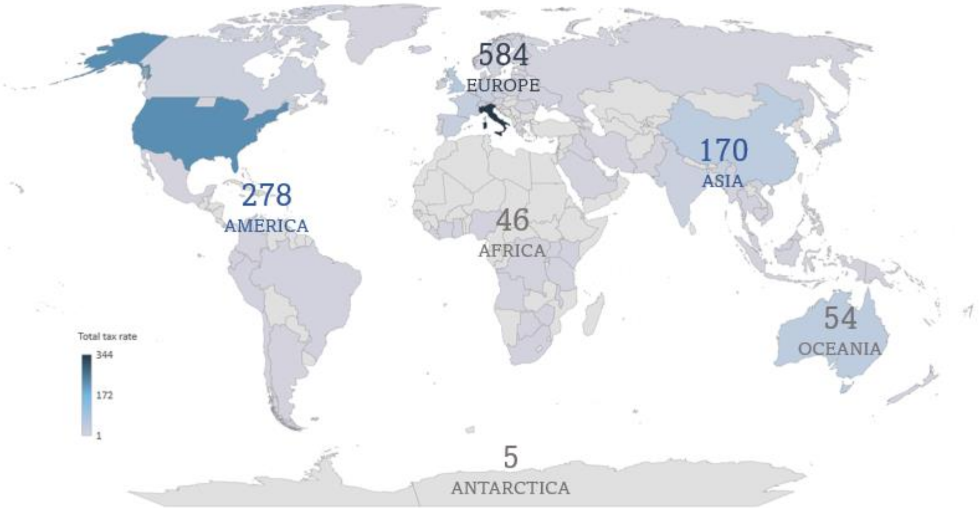
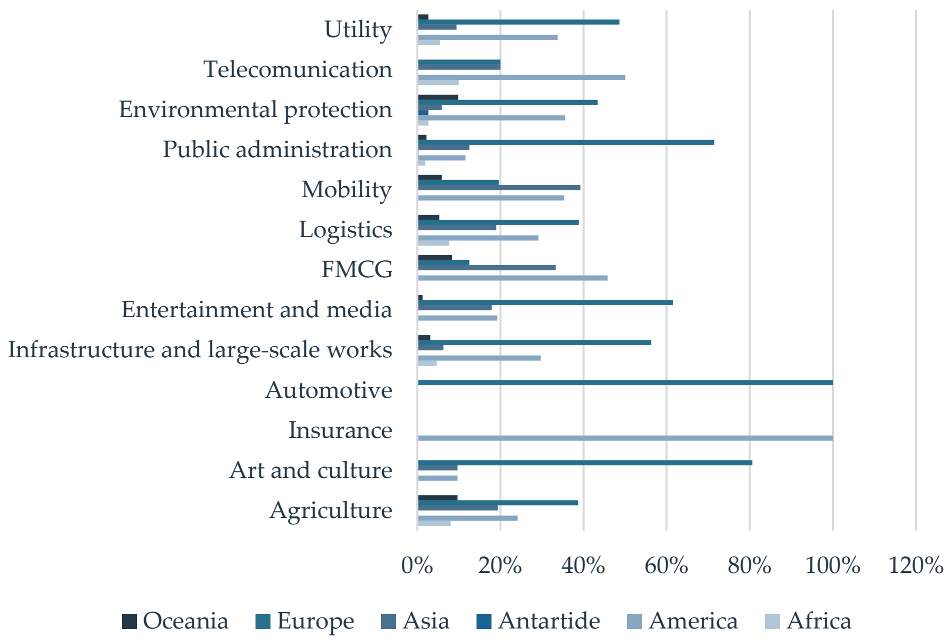


Figure 3.1: *Distribution of census cases (1,137) by continents*

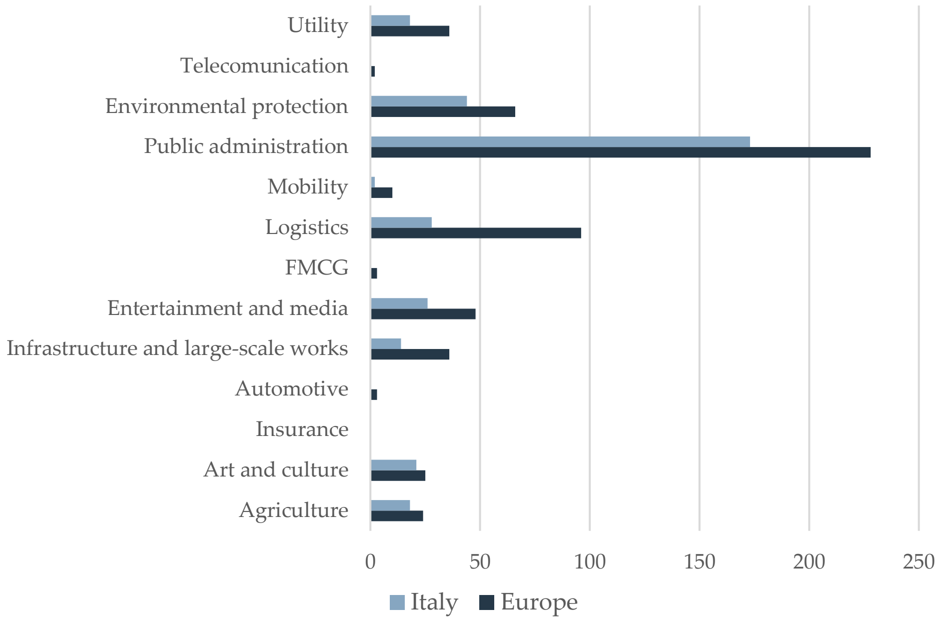
It can be seen from Graph 3.6 that most of the application cases are related to Europe. This may be a result of the innovative research being done in Europe, but also from the fact that it is certainly easier for Italian researchers to find information coming from both specialized and generalist Italian papers. This can also be confirmed by Graph 3.6 in which it is possible to see that most of the cases surveyed in Europe refer to Italian areas with a percentage of about 60%.

The exceptions in this case refer to the telecommunications, mobility, Fast Moving Consumer Goods (FMCG), and insurance sectors that find more application cases in America. Both mobility and FMCG refer to transportation, so it is possible that more stringent regulations are present in Europe due to the morphology of the territory. In America, in fact, there are vast sparsely populated areas where it is easier to conduct this type of activity. Also, for telecommunications more than 50% of the cases come from America, and probably the potential of this technology is still fully developed in Europe (Graph 3.6).



Graph 3.6: *Distribution of census cases (1,137) by macro sectors and continents*

Focusing instead on the distribution of application cases in Italy (Graph 3.7), on the other hand, it can be seen that no cases concerning the fast-moving consumer goods and telecommunications sectors were surveyed. While a significant percentage concerns public administration cases, which are almost 50%. Surely this result is also related to the fact that they are mostly one-time uses, so every time a drone is used in this area, a new news item is released, while when the use is operational, no news items are released constantly. These continuous uses, however, could easily lead to more constant use of technology in this area.



Graph 3.7: *Distribution of census cases (1,137) in Italy and Europe by macro sectors*

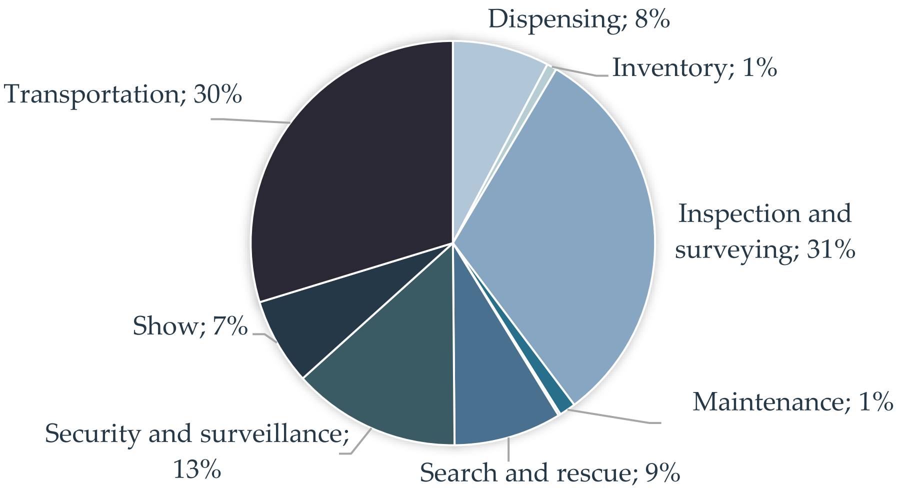
Once the analysis of macro sectors is finished, it is also important to focus attention on the application areas of the technology and the distribution of cases surveyed.

As can be seen from Graph 3.8, most of the news are concentrated in the areas of inspection and survey and transportation, with a greater percentage of 30%, as confirmed by the Literature review. The transportation category refers to both transportation of objects, postal packages, food, medicines and goods, and transport of people. Whereas inspections and surveying refer to various activities including infrastructure inspection, inspection after environmental disasters or incidents, monitoring and surveying, and mapping. These two areas are then followed by security and surveillance with 13% of cases surveyed. The remaining areas were studied with a percentage of less than 10% (Graph 3.8).

In fact, drone technology in the civil sector has been extensively used since its introduction with payloads such as cameras, cameras, and thermal imaging cameras that allow for top-down and 360-degree analysis of land and infrastructure. In fact, this confirms the wide use in inspection and survey and in security and surveillance.

Later starting in 2013, however, with Amazon's announcement that it would use drones for its core business, interest also shifted to using this technology for goods transportation services and only a few years ago to transport people as well [4].

The remaining application areas, on the other hand, involve more niche use of the technology related to more innovative and recent activities that deviate from the primary function of drones, which is why their distribution is more limited (Graph 3.8).



Graph 3.8: *Distribution of census cases (1,137) by areas*

It is interesting to understand for each macro sector which areas are most investigated based on the activities performed. As can be seen from Table 3.1, agriculture spans the areas of dispensing, mainly in materials release, and inspections and inspection with a focus on monitoring activities.

The cases related to art and culture, infrastructure and major works, environmental protection, and utilities are almost completely distributed in the inspection and survey activities. In particular, the arts and culture news refer to relief and mapping, while the cases in utilities and infrastructure and major works concern infrastructure inspections. Environmental protection, on the other hand, has broader applications, but mostly monitoring (Table 3.1).

In the entertainment and media sector, however, the cases censused are in the show field. Among them, it is possible to see a higher concentration for the activity of photo and video recording and the creation of air shows (Table 3.1).

On the other hand, in the areas of FMCG, logistics and mobility, the predominant activity is transportation. In FMCG it is transportation of food, in mobility it is transportation of people, while logistics includes transportation of postal packages, medical supplies, tools, etc. (Table 3.1).

The public administration sector shows cases distributed more evenly between inspections and surveying, search and rescue, and security and surveillance. Among inspections and surveying, a greater concentration can be seen in post-natural disaster or incident inspection and monitoring. Search and rescue cases, on the other hand, concern the search for people or first aid activities. Finally, security and surveillance extend predominantly into anti-Covid actions, due to the historical period and the inability to leave the house that has made this technology very useful. In addition, other widespread activities are also public surveillance actions, land and people safety and environmental, property and people protection (Table 3.1).

Macro sectors	Dispensing	Inspection& surveillance	Search& Rescue	Security& surveillance	Show	Transport
Agriculture	**39**	**22**				
Art and culture		**23**			4	1
Entertainment and media				5	**73**	2
Environmental protection	20	**112**	7	19		2
FMCG						**23**
Infrastructure and large-scale works	3	**53**		4		1
Logistics		2				**240**
Mobility						**53**
Public administration	18	**76**	**91**	**124**	2	10
Telecommunication	5	4				1
Utility	3	**61**		1		3
					Total	**1,137**

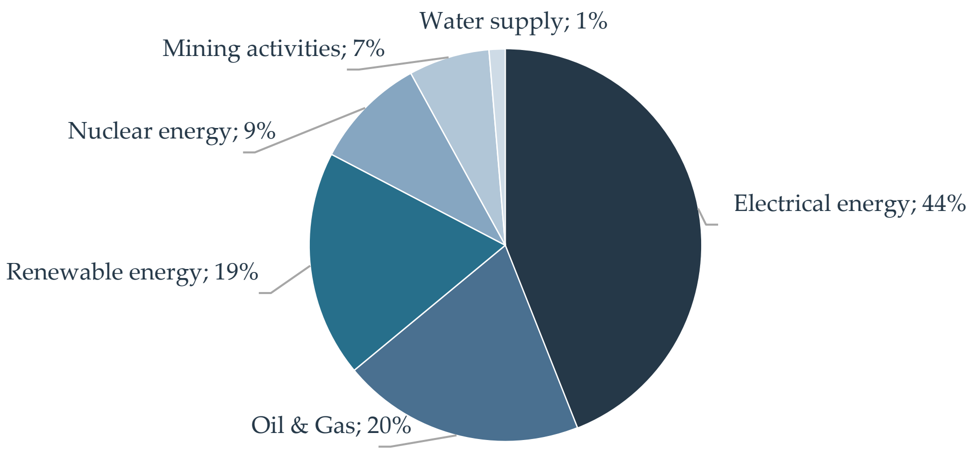
Table 3.1: *Distribution of census cases (1,137) by macro sectors and areas*

All the data analyzed in this section (RQ1: Main sectors and application areas of drone technology) are also present in the Appendix A (**Error! Reference source not found.**).

3.2 RQ1: Main applications in the utility sector

To answer the second research question, i.e. "What are the main applications in the utility sector", the census created through the application cases was again used. As already pointed out in the Objective and methodology for this part of the analysis, all application cases that did not contain the word "Utility" in the macro area field were eliminated.

The first thing that was investigated concerns the micro areas most dealt with in the utility sector. From Graph 3.9 it can be seen that the most investigated and observed area concerns the electricity sector with 44% of the 75 cases analyzed. In addition, the renewable energy sector (19%) and the oil&gas sector (20%) are also fairly investigated; while for the other sectors it can be seen that not many application cases were found. This suggests that it was certainly found beneficial to introduce drones within the most heavily investigated sectors. For the other sectors, it would seem that the use of UAVs is still an innovative discovery and therefore at the beginning of its evolution or in the worst-case scenario, although this is not expected to be the case, that they are not practical for the activities in which they are used. This does not appear to be a possible scenario because, even from what is apparent from the literature review, this technology brings so many benefits.

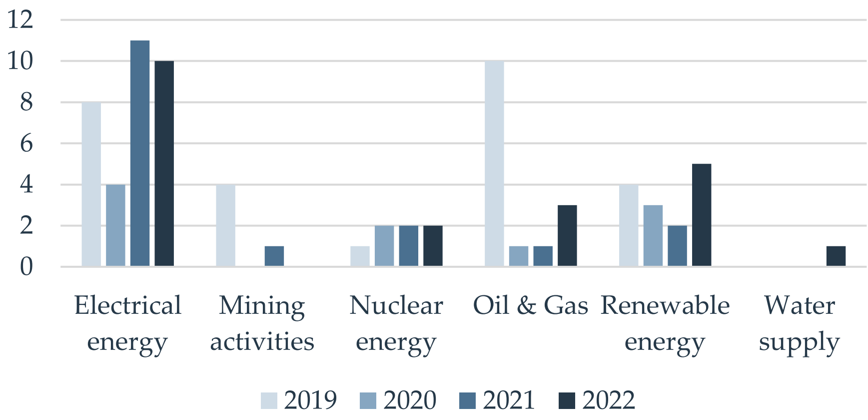


Graph 3.9: *Distribution of census utility cases (75) by micro-sectors*

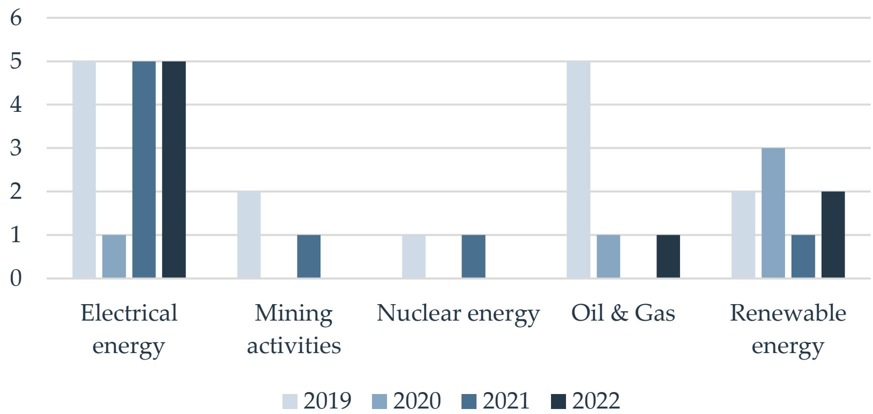
Going into even more detail, it is certainly useful to go and see if there are any trends among the micro-sectors evaluated.

In particular, it can be noticed that for the area related to electricity and the area related to renewables, there was a fairly constant value of articles between years both in terms of news in this area and articles related to experimentation. This could mean that in these two fields drones are a good element for the activities carried out and that it is certainly a field in which there is a lot of constant effort being made (Graph 3.10; Graph 3.11).

On the other hand, with regard to the oil&gas micro sector, it can be observed that in 2019 many articles were found and on the other hand in the following years there was practically no news (Graph 3.10; Graph 3.11).



Graph 3.10: *Census utility cases (75) by years and micro-sector*



Graph 3.11: *Census utility experimental cases by years and micro-sectors*

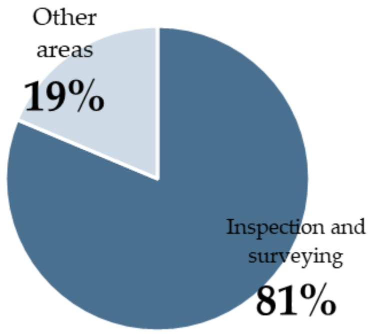
In terms of application areas, what to notice is that the activity that most interests the use of drones in this sector is that of inspections and surveys. In fact, it can be seen that 80% of the articles refer to this task while the remaining 20% are less covered areas, namely maintenance, transportation, dispensing, and security and surveillance (Graph 3.12; Graph 3.13).

It can be observed that the application of drones in areas other than inspection were found within the micro-sectors of greatest interest and thus electrical, renewables and oil&gas (Graph 3.13). What can be derived from this data is that probably in this sector the inspection activity is the one that can mainly be covered by drones and that once this comes to fruition perhaps further areas of development can begin to be considered in order to exploit the technology to its full potential.

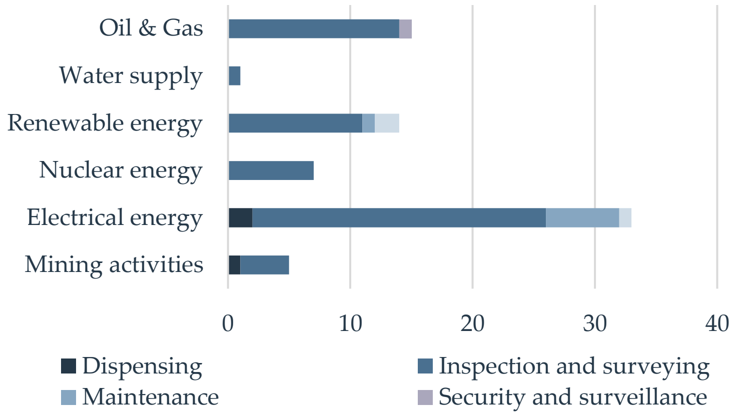
The second application area that follows the most covered concerns maintenance. This turns out to have enough importance within the micro-sector of electric power;

while, for the other fields the same cannot be said since no articles were found dealing with this application field (Graph 3.13).It is possible to expect that probably in the coming years this figure may increase, and application cases will increase especially if important benefits for this activity are found.

5.5



Graph 3.12: *Distribution of census utility cases (75) by most important areas and other*



Graph 3.13: *Distribution of census utility cases (75) by micro-sectors and areas*

It was also evaluated the time distribution of the various news items among the various years considered. The result is that in the area of inspections and surveying, the number of articles remains almost stable over the years except for the case of oils&gas in which many application cases were found in 2019 and then declined during the following years. For all other cases, a precise analysis cannot actually be made because no information with particular evidence was found (Table 3.2; Table 3.3).

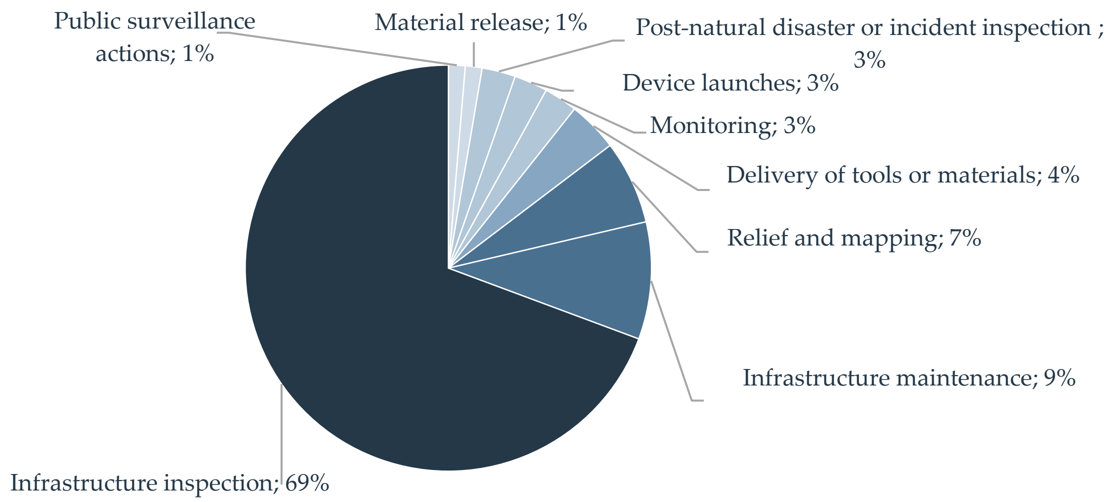
	Dispensing		**Inspection and surveying**			
	2019	**2022**	**2019**	**2020**	**2021**	**2022**
Mining activities	1		3		1	
Electrical energy		2	7	2	8	7
Nuclear energy			1	2	2	2
Renewable energy			4	2	2	3
Water supply						1
Oil & Gas			9	1	1	3

Table 3.2: *Census utility cases by some micro sectors and years pt.1*

	Maintenance				Security and surveillance	Transportation		
	2019	**2020**	**2021**	**2022**	**2019**	**2020**	**2021**	**2022**
Mining activities								
Electrical energy	1	2	2	1			1	
Nuclear energy								
Renewable energy				**1**		**1**		**1**
Water supply								
Oil & Gas					**1**			

Table 3.3: *Census utility cases by some micro sectors and years pt.2*

In particular, going into more detail about the areas, it can be seen that indeed the most performed activity turns out to be infrastructure inspection; out of 75 articles analyzed 52 turn out to deal with this task in the utility field, so the 69%, while the next area dealt with turns out to be infrastructure maintenance (9%) and finally relief and mapping (7%). The remaining areas, on the other hand, have an application rate below 5% (Graph 3.14).

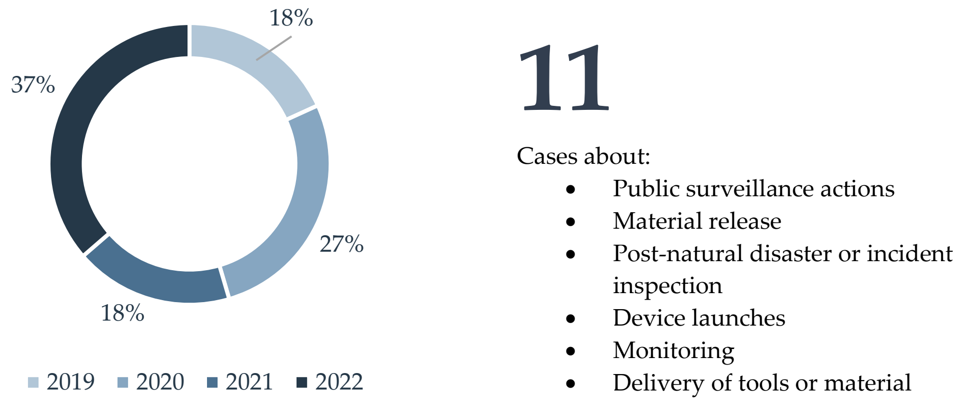


Graph 3.14: *Distribution of census utility cases (75) divided by activities*

In order to attempt to understand the reason why these areas are poorly treated, a focus was made on their temporal distribution. It can be observed that excluding the most investigated activities (illustrated above) there are only 11 cases treated during the four years considered. Of these, slightly less than half (37 %) were encountered in the last year. This could mean that in this area there could still be efforts to continue to investigate the feasibility of incorporating this new technology. Potentially this number should tend to increase over the years given that the technology is emerging and therefore not expected to have been thoroughly tested and applied in the past (Graph 3.15).

Furthermore, it can be noted that this data partly coincides with what was also mentioned in the Literature review inside the paragraph about the Analysis of literature review namely that, in the utility field, the most investigated activities were those related to maintenance and inspection.

With this information is therefore possible to conclude that in this area still there could be space for new experimentation in other application fields.

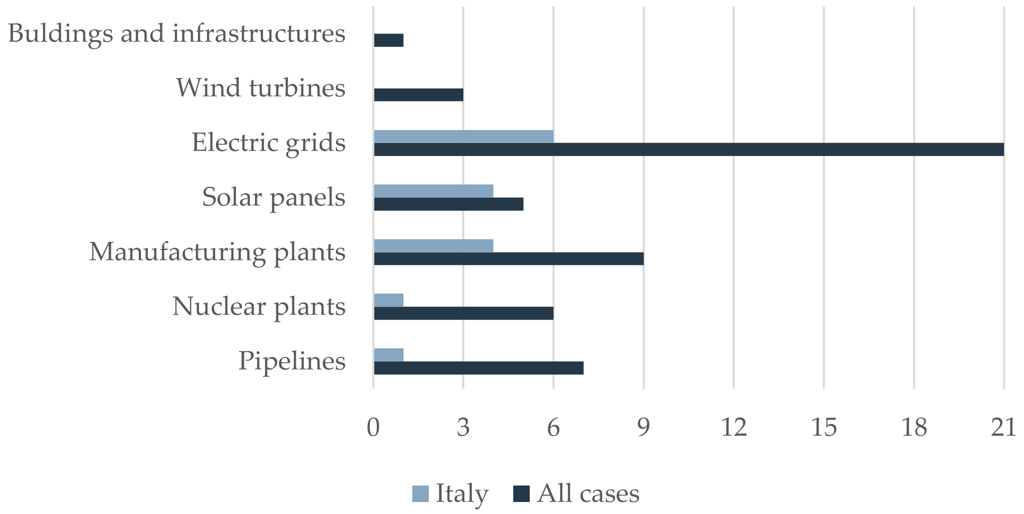


Graph 3.15*: Census utility cases about less used activities divided by years*

Finally, what is wanted to be investigated are the infrastructures that have been most inspected via drones in the utility sector. In this case, it is possible to note that, among the news found, there was a predominance of inspection on electric grids (41 %) but there were also many other facilities that were inspected through this technology. Specifically, the infrastructure that was found most were in order of importance: manufacturing plants (17 %), pipelines (14%), nuclear plants (12%), solar plants (10%) and wind turbines (6%) (Graph 3.16).

It was noted that the articles deal with different types of infrastructure, and this could mean that, as mentioned before, this activity may have already reached the mainstream or at least appears to be established within this sector. Also, from the Literature it is possible to note that all the resulting benefits lead companies to use this technology more and more, so probably the use of drones for infrastructure inspection brings very important benefits.

On the other hand, regarding the Italy side, let it be noted that the articles related to the inspection of electrical grids and production facilities turns out to be almost the same. With regard to other infrastructure, however, the situation appears to be different. In particular, no application cases were found dealing with wind turbines and few cases were found on pipelines and nuclear plants while many more articles were found on the inspection of solar plants. This might suggest that many companies are still very much attached to traditional methodologies, but as it will be possible to elaborate in the next chapter, the number of companies using UAVs for wind turbine inspections is not zero, but there are already cases that rely on this new technology. In fact, as anticipated, the census only refers to news reported from the year 2019, so it is possible that cases that introduced the technology previously to this time frame were not considered. However, it is important to note that there are no news reported on the wind field related to the last few years in Italy, making it an area of less interest to other companies in the sector (Graph 3.16).



Graph 3.16: *Census utility cases divided by infrastructure typology inspected and all cases and Italy*

3.3 RQ2: Benefits and criticalities of drones in the utility sector

This chapter will explore the benefits and critical issues related to the third research question, which investigates the benefits and critical issues of using drones to replace or flank traditional technologies for infrastructure inspection in the utility field.

As anticipated in the Objective and methodology chapter, to answer this research question, interviews were conducted with several companies in the industry that use drones for this activity. Summaries of these are outlined in Summary of interviews. Next, the results of the interviews separated into intangibles and tangibles will be analyzed. In Intangible analysis, the information that was classified as intangible is analyzed, while in Tangible analysis, tangible information, in terms of time and cost, is considered and cost models are analyzed.

3.3.1 Summary of interviews

This section presents a summary of interviews conducted with several utility companies that use drones for infrastructure inspection activities.

Of course, the sensitive data of the different companies have not been reported for a matter of confidentiality.

3.3.1.1 Case A – Electric grids

Company A, an electric power distribution company, is developing the use of drones for the inspection of power lines.

The interview discusses the introduction of drone technology for infrastructure inspection operations. The main motivation was to reduce costs per kilometer of inspected line and meet efficiency requirements imposed by the regulator.

The interviewee explains that before the introduction of drones, inspections were conducted by foot or helicopter. The inspections focused on assessing the physical condition of the poles or towers and the proximity of vegetation, as trees and plants can cause interruptions to the power lines. The company's goal was to find a more cost-effective and efficient way of conducting inspections. They want to reduce costs per kilometer of the inspected line and meet efficiency requirements imposed by the regulator.

The company initially planned to use a fixed-wing drone for inspections, but simulations revealed it was not suitable due to the terrain's steep gradients and the drone's inability to follow the terrain. Additionally, a fixed-wing drone flies too fast and requires a high-performance camera, which increases the payload weight. The team decided to switch to a multirotor drone due to its suitability for the task and payload capabilities. The drones could fly closer to the power lines and maneuver better in tight spaces than fixed-wing drones, making them a more appropriate choice. This technology was necessary for these inspections as the power lines are often situated in difficult terrain, making it risky for personnel.

Subsequently, the benefits of introducing technology are investigated.

The introduction of drones has significantly reduced the time required for infrastructure inspection. Previously, with a couple of operators, 2km per day could be inspected in mountainous regions, and 4km per day in flat areas. With helicopters, up to 150 km per day could be inspected. However, with drones, 9-11 km per day could be inspected, and up to 8 flights could be made per day. The entire infrastructure could be inspected in 2 years in mountainous areas and 1 year in flat areas without the use of drones, while it would take only a couple of months with a drone and a couple of operators. The saved time has allowed resources to be allocated to other company activities.

Another point discussed in the conversation is related to cost savings through the use of drone technology for inspections. The exact amount of savings is not provided, but it is mentioned that if helicopter inspections cost 100, 70% of it goes towards the helicopter flight while 30% goes towards image analysis. By using drones internally, the cost of helicopter flights can be reduced by approximately 50%, and after factoring in authorization, training, maintenance costs, etc., the remaining costs are related to data analysis, which requires external expertise.

The use of drones reduces risks associated with inspections in difficult and remote locations, where it may be necessary to send multiple people for emergency support.

"Drones also have a double parachute system for added safety"

The use of drones results in reduced environmental impact compared to helicopters, such as a reduction in CO_2 emissions. This is positively received by local communities due to the reduced noise pollution and social impact.

Then it is discussed the quality of data. During the inspection, the company collects data on the health status of their assets, including identifying any damage, deformities, or deterioration in the physical structure of poles or towers. They also analyze the proximity of vegetation to the infrastructure to prevent any potential damage that could occur. In particular, drones enable the collection of information that was previously difficult or impossible to acquire, such as identifying infrastructure damage or leaks in advance, providing a significant advantage to the company.

The company has noticed significant improvements in the quality and accuracy of the data acquired through drones compared to previous technologies. They have conducted tests to verify that the quality of the data, including photos and LiDAR, is compatible with the needs of their analysis. They have also received feedback from another company.

The company has attempted to use more sophisticated techniques, such as data analytics and image recognition, but they are still far from achieving the necessary level of precision to identify specific damages. Additionally, they require a large number of images, and there is currently a lack of a database to support such efforts.

During the interview, several criticalities related to use of drones for infrastructure inspections are discussed. Firstly, the interviewee explained the administrative process of obtaining specific authorizations from regulatory authorities, such as

ENAC. They mentioned that this process was not easy and that previous guidelines published by ENAC were not applicable to their context. However, a new European regulation was published in December 2020, which allowed them to perform inspections at higher altitudes and in less populated areas.

Then the interviewee is asked about the impact of weather conditions on the collection of images and videos. They explained that it is a specialized field that requires constant updating of technical skills, and that bad weather can limit the use of drones. This can lead to difficulties in keeping personnel trained and available for drone-related activities.

Lastly, the interviewee discussed the battery life of drones and how it affects the duration of inspections. They stated that battery life was not a limiting factor in their experimentation, and they were able to fly long distances with a good margin of battery life left. However, increasing the capacity of batteries would not allow them to cover longer distances due to limitations in the remote control's range.

3.3.1.2 Case B – Electric grids

This interview is about an electric power distribution company that uses the drone for the inspections of electric grid.

Before introducing drones, the company used different methods for inspecting power lines based on their voltage. For high voltage lines, inspections were done using a combination of helicopters, vehicles, and walking inspections with expensive thermal cameras that had zoom capabilities. For inaccessible areas, colleagues were equipped with binoculars and pickup trucks. In medium voltage lines, inspections were only done on foot. The use of helicopters for high voltage lines has decreased in recent years and is expected to be phased out in favor of drones, which are more cost-effective.

Drones are used to verify and inspect the alerts, as well as other sources of alerts, such as operator reports, but they are used also for cyclic inspections. The use of drones has enabled them to move from event-based inspections to predictive inspections.

The introduction of drones was driven by the need to speed up inspection operations and improve their quality, as walking inspections can miss things and only provide a limited view. In addition, the cost of drones has decreased while the quality has increased over time. Using drones also avoids traditional operators having to walk in difficult terrain, such as through plowed fields, thus increasing safety. The use of new technologies such as drones has transformed the inspection process and made it more efficient, safe, sustainable, and frequent.

The success of the new process also relies on the digitalization and integration of legacy systems. The process was developed through a gradual prototyping and experimentation approach, which allowed for operator feedback and optimization. Overall, the integration of new technologies and careful digitalization of the process have resulted in a more efficient and effective inspection process.

The interviewee explains that they use various types of drones and payloads depending on the scenario. For classic inspections, they use drones weighing around 1300-1400 grams with 4K cameras and high-definition thermal cameras. In more covered areas, they use slightly larger drones, such as the DJI M30T, which has a powerful zoom. In urban areas, they use drones below 150 grams, such as the Mavic Mini, which is harmless and follows regulations. For open areas, they use Autel Evo Dual Enterprise with proximity sensors and excellent thermal cameras, especially for high voltage inspections. They also use fixed-wing drones, such as SenseFly, for high-precision photogrammetric surveys.

The benefits they have gained through the introduction of technology have been discussed.

The speaker explains that prior to the introduction of drones, inspections of the complex were done by foot, focusing on specific areas, and requiring multiple visits. However, after the introduction of drones, inspections became more efficient, with a time savings of 1/5, improved sustainability, higher quality inspections with close-up high-resolution photos, and better documentation and archiving of data. The process of archiving data is semi-automated, with mass uploading but manual analysis of individual photos for accurate recognition. The speaker also notes that drones are necessary for more detailed inspections.

Moreover, the introduction of drones has improved efficiency, sustainability, and the quality of inspections. Efficiency has improved by approximately 1/5 compared to inspections done on foot. There has been also a slight reduction in logistics costs due to fewer movements of machines, but not a significant amount because there are still costs associated with transporting the drones to the inspection site.

Sustainability has also improved due to reduced emissions from vehicles and the use of solar panels on inspection vehicles to charge drone batteries. Drones are now being charged using solar panels installed on the roof of the operators' vehicles, eliminating the need for diesel generators. The batteries are charged and discharged as needed, and the system has the ability to store and discharge up to 70-80% of the energy.

Then the interview focus on criticalities of the UAVs.

The interviewee discusses the regulations related to drone flights, stating that the VLOS regulations have been favorable for drone inspections, allowing flights up to 700-800 meters. With BVLOS, the regulations are more stringent, requiring authorization from ENAC and limiting flights to certain distances. The interviewee also mentions that there is a lengthy process of obtaining authorization from ENAC for BVLOS flights.

The speaker explains that currently, batteries are a limit for drones because they cannot be charged in-flight. However, if in the future a drone with a 4-hour flight time were to be developed, it would be comparable to the autonomy of a helicopter. However, it is important to point out that this limitation is currently overcome by recharging the batteries directly at the inspection site also thanks to the solar panels mounted on the machines. The goal for the next year is to set up a charging station with a charging box that allows the drone to take off and fly programmed or manually guided sections of the power line. The speaker also notes that the technology is available, but regulatory authorization is needed.

The interviewee discusses the impact of weather conditions on their operations. With drones, excessive wind can be a problem, but modern drones can fly in winds of up to 35-40 km/h. Rain is not a significant issue because brushless motors are not affected by water droplets, although sensors can get dirty. However, they have not experienced any significant weather-related problems and were able to operate even in light rain.

3.3.1.3 Case C – Pipelines

Company C is a gas distribution company that has introduced drones for pipelines inspection.

Before the introduction of drones, inspection activities were conducted using traditional methods such as helicopters or personnel performing these activities in cramped and dangerous places. However, these methods posed safety risks and were costly. Drones were introduced to address these issues, allowing for safer and more cost-effective inspections.

One significant advantage of using drones for inspection is the quality of data collected. With traditional methods, inspectors could only obtain a partial view of the asset being inspected. In contrast, drones can provide a comprehensive view of the assets and automate repeatable flights for more accurate data collection. This feature can be particularly useful in industrial settings where inspections need to be carried out repeatedly.

Using drones for inspections of utility pipelines and other infrastructure also provides significant cost savings. In the past, helicopters were often used for such inspections, which were more expensive and less precise. Drones can perform the same inspections at a lower cost and with more accurate data collection.

Overall, the use of drones for inspections has revolutionized the industry by providing safer, more cost-effective, and higher-quality data collection.

For doing these types of activities, the drones used by the company are typically quadcopters or octocopters from brands such as DJI and Falconate. Payloads include thermal cameras for inspections, multispectral cameras for agricultural monitoring, and lasers for detecting emissions. The use of fixed-wing drones is less common due to the need for additional authorizations and the time required to obtain them.

Subsequently, the focus of the interview shifted to the benefits gained from the introduction of technology.

In terms of time savings, the use of drones can result in a reduction of about 1 to 4 times the amount of time required for traditional inspection activities, although this can vary depending on the specific case. The frequency of inspections depends on the type of activity being carried out. For some industrial assets, inspections may only be required once a year, while in other cases, more frequent inspections may be necessary. In the case of pipeline inspections, the frequency before and after the introduction of the new technology remains the same. Moreover, the use of drones has allowed for more efficient use of time, which can be used to conduct more in-depth analyses and qualitative assessments that would not be possible otherwise. Rather than reallocating personnel to other activities, the time savings can be used to optimize their time and improve the overall quality of the work being done.

Speaking instead of cost savings, it is clear that this was not one of the main points the company considered when introducing UAVs, but it still stated that there are significant savings present compared to using the helicopter for this type of activity.

The benefits of using drones go beyond time savings and include safety and environmental considerations. From an environmental perspective, the use of drones can help reduce the impact of leaks and spills on the ground and can help reduce the costs of cleaning up and repairing infrastructure. Drones also generate less noise and emit fewer emissions compared to traditional inspection methods such as helicopters or trucks.

In terms of safety, drones can reach difficult and dangerous locations without risking the safety of personnel. Drones can also increase the area that can be inspected, as they can access areas that were previously inaccessible to personnel.

Overall, the use of drones in inspections provides benefits in terms of safety, environmental impact, and efficiency. The technology allows for more efficient and effective inspections while reducing risks to personnel and minimizing the impact on the environment.

Another important advantage that is studied during the interview is the quality of data. The use of drones for asset inspections allows for more comprehensive and accurate information to be gathered compared to traditional methods. With drones, a 360° view of the asset can be obtained, and a 3D mapping can be created for easy access to information and comparison over time. Anomalies and deteriorations can be detected much faster allowing for proactive maintenance planning and resulting in significant economic benefits.

The approach taken for the analysis of data depends on the specific requirements of the inspection. The use of a database or platform for data processing depends on the type of activity. The role of humans is still important in generating reports and making decisions, but the use of artificial intelligence may also be considered in some situations, such as corrosion analysis.

Regarding the limitations of using drones in industrial inspections, the need for regulatory authorizations depends on the location of the industrial sites. In some cases, the company needs to ask for permission, while in others, it doesn't. Moreover, the company primarily operates in visual line of sight (VLOS) mode but has also conducted experimental beyond visual line of sight (BVLOS) operations, which are subject to more stringent authorization requirements, particularly in more urbanized areas such as Italy. The use of BVLOS mode may be easier in less populated areas.

The weather conditions can also affect drone usage, but the company tries to work around this by rescheduling flights when necessary. Most drones are also able to fly in some wind or light rain, but this definitely goes to lower the quality of the data being collected.

"I never remember an activity that was cancelled because it was raining or because it was windy; it was postponed maybe by a few hours."

Battery life is not a significant issue as the company carries spares. However, there are limitations with importing equipment into different countries, such as customs regulations.

Finally, the need for specialized personnel or training depends on the case. The company decided to develop in-house know-how by training its staff, and for now it is not necessary to hire specialized personnel.

3.3.1.4 Case D – Solar panels

This interview regards an energy company for the distribution of solar energy that uses drones for infrastructure inspections, in particular for solar panels.

This company has always used manual inspections with thermographic cameras as the traditional method of performing surveys, but the time allocated to the activity was really a lot.

The speaker explains that their company has decided to use DJI drones, because of their market-leading position, with thermal cameras. They may also use RTK modules to ensure precise flight paths, especially when creating industrial-grade images for inspection purposes. Output from inspections include thermal maps, 3D models of infrastructure, and reports on anomalies and malfunctions.

By using drones, the company was able to allocate people to more valuable activities, as drones could perform inspections faster and more efficiently than humans. With traditional methodology in fact, it used to take about 5/6 hours to do 1 MW of thermography, while with the use of UAVs it is possible to do the same amount in half an hour. Moreover, they have doubled the frequency of inspections, with two termographies per year for solar infrastructure.

This led to a reduction in labor-intensive work and allowed for more time for other activities. The company has increased the allocation of people on value-added activities by at least 50% and up to 300/400% for thermography inspections.

Then it discusses the cost savings achieved by the implementation of drone technology in the inspection operations of a company. While there is no precise data available, the company estimates a 30% reduction in costs for inspections, with a 2% improvement in production.

Additionally, the interviewee discusses the expansion of inspection areas and improved safety resulting from the use of drone technology in the renewable energy industry. Drones allow for expanded observation areas and easier access to difficult locations, reducing the risk of injury for workers.

The use of drones also led to cost savings and improved identification of anomalies in the infrastructure. Overall, drones provided a clearer and more comprehensive view of the infrastructure, which allowed the company to optimize production and reduce failures. This is due to better data quality and accuracy of the images.

With regard to environmental impact, this is not the greatest of the benefits gained from the new technology, but it has still had a slight improvement due to the reduction in CO_2 associated with less machine use.

The criticalities of the new technology are discussed.

First of all, the interviewee discusses their use of drones for infrastructure inspections and the regulatory challenges they face in obtaining authorizations from ENAC. They have signed an agreement with ENAC to use drones for video surveillance purposes, subject to current regulations. However, they have mentioned that this process is more difficult in some particular areas and in some cases it is long.

Regarding the impact of weather conditions, the speaker says that they plan inspections accordingly and do not fly drones in the rain. They also mention the effects of climate change on the use of drones, particularly in relation to thermography of solar panels.

Regarding the battery of UAVs, they carry spare batteries for longer inspections and so, it is not a limitation.

Finally, they have trained their staff in drone operation, opting for a cross-functional approach rather than specializing in one role. The interviewee emphasizes the importance of training and adaptation to keep up with technology changes and to optimize resource management.

3.3.1.5 Case E – Wind turbines

Company E, a wind power distribution company, is developing the use of drones for the inspection of wind turbines.

Previously, wind turbine inspection activities were carried out manually by operators directly from the ground. The big problem with this type of inspection was that it was not possible to have a 360-degree view of the inspected infrastructure, and so this penalized the analysis.

The company relies more on DJI drones equipped with integrated cameras that enable it to obtain excellent images. Data collection is enabled by algorithms that are built into the technology and allow detailed examinations even with the use of artificial intelligence.

The company began experimenting with drones in 2018 to perform tasks and quickly realized the time-saving and cost-saving benefits of using drones for inspections. By using drones, the company has been able to allocate more time to value-added activities and reduce the time spent on manual inspections.

Regarding the time it takes to inspect the entire infrastructure complex with and without drones, they estimated that drones can complete a full inspection in 45 minutes per turbine compared to the previous time of 2 hours.

The company also mentioned that drones have increased the frequency of inspections, with two inspections per year for wind turbines. The use of drones has allowed for a 50% reduction in the time required for inspections, allowing for the allocation of personnel for value-added activities.

Additionally, using drones has improved safety and reduced risk exposure. The interviewee emphasizes that drones have greatly reduced the risks associated with traditional inspection methods, such as climbing to the top of wind turbines, which requires double harnessing and increases the risk of injury. So, the use of drones has greatly improved safety and accessibility in the renewable energy inspection industry.

Moreover, UAVs allow for a clearer identification of anomalies. The use of drones has also enabled the company to optimize production and reduce equipment failures. This is also connected to the reduction of costs that are not only on the operational side, but also in the effectiveness.

CO_2 reduction was also a benefit of the technology. Although not much investigated and not very significant in terms of quantity, respondents say there was an environmental benefit.

The interviewee also discusses the improvements in image and data quality and accuracy achieved through the use of drones for inspections. With drones, each photo has its own metadata, making it easier to organize and analyze data. The use of artificial intelligence allows for clustering of data points and provides more information. The goal is to have an integrated structure for data analysis.

These are the main motivations for the introduction of the new technology.

In this interview, the speaker also discusses the challenges for using of drones for infrastructure inspections.

They mention that they have daily communication with ENAC, the regulatory body, to obtain necessary authorizations for using drones. The speaker notes that bureaucratic procedures and outdated regulations can hinder the use of drones.

They also mention the impact of climate change on their drone operations, which can affect the planning and duration of inspections.

Regarding the battery life of drones, the speaker notes that, in some cases, even if they have to change the battery during the inspection the duration is not a big problem and can be managed.

Finally, the speaker discusses the training of personnel for drone inspections. They have trained all their employees rather than creating a specialized team, so that everyone can raise their level of knowledge and contribute to the company's growth.

3.3.1.6 Case F – Solar panels

As for this interview, it is about a company that is focused on energy production and services and uses drones for inspections of photovoltaic systems.

Previously, inspections of solar panels were performed on foot by operators directly inspecting the infrastructure, while now they are performed through the use of drones equipped with thermal cameras. The types of drones used for this activity are very diverse, and among them is DJI Matrice 300 drone.

The motivations behind the introduction of UAVs are related to efficiency. With regard to time reduction, the time saved in conducting this activity translates into more frequent inspection of the infrastructure being considered and thus better monitoring of it. For solar panels, drone inspections completed in four hours covered the same amount of work that previously required two or two and a half days of manual inspections. However, the frequency of inspections has remained the same, although the lower cost of drone inspections may encourage more frequent inspections. The speaker also suggests that ad hoc inspection requests are now occurring more frequently, although no data is available to confirm this. Finally, the speaker notes that drone inspections are becoming increasingly common in the context of maintenance inspections of power plants.

This reduction in time and cost also allowed people's time to be allocated to other value-added activities. It is important to note that most of the personnel who are used for drone inspection are internal people in the company who are formed through a training course to carry out this activity. It is therefore an investment for the company that is nevertheless covered by the reduction in costs compared to traditional methodologies.

In addition, the use of drones also allows humans to avoid going to particularly dangerous or inaccessible areas and thus decrease the risk associated with accidents. Additionally, using drones can reduce the number of personnel needed for a job and minimize the risk of accidents, leading to cost savings. The economic savings are primarily attributed to the reduction in labor costs and downtime for the equipment being inspected or serviced. Overall, the use of drones for inspections is becoming more common and accepted.

It is also important to note that the company has not done any analysis for the time being with regard to improving environmental impact because it was not a core concept for the introduction of the technology.

Then there are addressed some challenges about the introduction of drones.

The use of drones is subject to regulations, which can be complex, but training for pilots is not overly burdensome for open spaces The speaker explains that restrictions on flight zones could present challenges, but these have not been a major issue for the facilities. The company is also exploring the potential benefits of increased automation for drone flights, particularly for inspecting linear infrastructures, but their current operations involve inspecting relatively small sites.

Then the speaker discusses the potential impact of weather conditions. The use of drones can also be limited for outdoor inspections that require optimal conditions. For many of these inspections, adverse weather is a problem even if drone is not used because thermography on a photovoltaic system has to be done in the sun otherwise the system doesn't work and doesn't see anything significant. In this case the limitation is not related to the type of technology used, but to the type of inspection itself. In most cases the operation is simply reprogrammed.

As far as batteries are concerned, however, battery life does not turn out to be an issue. Since inspections have to be carried out in the open and the pilot has to follow the points of interest, the battery change is often also for the pilot to rest.

3.3.1.7 Case G – Wind turbines

This is an energy company, uses drones for infrastructure inspections in the areas of energy production and services for industrial customers. The company focuses on renewable and traditional energy production assets, including wind power plants.

The method previously used to inspect these infrastructures is manual, that is, inspections done in the field directly by the operators even climbing on the wind turbines. The difficulty of this activity has pushed the company toward new technologies such as drones. Different types of drones and payloads are used, such as visual cameras, to detect anomalies, monitor the condition of wind turbines, and perform maintenance activities.

The advantages of using drones are numerous, including saving time and increasing safety. Drones can be used to inspect hard-to-reach areas, such as the top of a wind turbine, which would otherwise require a human to climb. This results in significantly less time spent on inspections and lower safety risks. In addition, the use of drones allows operators to no longer have to climb on the turbines for inspection, but to do it directly from the ground, and this greatly reduces the risk of accidents. Overall, using drones for inspections can lead to increased efficiency, cost savings, and improved safety.

There are other economic benefits of using drones for various activities such as inspections. The first level of benefit is the cost-saving of avoiding the need for a third-party provider, which is quickly offset by the investment in training. The second level is the time-saving achieved by using drones, which can be done in a few hours compared to a few days of manual inspection. The third level considers the impact of these inspections on avoiding damages or breakdowns, and the fourth level is the reduction in the risk of accidents and the resulting cost to the company. The use of drones also allows for fewer people to be allocated to inspections, and the time saved can be used for other tasks. However, there is still a need for specialized personnel to operate the drones, but this can be offset by the increased efficiency in operations.

The persons who are no longer allocated to traditional inspection activities can be used for value-added activities. These individuals may be either internal or external resources and typically dedicate a portion of their time to inspection activities each year while also focusing on other value-added activities. The use of technology can facilitate the internalization of some activities, allowing personnel to be more efficient and potentially reducing the need for external resources. The organization uses a mix of internal and external resources, including trained personnel, to support its activities.

Moreover, there can be environmental benefits of using drones for inspections. If certain activities were not being done before, there may not be a benefit to the environment. However, reducing downtime for renewable energy sources like wind turbines can be beneficial, but this is not investigated by the company.

Subsequently, the critical issues of using drones were considered.

First and foremost, the regulations, which in any case do not seem to be a limitation for companies since inspections do not take place in enclosed spaces and it is therefore easier to obtain permits. For the same reason, the personnel conducting this activity also do not need to be highly specialized, so the initial investment is not expensive.

Weather conditions for drone inspections, on the other hand, cannot be considered a limitation. Even with traditional methodology, when bad weather was present, the activity was suspended and rescheduled because it was still very particular to have people climb on the turbines. With drones this risk is not present, but rain or wind would lead to inaccurate images, so it is preferred to postpone the operation.

Batteries are also not a real limitation as very often it is not even necessary to change the drone batteries during an inspection of a wind park. On the other hand, when the UAVs power supply is insufficient the battery is easily replaced, and the activity resumed.

3.3.1.8 Case H – Pipelines

The company H is a natural gas transportation and storage company that has introduced drones for periodic inspection of its infrastructure.

At the beginning of the interview the motivations behind the introduction of UAVs for infrastructure inspection are discussed. It is important to say that the use of drones has not changed the nature of the activity, which involves the periodic inspection of the area surrounding the pipelines that are off-limits to certain activities. Previously, the inspection was done by foot, car, or by helicopter, which covered a significant portion of the infrastructure. There is an external helicopter service that flies over an important part (from ½ to 2/3) of the 'infrastructure supplementing with top view the other types of controls.

Drones have been introduced to make the inspection more efficient, safer, and to provide a more detailed view of the infrastructure. This has helped in accessing difficult areas and documenting issues more accurately. Methane pipelines, in fact, being at high pressure are placed in uncomfortable areas to prevent people from getting too close, however, this makes inspections much more difficult. This new technology offers multiple angles for a more in-depth analysis of the infrastructure. The drones have also been helpful in analyzing and interpreting ground movements in unstable areas. Company H has added a new tool to its inspection methods to make it easier and safer for its workers to do their jobs.

During the conversation, the speaker talks about the drones that its company has decided to introduce. They have a fleet of DJI Mavic 2 drones with high-resolution cameras that are used for operations in heavily populated areas. Therefore, they are looking to introduce the Mavic 2 Advance with additional sensors for photogrammetry to measure the movement of the terrain. The company currently uses only multicopters, as they require drones that fly in VLOS, which are more flexible and lightweight.

Then interviewer discusses the advantages of using drones for inspection purposes, such as cost and time reduction and increased safety.

The frequency of inspections remains the same, but the time saved through drone inspections allows human resources to be used in other business activities.

Furthermore, the company saves time and cost by preventing potential problems within their areas of operation. For instance, contesting a third-party property's improper activity within the service area would require significant resources. By using drones, the company can prevent such issues from arising, saving them from incurring more costs. Therefore, the focus should not be on the number of hours saved, but on the overall benefits that drone technology provides.

It is important to note that several times interviewees focus attention not on efficiency, in terms of monetary savings, but rather on the effectiveness of using drones that leads to observing details that they were not able to achieve with other technologies.

The interviewee focuses on the quality and accuracy of the data collected during inspections using drones. Currently, the type of output generated is photos and videos of possible evidence of interference. In the future, the aim is to create digital reconstructions of the slopes under study that are affected by slow movements of the terrain. This will enable the correlation of data collected from instrumented pipelines with what a geologist observes when inspecting the slope. The creation of digital models that can be observed from various angles will enable the measurement of zones of deviation and improve the interpretation of data. The use of drones can offer potential benefits, including the ability to acquire information that was previously difficult or impossible to acquire, such as recognizing damage to infrastructure or leaks with greater anticipation. The drones also allow for the collection of data on any activity occurring near the pipelines, which can have an impact on their operation. For example, drones can detect signs of human activity near pipelines and help to determine the type of activity and its impact on the infrastructure. This information is useful for ensuring compliance with regulations, maintaining safety, and creating a database of threats to the infrastructure that can be used for analysis and prediction of future issues.

Moreover, the use of drones instead of traditional methods such as helicopters or ground vehicles can potentially have a positive impact on the environment. UAVs are smaller and more efficient than helicopters. Moreover, they are powered by batteries rather than fossil fuels may have even lower emissions. Overall, the use of drones has the potential to reduce the environmental impact of certain industries, such as oil and gas, by minimizing the need for workers to travel to and from job sites.

Regarding the criticalities, the first theme that is discussed is the regulations. The use of drones for infrastructure inspections requires specific authorizations from regulatory agencies. Regulations can vary between different countries, and compliance is essential. The company is experimenting with BVLOS flights and plans to adopt them in the future. The main challenge for them is not the technological aspects but rather defining and adhering to the still-developing regulations while also meeting their specific use cases.

Moreover, weather conditions can also impact drone operations, and in adverse conditions, traditional inspection methods may be used instead. Rain affects drones more than wind, but overall, the impact on industrial output is minimal.

As far as batteries are concerned, they are not a big limitation since it is possible to change them during the inspection. Replacing them, however, turns out to be a non-value-added activity. It is also true that if they had a longer life, and therefore did not need to be changed, however, the current regulations would not allow me to inspect long distances. For now, durability of batteries is not a critical factor.

3.3.1.9 Case I – Solar panels

In this case, a power distribution company was interviewed. Specifically, this enterprise uses external drones, i.e., provided by third parties, that inspect photovoltaic systems.

The Interviewee discusses the use of UAVs' thermal imaging for inspecting solar power plants.

In the past, thermal imaging was only used in certain situations, such as when there were significant problems with the panels, and inspections were done manually by an operator passing panel by panel. However, with the use of drones, thermal imaging inspections can be done more efficiently, allowing for repeatable and historical data to be collected. This has resulted in significant time and cost savings compared to manual inspections. The use of drones for thermal inspections provides a high-quality image that can be analyzed quickly using software. Overall, the technology has significantly improved the efficiency and accuracy of inspections, resulting in cost savings and improved maintenance for solar power plants.

They mention using third-party services for photovoltaic inspections and using drones with a payload that includes a camera and a thermal camera for inspections. The drones used typically weigh over 600g and require permits and authorizations to operate. The company notes that while drones are useful for pinpoint inspections, covering a vast area can still be challenging. The main focus of development is on automatic analysis of the collected data. The main challenge in using drones is not in acquiring images but in analyzing them quickly and efficiently.

They have currently contracted external services for these inspections but anticipate increasing internalization of the activity in the future, particularly for outdoor emergencies after major weather events. The speaker believes that drones are not the most cost-effective solution for inspecting photovoltaic installations due to their current infrequent use and the need for specific personnel to operate them. However, they do not rule out the possibility of using drones equipped with cameras for visual and thermal inspection in the future because they want to increase a lot the frequency for a better monitoring of infrastructure. The speaker also notes the importance of post-processing data and analytics in drone inspections, which are currently outsourced to external services.

Then it was discussed the use of technology to improve the efficiency and speed of inspections for solar panel. The use of drones for thermal imaging has significantly reduced the time it takes to inspect solar panel systems, from one or two days to half a day or less. The cost reduction from these methods has allowed for more frequent inspections, allowing for preventative measures to be taken and reducing the need for costly spot inspections. So, instead of doing inspections only in case of evident anomalies, now they are inspected approximately once a year for general maintenance purposes.

One of the biggest benefits of the introduction of the technology is definitely related to the safety of the operators. Although the company claims that the number of injuries already with the previous methodology was tending to zero, thanks to UAVs it is possible to greatly reduce the risk of accidents.

It is important to say that the environmental benefits of these inspections have not been quantified, so the introduction of this technology is not related to an environmental need.

Then, the criticalities are discussed.

In terms of regulations, it is not the responsibility of the company due to the presence of external contracts for using drones. However, for photovoltaic systems in open areas, it is necessary to notify and request authorization from the relevant authorities.

Regarding weather conditions, it can be a critical issue for thermography inspections because there must be a minimum level of solar irradiation for the inspection to be certified and to produce accurate results. However, this is not a limit only with drone but also with manual inspections with thermal cameras.

Battery life is also not a big issue for the company since it is possible to recharge them or do a replacement battery during long inspections.

As for staff training, however, it has not been received since it is an external service.

3.3.1.10 Case J – Solar panels

Company J is a company recently formed and it is comprised of renewables. It builds large solar power plants, and their own branch, which focuses on building solar power systems for businesses to use for self-consumption. The particularity of this company is that it uses external drones for a third company.

The interviewee mainly works on constructing large photovoltaic systems on buildings or land for company self-consumption. The company has seen significant growth in these years. They have two categories of solar power systems: medium-small systems that do not require a drone for maintenance and larger systems that are currently being built and may require drone maintenance.

They have only used drones twice so far, once for commercial reasons and once to verify the layout of a building before installing solar panels and so the discrepancies for a large project. The interviewee also highlights the importance of accurate layout measurements due to fire safety regulations and the need to maintain the company's production guarantees for customers.

In the future, they plan to use thermography during system testing to identify issues from day one.

Previously, activities were done manually and the main motivations for using drones are related to safety reasons and on the accuracy of the data that they can acquire with UAVs.

The speaker explains that their company does not have an internal drone, but rather outsources drone services. The drones used are medium-range and cost varies. The marketing department used drones for filming, which cost approximately €500 for two days, but the post-production costs were high. For inspections, the speaker uses a package that costs around €1,000, which covers the drone flight, a day's work, and the creation of a DVG. Maintenance costs for drone usage were around €500.

Then, the speaker discusses the advantages of using drones in their company's operations, compared to manual labor.

Drones allow for a faster and more accurate collection of measurements, resulting in time and cost savings. For this, the company has been able to allocate resources to more value-added activities by using drones for inspection and data collection. This has allowed them to send specialized workers to specific jobs, rather than having them conduct general inspections. The data collected by the drones is processed by external contractors, which reduces the need for on-site workers. Previously, the company used a sampling method for inspections, which required more workers to be sent to job sites for longer periods of time. By using drones, the company has been able to reduce the number of workers needed for inspections and allocate their resources more efficiently.

The quality of the information gathered is also higher, with more details visible from the drone's aerial perspective and the margin of error is lower. The speaker mentions that even important companies have poor drawings of their roofs, which can be misleading, and drones can provide additional information on the state of the roof.

In terms of data collection, drones allow for easier measurements. Additionally, the speaker notes that the drone's data can be used for future inspections and analysis, and is more reliable than manual measurements.

In terms of data collection, drones allow for easier measurements, and the information obtained is more reliable and easier to analyze than when done manually.

Overall, the use of a drone allows for easier and more accurate measurements and inspections, which can save time and provide more detailed information.

Another advantage of using drones is that they can reduce the risks associated with sending people in dangerous situations. For example, sending a person to a difficult-to-reach rooftop can be risky and challenging to retrieve someone if they become injured. Drones provide a safer alternative for collecting data or assessing safety in challenging locations, minimizing risks to human operators.

Drones can also collect data and images that can be processed post-inspection to provide more detailed information about the building. The data collected by drones is usually processed by a third party, but the company can use it for marketing purposes.

Additionally, using drones can reduce the environmental impact of building inspections by reducing the need for travel and transportation. Overall, drones can provide significant economic, time, and environmental benefits in building inspections.

Summarizing, the main needs that led to the introduction of the drone were better quality, greater safety, and time savings. The economic savings come from the savings in time, and it is difficult to quantify the fact that resources are being used elsewhere instead of being used on a difficult or dangerous project. Safety and quality are essential, and using a drone can provide more details in less time. The cost of the drone and its use is only 1500 euros, which is negligible compared to the cost of multi-million-euro projects.

Moreover, the use of external drones has allowed the company to avoid specific regulatory authorizations by sending a flight plan and obtaining permission to fly in a specific area. While some companies require additional documentation, no restrictions or specific instructions have been given.

Weather conditions have been a limitation, with the drone unable to fly in heavy rain, but this is not a significant issue since sending a person to a rooftop in similar weather conditions would also be dangerous.

Battery life has not been a problem in the three cases where drones were used. There isn't the problem of the duration because the inspections require few times and there is not the need of recharge.

Then, there is not the necessity for conducting internal training for people because the inspection with UAVs is an external service. In the future, they plan to internalize the activity and therefore staff training will be required.

3.3.2 Intangible analysis

In this section, it is considered the analysis related to intangible data from the interview divided into advantages and disadvantages.

Some aspects are included in the intangibles section that, although they are quantifiable, data about them are not shared by the companies and therefore cannot be defined quantitatively. Moreover, there are also some data that are included in both sections since they can influence in a qualitative and quantitative way the decisions of companies.

3.3.2.1 Advantages

In this first part, what are the intangible benefits that emerged during the interviews will be analyzed. For each of these aspects, the impact that has actually been brought inside the company will be defined in order to understand the benefits provided by drones in the different areas of the utility. Following this, different aspects will then be discussed: the possibility of reaching hard-to-reach places, environmental impact, inspection quality, inspection frequency, and operator safety.

3.3.2.1.1 Environmental impact

Environmental impact is one of the benefits investigated when discussing the introduction of drones. Specifically, in the cases analyzed, most companies refer to CO_2 emissions released into the environment and only a small part also refer to what is the reduction of noise pollution (Table 3.4).

In the case of electric grids and pipelines, helicopter replacement is definitely a strategy that has positively affected this benefit. The great impact this benefit has depends on the fact that a helicopter releases much more CO_2 than a drone (Graph 3.17; Table 3.4).

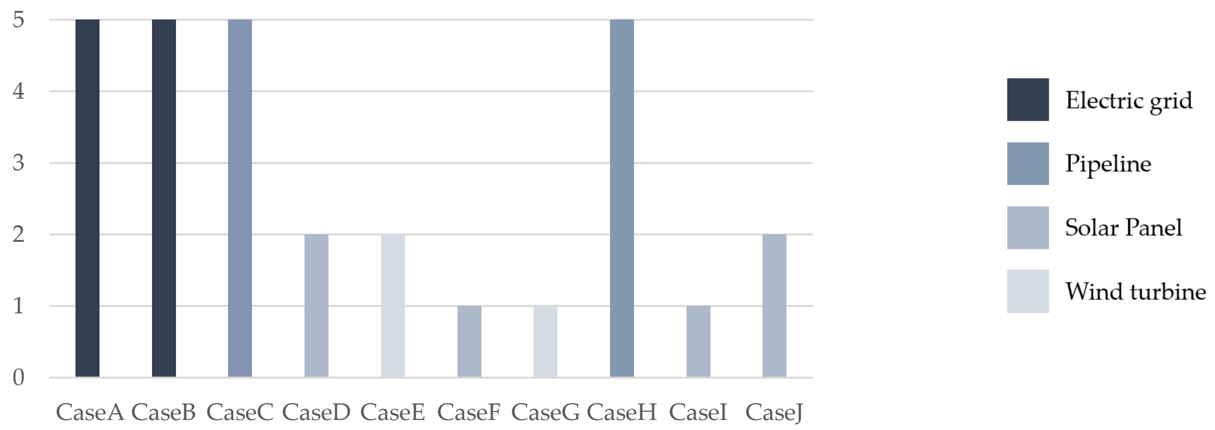
In addition, the interlocutor in case A was able to achieve further CO_2 reduction through the introduction of solar panels installed over the machines used for inspection activities. This makes it possible to reduce pollution related to the use of diesel for transportation and that used to recharge the batteries (Graph 3.17; Table 3.4).

Among the interviewees, those related to case A and C stated that in addition to CO_2 reduction they were able to achieve an additional environmental benefit: that related to noise pollution reduction (Table 3.4). This is possible because the noise generated by the helicopter is much more intrusive than that generated by a small drone. In addition, the interlocutor in case A was able to achieve further CO_2 reduction through the introduction of solar panels installed over the machines used for inspection activities (Graph 3.17).

For solar and wind cases, the introduction of the new technology has not translated into much environmental benefit. One of the main reasons concerns the methodology by which infrastructure was previously inspected. For these assets, it was not necessary to use a helicopter to carry out the activity, but they were carried out by operators manually. It is therefore natural that the cases related to pipelines and power grids noted a major benefit while the other cases noted a minor impact. However, the people interviewed referred to a decrease in CO_2 release related to the shorter road length to be performed. The reduction in time to perform the activity led companies to decrease the number of days needed to complete the activity and thus also to a decrease in the distance to be traveled by car. This decrease was not defined as a major decrease in fact it can be seen from Graph 3.17 that there are some cases that have a very low value. Case F, G and I in fact hypothesized the possible presence of CO_2 decrease but it was not investigated in depth when evaluating the new technology because it was not considered a decisive aspect regarding the introduction of UAVs.

Clusters	Total cases per cluster	CO2 reduction	Noise pollution reduction
Electric grid	2	2	1
Pipeline	2	2	1
Solar panel	4	2	0
Wind turbine	2	1	0

Table 3.4: *Type of ecological reduction per clusters*



Graph 3.17: *Impact of drones on possibility to reduce ecological impact*

3.3.2.1.2 Reaching problematic places

The ability to reach places that are difficult to access is one of the main benefits that can be obtained as a result of the introduction of drones. It can be seen that even for the utility sector this benefit is confirmed by almost all the areas analyzed (Graph 3.18). In particular, it appears that in the case of power grids and pipelines it has a significant impact. In the case of renewables, it seems to have a fairly significant impact for inspection activities on wind turbines, while much less important in solar (Graph 3.18).

Electric grids and pipelines seem to be placed along particularly hostile areas. In particular, as it can be seen from Table 3.5, the respondents state that they have part of the infrastructure both in populated places and in places with a complex landscape (ex., forest, mountain). They also claim that the issue of safety is very important for this activity since workers previously were very exposed to risks related to having inaccessible places to access (Graph 3.18).

It is also a very important issue for pipelines because of the location of this infrastructure. The interviewee from case H stated that:

"Since the pipelines are high-pressure, we try to place them in as inconvenient places as possible so that people stay away from them ".

Furthermore, it can be noted that it is the case that has benefited the most from the introduction of the new technology, since the widespread presence of this company and its very long network of pipelines means that they are in places that are hard to reach. They have also been able to reach private places much more easily than with a helicopter or manual inspection. This is because:

"There are some areas where the pipeline passes through private areas that are enclosed; therefore, difficult to access, because even though we have the titles we have to make appointments with people, etc. The fact that we have a tool that allows us to fly over them frees us from the willingness of a third party to give us access, and so we gain a lot of time from this point of view".

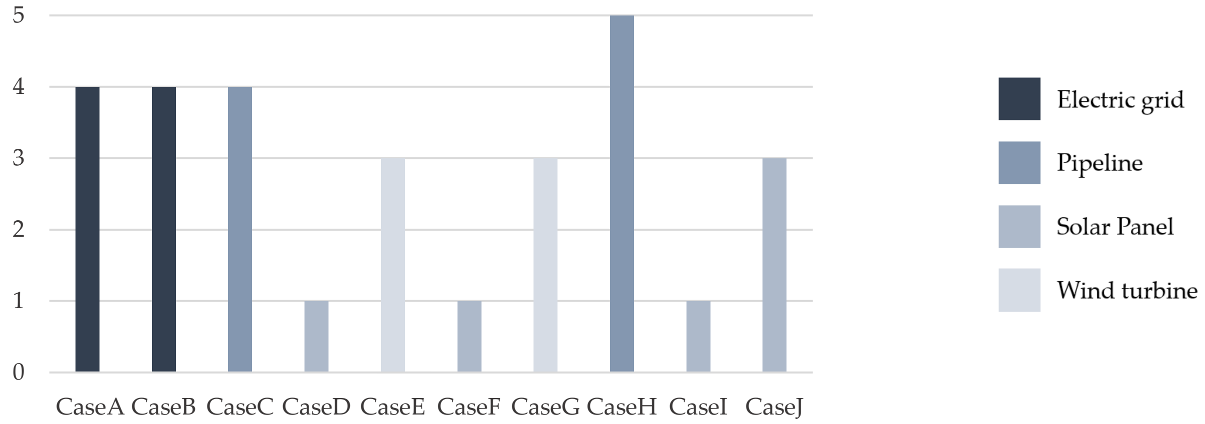
In the case of turbines, the benefit in terms of being able to access hard-to-reach places is related to the need to reach the top of the turbine, which is a dangerous place in any case that requires a special harness to the operator who has to carry out the manual inspection. Unlike electric grids and pipelines, which can be placed in places that are actually very dangerous for humans, turbines do not require reaching such a difficult-to-access place (Table 3.5) so for this reason the introduction of drones in this area has less impact on this factor than that of electric grids and pipelines (Graph 3.18).

Finally, regarding solar, respondents say that the panels are neither in cramped or difficult to access locations (Table 3.5), nor does the activity require access with slings to the infrastructure. Thus, drones did not provide much benefit in this case (Graph 3.18).

Case J turns out to be a case that differs from the other solar cases. The difference is due to the type of inspection that is carried out in that it does not involve the inspection of a ground-mounted photovoltaic system, but it involves sending the operator to inspect the solar panels on the roofs of homes. In fact, from Table 3.5 what to note is that only one in four cases in the solar cluster row stated that they inspect infrastructure in populated areas and in complex environments. In addition, another problem that could arise involved the possibility of stepping on the roof (Graph 3.18).

Clusters	Total cases per cluster	Populated areas	Complex environment	Not complex environment
Electric grid	2	2	2	2
Pipeline	2	2	2	2
Solar panel	4	1	1	4
Wind turbine	2	0	0	2

Table 3.5: *Type of environment where infrastructures are positioned*



Graph 3.18: *Impact of drones on possibility to reach problematic places*

3.3.2.1.3 Increased safety for workers

One of the major advantages found through the introduction of drones within the different sectors is definitely related to the factor of worker safety. Indeed, a significant advantage can be noted that this aspect results, even in this sector, which also comes from reaching inconvenient places more easily. The cases that are affected by increased safety for workers are those related to the inspection of power grids, pipelines and wind turbines (Graph 3.19).

Regarding electric grids and pipelines, the previous methodology involved a part of manual inspection. This type of activity required the operator to inspect places that are potentially very dangerous for humans such as, for example, they might have to go to mountains or go through forests. One of the entities we interviewed stated that:

"Doing this kind of activity with our people, i.e. visual inspection by walking on the pipeline, there are a number of problems I can encounter: trivially, I may have to access inaccessible places. This causes a safety problem for the people who have to access them. Gas pipelines are not laid by the roadside, they are in the Apennines, in the mountains, they cross watercourses..."

The new mode of inspection, on the other hand, requires the operator to stand still in one spot and therefore there is no longer a need to go to cramped places since it will be the drone that will fly over these areas. Because of this, the operator performing this activity will be much less exposed to risk and in fact the risk related to injuries will be very close to zero in this case (Graph 3.19).

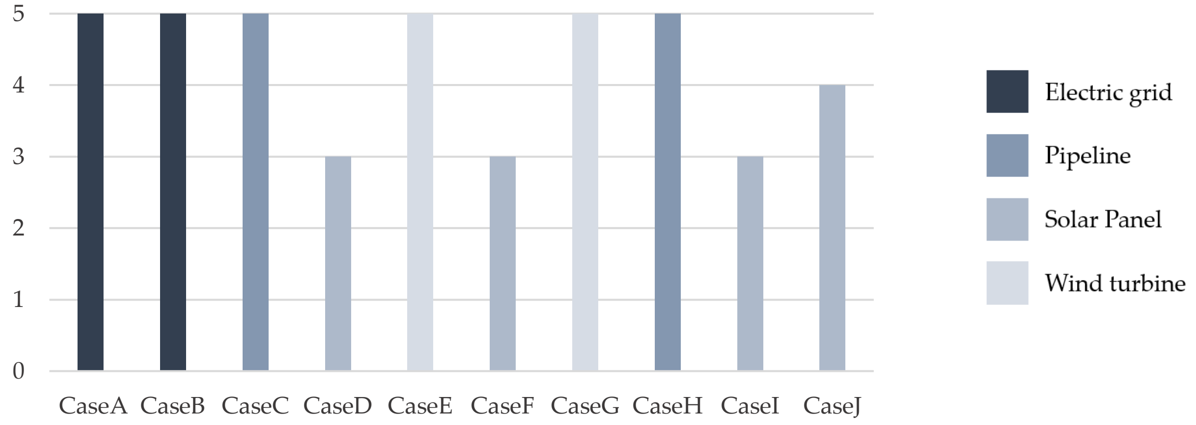
In the case of turbine inspection, on the other hand, the operator would be required to reach, harnessed, to the top of the turbine in order to inspect even the part of the turbine furthest from the ground. The necessity of having to make a vertical observation and thus having to carry the operator to height is why the inspection activity was considered an activity with a high risk of accidents. The ability to inspect the turbine from below and to be able to take advantage of the drone to get a closer look at the health of the asset all the way to the top has allowed companies to increase worker safety and not expose the worker to any hazards (Graph 3.19).

On the other hand, with regard to the inspection of photovoltaic parks, the operator was previously exposed to less risk than in other cases. In the traditional methodology, the operator neither had to make upward inspections nor go to dangerous or hard-to-reach places, but the inspection was from below with an operator inspecting the infrastructure with binoculars. However, the introduction of drones has contributed, although with less impact than in other cases, to reduce the risk related to operator injuries (Graph 3.19).

From Graph 3.19 it can be seen that Case J is a special case in the photovoltaic sector this is because the panels they go to inspect are not on the ground but are mounted on roofs. Therefore, the introduction of drones has prevented the operators from having to go up on the roofs in order to inspect the panels and allowed them to stay on the ground. This mode has therefore reduced all the possibilities of injuries associated with having to go up on the roof and thus increased safety for workers. The interviewee stated that:

"The accessibility of the roof by the operator is not a given. There are risks that the drone shoots down. The client may have provided documents proving that the roof is walkable, but it may also be the case that the calculations are wrong, and that part of the roof is not properly sealed. With drones, the dangers associated with this problem would not exist.".

In addition, another aspect to consider is also related to the fact that the rooftop, being a difficult place to reach, could also be problematic at a time when an operator is not feeling well.



Graph 3.19: *Impact of drones on safety for workers*

3.3.2.1.4 Inspection frequency

One of the main aspects to consider is related to the frequency of inspections. From Graph 3.20 it can be seen that the introduction of drones did not always cause a significant increase in frequency for the different cases interviewed. From the interviews let it be noted that the answers that were given are aligned depending on the infrastructure inspected.

In the context of power grids, the introduction of UAVs has been an important element in this factor. In both cases the frequency has increased significantly, as companies have been able to increase the observation of their assets due to the reduction in time and the ease of reaching narrow places. The need to increase the frequency of inspection of assets is related to the ability to check the health of power grids and the growth of vegetation more systematically around the asset itself and thus, the ability to intervene prematurely if needed. In particular, they stated that:

"We used to look at the lines once every two years on average and could not inspect the entire length. We would only inspect the part that was most critical and the places that were most difficult to access. In addition, many inspections were done following faults that were relayed from the operations room. Now, however, we are able to detect problems much more quickly and effectively, thanks precisely to the possibility of increasing the frequency".

Cases related to renewables have also experienced an increase in the frequency of observations, as the ability to increase the frequency allows companies to anticipate damage and thus avoid what may be major economic losses. One of the cases analyzed in the solar sector claimed:

"We have been able to double the frequency on solar, with the drones we are able to do two thermographs per year per plant whereas before we could only do one".

While in the wind field:

"Thanks to the introduction of drones, we have also been able to increase the number of inspections that are carried out on a wind turbine in a year. If before we could only do one, now we can do three and this also allows us to anticipate the damage that can be caused on infrastructure".

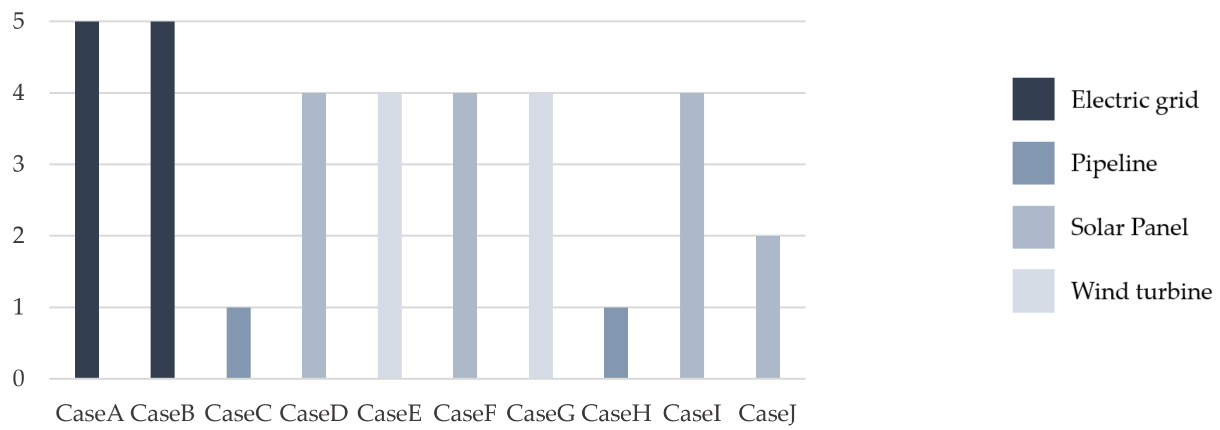
The difference between the renewables and electric grid cases lies in the fact that in renewables the companies decided to duplicate or triple the observations of an asset over the course of a year, while in the case of electric grids the observations increased much more dramatically, up to four times more than manual inspections (Graph 3.20).

From Graph 3.20 there is one case, Case J, that responded somewhat differently than the other solar cases. This company is more unique in that the drones do not have a mode already in place within the company. So currently they have not decided to increase the number of observations because they are in the development phase, but they plan to increase this factor in order to take advantage of the ability to do predictive analysis.

In the case of pipelines, on the other hand, frequency is not something that has changed in the transition from one methodology to another, and in both cases the companies have held constant the periodicity with which they carry out this activity.

"The introduction of this new technology has not changed the frequency with which we inspect our infrastructures, but thanks to the greater simplicity of the activity we are able to carry out inspections on relevant parts. Ad hoc inspections were definitely present before but with the introduction of the drones we have definitely been able to increase them".

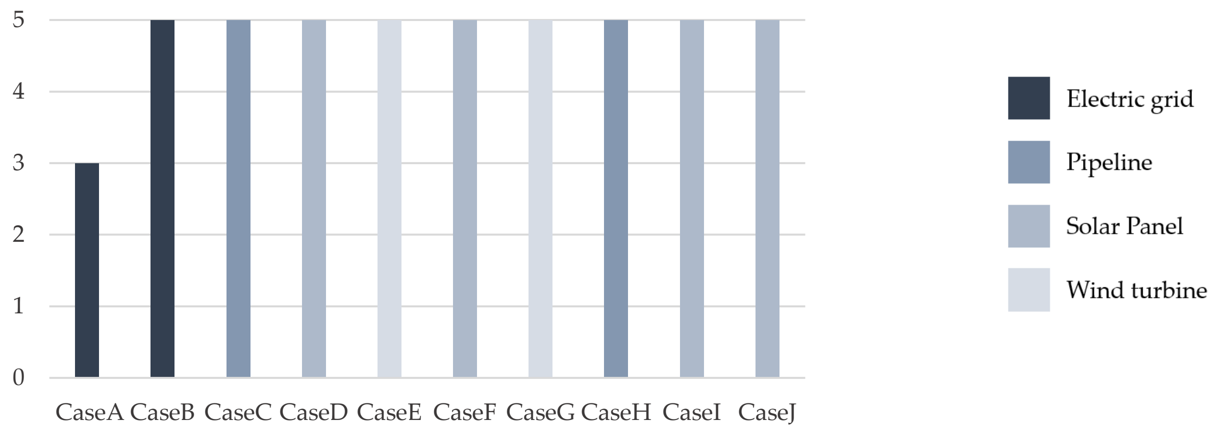
In fact, for the companies surveyed in the pipeline field, it is sufficient to maintain the frequency of inspection as defined by regulation (Graph 3.20).



Graph 3.20: *Impact of drones on inspections frequency*

3.3.2.1.5 Quality of inspections

The quality of inspections is another predominant benefit that is achieved with the introduction of this new technology. In the specific area being addressed, it is the element that has the greatest impact on all the areas being investigated. In fact, all companies rated this benefit as the most important (Graph 3.21).



Graph 3.21: *Impact of drones on possibility to reduce quality of inspections*

Case A appears to be the only one to attribute the introduction of drones as having less impact on the quality of the business. This is probably due to the fact that this new technology has not currently come to constitute a fully established process and therefore the company may not have fully realized the quality potential that can be derived from their use.

Inspection quality actually means a variety of elements. In particular, those analyzed were identified as a result of interviews with companies (Table 3.6).

One of the aspects to consider is the possibility of data digitization. In fact, with the introduction of this new technology all cases have introduced data digitization. In particular, some of the cases that previously used aircraft as a means to inspect already used data digitization; while the cases that previously relied on manual observations have introduced this new part of the process as a result of the use of drones. The ability to digitize data is an aspect related to the quality of inspection because it enables to bring additional benefits related to improving the activity and also allows to create a database of historical information that can be useful for a variety of activities. Digitization, for example, allows companies to monitor of the status of infrastructure and consequently do preventive maintenance (Table 3.6).

Another advantage shared by almost the entire sample relates to the higher quality of information that the drone is able to capture. The information that is gathered with this new technology is much more detailed and complete. Comparing the amount of information with manual inspections is much more precise and accurate; in fact, it was stated by several respondents that they were able to obtain much more information related to even a small part of the asset. Among the respondents, one stated:

"We have been able to achieve a higher quality of inspection; in fact, by looking manually so many things were not visible. Today's technology has allowed us to look at our assets 360° and we do not only have a view from below".

Another factor found was that of the possibility of improving information for future surveys, but not all companies referred to the presence of this benefit following the introduction of the new technology. The ability to digitize data and higher quality of information certainly allows companies to benefit from this additional advantage. Among the respondents it was stated that:

"The fact that we have digital models that you can look at from so many angles and that you can build year after year or even month after month allows us to measure areas of deviation and improve this type of interpretation".

This aspect causes an additional, important benefit, that of better damage identification. Drones, in fact, are able to get much closer to infrastructure and get better images. Companies are therefore able to improve damage identification (Table 3.6).

Previously, especially with regard to electric grids and pipelines, many times certain anomalies were not visible to the naked eye and therefore were not even identified. The representative of Case B stated that:

"Previously, both the operator in the field and the helicopter could not identify many details; in fact, thanks to this new technology we are able to define about 40% more anomalies that we could not see before".

Moreover, even in the case of, for example, solar panels, it is possible to improve damage identification, in fact, the respondent in Case D stated:

"Doing an analysis with the thermal imaging camera on a few MW and going to see all the points where we had hotspots meant going there with pen and paper and marking the anomalies. This is impossible now that we have many MW to inspect. In fact, the drone does a flight and thanks to artificial intelligence everything is schematised in tabular form, so we understand where all the production loss is".

This benefit is also attainable through the ability to increase the frequency of inspections: having repetitive and periodic information about infrastructure certainly allows for monitoring the state of assets and acting proactively as they deteriorate.

In fact, the ability to more accurately identify damage also allows operators to act in advance when an unfavourable condition for the infrastructure arises. Therefore, the moment damage is identified, a decision can be made to act immediately. This also leads to a subsequent reduction in costs associated with maintenance. Previously, checks were done mainly as a result of alerts that came from the central system so when maintenance was now needed. With the new methodology, companies are able to work through preventive maintenance and achieve economic savings (Table 3.6).

Among the benefits that had been found in Literature review was that related to improved image quality compared to other technologies. Among the cases interviewed, those that could have claimed to have noticed an increase in image quality were those related to the inspection of electrical grids and pipelines. Among the four cases, one of them, Case B stated that through the helicopter some peculiarities were not visible while with the drone, being able to get closer to the asset they are able to detect more information. Among the other cases, the only one that mentioned image quality was Case A, claiming that:

"the quality of the data was compatible with that required by the external company doing the analysis".

This does not actually mean that the quality is better or worse than the images made on the helicopters; therefore, since it has not received feedback from the different cases it is not possible to claim an improvement in image quality.

Clusters	Data digitalization	Improve data information	Better information for forecasts	Damage identification	Anticipation of damages
Electric lines	2	1	1	1	2
Pipelines	2	2	2	2	2
Solar panels	4	4	3	4	4
Turbines	2	2	1	2	2

Table 3.6: *Type of benefits about quality inspections per clusters*

3.3.2.1.6 Resume of benefits

As a result of what has been said so far, it is possible to identify what relationships exist between the different benefits that emerge as a result of the introduction of drones in the utility sector and specifically in the four different clusters that have been identified.

In the cluster related to electric and wind turbines, the introduction of drones has brought five main benefits. The first one is related to environmental benefits that then have no consequence on other benefits. The second one is related to the possibility of reaching places that are difficult to access; this, has allowed companies to increase the safety of workers and thus decrease the risks related to the activity and to increase the frequency of inspections since it decreases the difficulty of doing the inspection activity even on inconvenient assets. The third is related to time reduction that allowed companies to increase the frequency of inspections. The last ones, on the other hand, related to the digitization of data and the improved quality of the collected data directly impact the possibility of obtaining better predictions on the state of assets. This aspect along with increased frequency allows companies to improve damage identification and subsequently be able to intervene with a preventive rather than corrective mechanism (Figure 3.2).

In contrast, in the case of solar, the only difference is that the benefit related to reaching problematic places is not taken into account because photovoltaic installations are not located in difficult or problematic places. (Figure 3.2).

Instead, for pipelines, the increase in frequency is missing because although there is a reduction in time, it does not appear to add value to increase the frequency of inspections on this infrastructure (Figure 3.2).

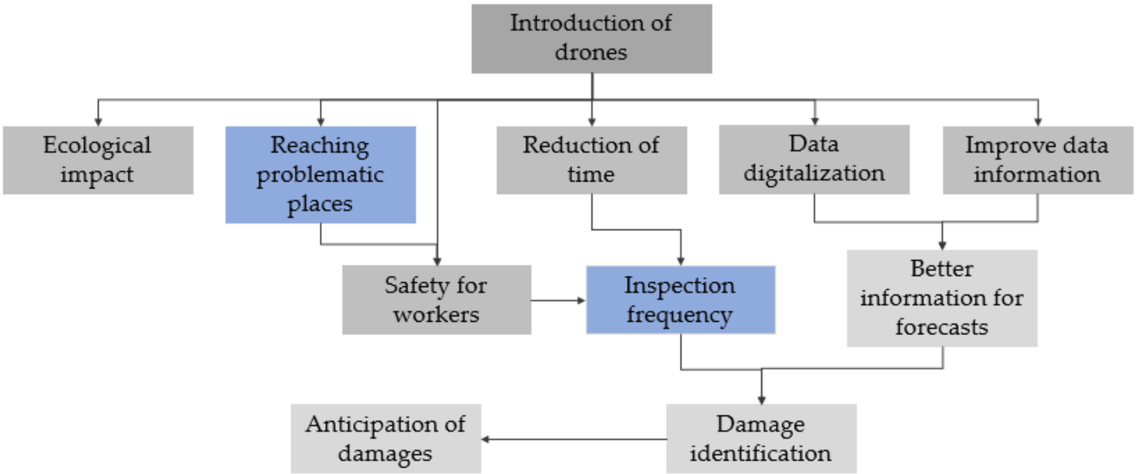


Figure 3.2: *Relations between the different benefits of introducing drones*

3.3.2.2 Disadvantages

In this second part, intangible criticalities emerged during the interviews will be analyzed. For each of these aspects, the impact that has been brought inside the company will be defined in order to understand the criticalities that can arise with the introduction of drones. Following this, different aspects will then be discussed: the limited life of drone batteries, the impact of weather conditions, the investment in personnel training and regulations.

3.3.2.2.1 Batteries

From the Literature review, it was found that one of the critical issues with the introduction of drones was related to the problem concerning battery life. Normally, a battery lasts on average 35 to 45 minutes depending on the weight of the drone and depending on the weather conditions present. In this area, this disadvantage actually does not have such a major impact on the cases analyzed (Graph 3.22).

With regard to electric grids, pipelines, and solar panels, batteries are not considered to be a problem because when going out to do the inspection, the teams carry spare batteries with them and therefore during the day they can easily finish the task. In fact, it was reported by one of the interviewees that:

"As far as batteries are concerned, we manage to regulate ourselves by bringing various spares; therefore, this does not cause us any major problems. We bring a number needed to complete activities".

In addition, it should be noted that there are limitations arising from regulations. In fact, current regulations do not allow companies to fly freely remotely. Therefore, if the ENAC were to allow increased flight distances at this point, battery life would no longer be sufficient to complete a flight and would become a more important issue for companies. On the other hand, as far as solar is concerned, this reasoning applies only in part. This is because certainly for a large extension of a field the same problem of electric grids and pipelines could arise; whereas for a less significant extension, the battery life would be sufficient, and the problem would not arise (Graph 3.22).

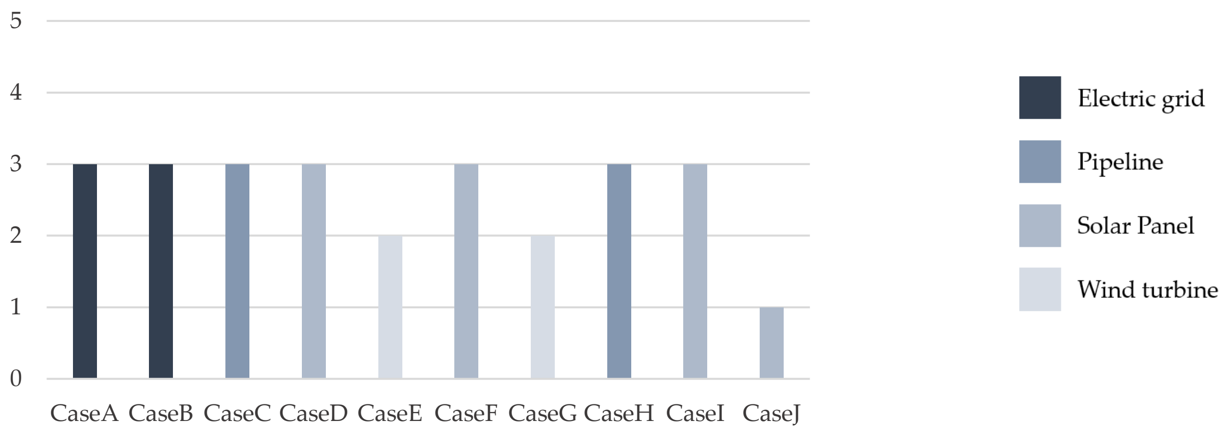
With regard to wind turbines, on the other hand, the impact of this factor is less significant because it takes 45 minutes on average to inspect a turbine. This time coincides with the life cycle of a battery so the extension of their lifetime would not be significant until two, three, four, etc., turbines could be inspected (Graph 3.22).

As for case J, as could be seen from the previous aspects as well, it is a special case. In fact, the respondent stated:

"Battery life is not a significant problem as the roofs we inspect do not have a large extension, so we are able to complete an inspection with a battery".

Again, the increase in battery life could become more significant as the company could leverage a recharge to inspect more infrastructure.

Finally, it has been reported by several companies that have been using drones for more years, that during the first uses of this new technology the battery life was less performing. So, they expect that the possibility of battery growth may be something not too impossible to imagine. This would certainly allow for a decrease in what are the downtimes due to battery replacement and thus greater efficiency in the inspection process (Graph 3.22).



Graph 3.22: *Impact of batteries of drones in inspection activity*

3.3.2.2.2 Weather conditions

Weather conditions, as it has been seen in the literature, are a negative aspect for drone activities since it might cause difficulties in data collection and also, it might not allow the technology to get off the ground (Graph 3.23).

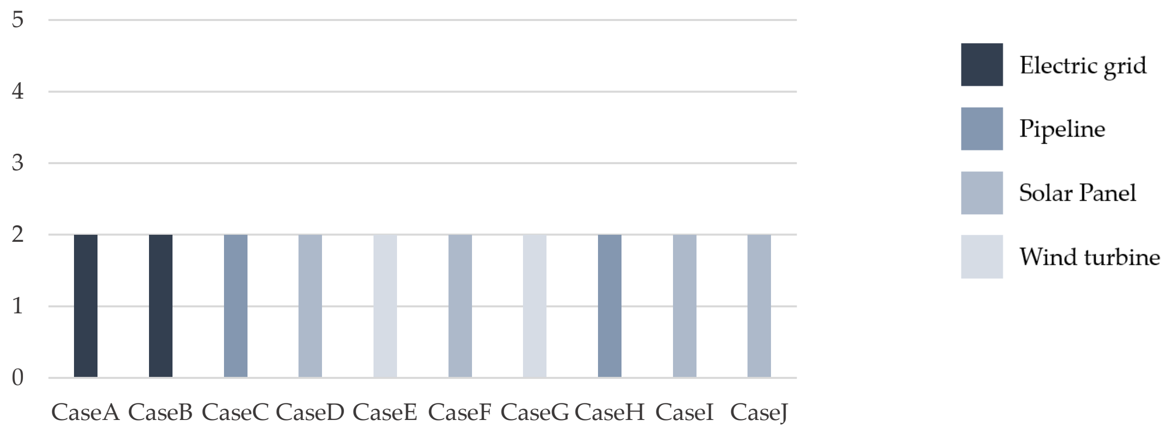
As far as the utilities sector is concerned and as far as the cases covered are considered, weather conditions do not seem to be such a major problem since it is easily manageable. The activity under consideration is not one that companies do on a fixed basis but is done more sporadically than other activities. This means that operators will also have tasks to perform, and therefore all interviewees implied that it is possible to reschedule the inspection in case there are adverse weather conditions. The main problem is not only related to the drone itself but also the payloads that are installed in it. Some interviewees claimed that:

"There are drones that can fly in the rain, however, if the objective of the activity is to collect good data, it could happen that rain on the payload ruins the analysis. So, at that point, there is no point in flying if you cannot get useful data for the analysis".

Moreover, making a comparison with the old methodologies, particularly helicopter inspections, this problem was also present in that scenario. In fact, one of the interviewees stated that:

"Weather conditions are not a factor that appeared with the introduction of drones. Previously, with a certain wind I could not get the helicopter out and with rain the images were not accurate, so I had to reschedule the activity".

Of course, the conditions under which one technology can be flown rather than another are different. Since drones used for utility field inspections are very small compared to helicopters they will require the presence of smaller winds (Graph 3.23).



Graph 3.23: *Impact of weather conditions on inspection activity*

3.3.2.2.3 Investment in personnel training

This aspect related to investment in personnel was considered as a result of the fact that the introduction of a new technology certainly needs training in order to be used. What was done here is to go and analyze how deep the training related to the inspection of an infrastructure in the utility world should be and whether it differed from case to case (Graph 3.24).

The result of the analysis shows that there is no specific behavior according to the type of infrastructure inspected, and in fact, it can be understood that the decision made in this case comes from a pure strategic decision of the company, therefore, differs from case to case (Graph 3.24).

Most of the cases decided to opt for a basic training course since piloting drones for this type of activity does not require highly specialized training compared to other activities. In fact, one of the companies interviewed stated that:

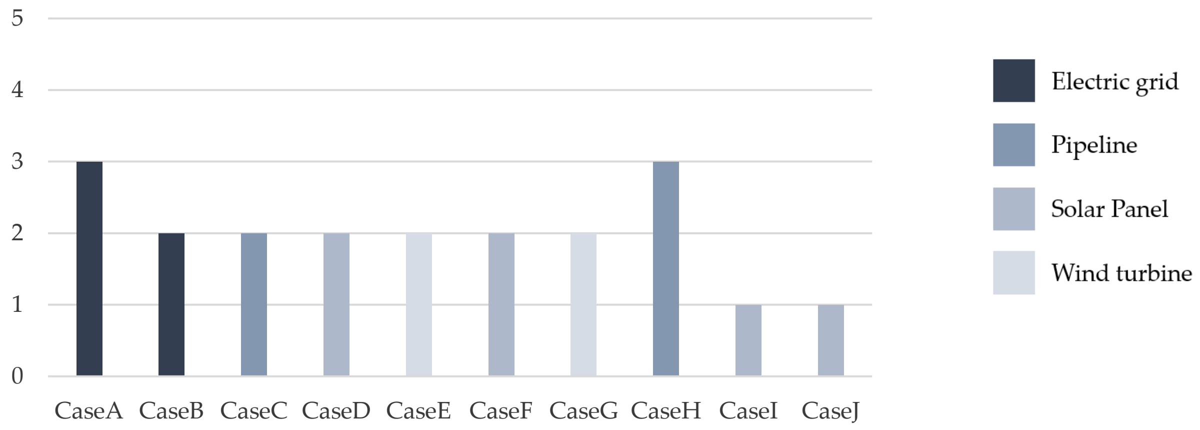
"The in-house training of a pilot is not that onerous for free spaces, whereas for confined spaces a short technical and dedicated training is required".

Moreover, it is important to note that this training on the one hand comes as a disadvantage in monetary terms, but, on the other hand, it is also an asset to corporate know-how. One of the interviewees claims that:

"We currently have people within the company who know how to do different tasks, and this has allowed us to have staff who have been able to develop different skills. So, the person who knows how to connect a meter also knows how to do inspections, so when he is free from connecting meters he also does the inspection."

There are some cases, on the other hand, which argued that there was a need to have more specialized personnel in-house and support more professional courses in the case of a highly specific inspection activity (Graph 3.24).

Case I and Case J is a special case in that they decided to outsource the inspection activity and therefore in this case they will not do personnel training as the drone pilots will be resources of the external company. Moreover, Case J also says that in case of internalization of the activity for sure they will train their employees (Graph 3.24).



Graph 3.24: *Impact of investment in personnel training on inspection activity*

3.3.2.2.4 Regulations

Regarding the impact of the current regulatory framework, it can be seen that it follows a different pattern depending on the infrastructures inspected (Graph 3.25). It turns out to be a negative factor in the case of power grids and pipelines, while it is a less incident in the cases of renewable energy.

In the electric and pipeline systems, regulations are very stringent regarding the distances that the drone can reach relative to the pilot. In fact, as previously anticipated, the possibility of extending flight times would allow companies to eliminate/reduce many costs, such as transportation, and also time. Moreover, given the complexity of the Italian territory, in many cases companies have had to apply for specific authorizations in order to carry out activities in certain locations. Requesting these authorizations sometimes takes so much time that the company is directly better off performing a manual inspection (Graph 3.25; Table 3.7).

Case B is a special case compared to the others. The interviewees confirmed, like the other cases, all the issues related to the distance that the drone can cover. On the other hand, however, its networks are located in less cramped places; in fact, they did not mention issues related to, for example, authorizations of private places or requiring precise authorizations such as those needed when flying over areas near airports or military zones, etc. (Graph 3.25; Table 3.7).

Regarding the case of solar panels and wind turbines it can be seen from Graph 3.25; that the legislation in this case is not so binding. The problem regarding the distances that can be covered by the drone does not affect so much for this type of inspection. Certainly, less stringent legislation would benefit even in the cases of inspection for solar and wind but still the current condition is not seen as a problem at all as opposed to the other cases.

Turbines and solar panels, as it can be seen from Table 3.7 are mostly located in places that require precise permits. In this case, however, only two cases D and E claimed that the waiting time to receive these permits is very long and thus they see this as a limiting factor for their operations. In fact, one of the interviewees states:

"We do a lot of inspections, we should be able to use those images, according to video surveillance regulations in force today. We have in fact made an agreement with ENAC and trade unions to be able to do this. Bureaucracy blocks us a lot from this point of view, but also in terms of updating regulations and permits".

Another important issue that has arisen for regulation concerns the mode of flight. The type of flight can be distinguished into Visual Une of Sight (VLOS) or Beyond Visual Line Of Sight (BVLOS). Flying in VLOS means that the drone cannot be lost sight of the pilot and the maximum distance allowed according to ENAC are 150m in height and a maximum distance of 500m horizontally during the day. While BVLOS allows a flight in which the pilot does not have to maintain constant contact with the drone; in this case the ENAC articles state that:

"BVLOS operations are pipelined beyond the horizontal and vertical VLOS limits, i.e. at such distances that visual observation collision avoidance procedures cannot be applied. BVLOS operations require systems and procedures for maintaining separation and avoiding collisions that require approval by ENAC[5]"

"BVLOS operations may require the use of segregated airspace (temporary or permanent), subject to the limitations and conditions of use identified by ENAC, based on the type of operations and the results of the risk assessment carried out by the SAPR operator[6]"

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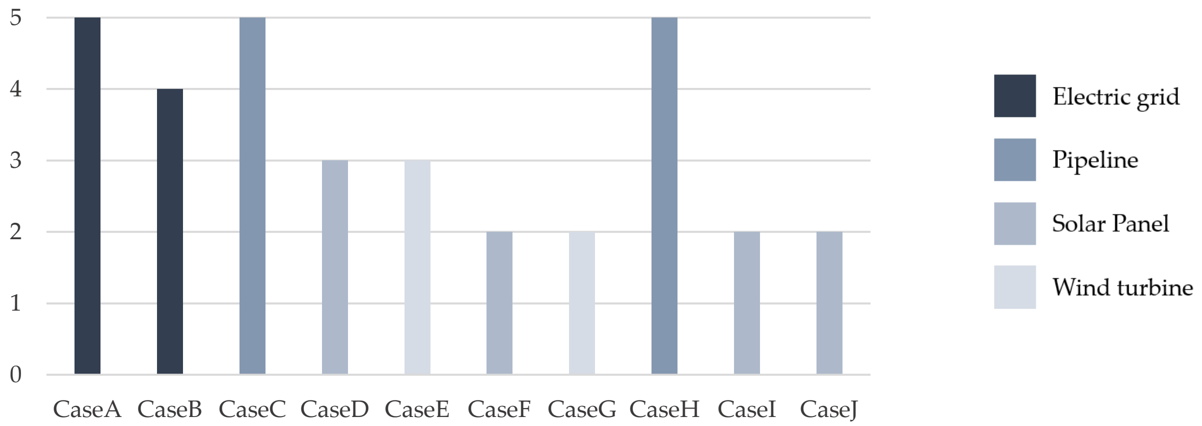
[5] Italian Civil Aviation Authority
[6] Italian Civil Aviation Authority

Most companies also referred to the BVLOS flight mode. In fact, they state that should they wish to introduce this mode, the regulations would be a consistent impediment given the waiting time and restrictions in place to obtain permits. Despite this, however, in the case of inspections in very large areas, such as electric grids and pipelines, flying in BVLOS could be a consistent advantage.

Clusters	Total cases per cluster	Limiting legislation	Long process	Precise authorisations per location
Electric grid	2	2	2	1
Pipelines	2	2	2	2
Solar panels	4	0	1	4
Turbines	2	0	1	2

Table 3.7: *Legal problematic aspects respect inspected infrastructure*



Graph 3.25: *Impact of regulations on inspection activity*

3.3.3 Tangible analysis

In this section, it is considered the analysis related to tangible data derived from the interview divided and it is divided into creation of the model and results.

3.3.3.1 Creation of the model

This paragraph explains how the cost model is constructed for the different clusters identified previously. In particular, it discusses the different cost items that have been taken into account in both the AS-IS and TO-BE cases and the relative differences in the various clusters investigated.

3.3.3.1.1 Case AS-IS

This section analyses the macro-cost items of the AS-IS methodology which concern all the clusters identified above. Since the cost model used for the inspection activities of electricity grids and pipelines are the ones with the will largest differential items, they will be the first illustrated. Subsequently, a comparison with respect to the cost items in solar panels and turbines are reported.

In particular, the total cost with the old methodology, i.e., the AS-IS case, depends on operational cost items, on those related to extraordinary inspections, i.e., non-recurring costs that arise in times of need, and on finally safety expenses (Equation 3.1).

$$Total\ AS-IS\ [€/km] = Operating\ cost\ [€/km] + Cost\ of\ extraordinary\ inspections\ [€/km] + Cost\ of\ safety[€/km]$$

Equation 3.1: *Total AS-IS [€/km]*

Going into more detail, since the activity was previously carried out partially by direct observation and partially using a helicopter, the operating cost results to be the sum of the cost items relating partly to helicopter inspections and partly to manual inspection. The percentage incidence of these two cost items is defined according to how much of the line was inspected by helicopter and how much by hand. In addition, manual inspection requires an additional cost relating to the transport of the personnel themselves along the part of the line inspected by direct observation (Equation 3.2).

$$Operating\ cost\ [€/km] = X * Helicopter\ inspection\ cost\ [€/km] + (1-X) * Manual\ inspection\ cost\ [€/km] + (1-X) * Transport\ cost\ [€/km]$$

X= percentage of line or pipeline inspected by helicopter

Equation 3.2: *Operating cost AS-IS [€/km]*

As far as the cost of extraordinary inspections is concerned, this is the sum of three other cost items: those relating to extraordinary inspections carried out by helicopter, those carried out by staff and the related cost of transport (Equation 3.3).

$$\begin{aligned} Cost\ of\ extraordinary\ inspections\ [€/km] &= Cost\ for\ extraordinary\ inspections\ by\ helicopter\ [€/km] \\ &+ Cost\ of\ extraordinary\ inspections\ with\ personnel [€/km] \\ &+ Extraordinary\ transport\ cost\ [€/km] \end{aligned}$$

Equation 3.3: *Cost of extraordinary inspections AS-IS [€/km]*

All the above-mentioned cost items will be explained and detailed below.

One of the items that constitute the Operating Cost (Equation 3.2) is the cost of inspection with the helicopter. From the feedback of the different companies, it was assumed, for each case and each model, that this activity would be outsourced. The cost in the medium case is a figure that was provided by the different companies, and which was defined based on the rental cost and the kilometres that the helicopter inspects. The cost in the medium case is a figure that was provided by the different companies, and which has been computed based on the rental cost and the kilometres that the helicopter inspects. The variation in the rental cost, compared to the medium case, will be 5% lower in the best case and 5% higher in the worst case (Equation 3.4).

$$Helicopter\ inspection\ cost\ [€/km] = \frac{H * C}{L}$$

$$H = Helicopter\ rental\ cost [€]$$

$$C = Change\ in\ rental\ cost$$

$$L = Line\ length\ [km]$$

Equation 3.4: *Helicopter inspection cost AS-IS [€/km]*

Another item within the operating costs is the cost of inspection with personnel. The definition of personnel costs assumes that the persons employed in the activity are internal resources of the company and that they work 8 hours per day for a total of 220 days per year. In fact, to define this cost, the yield of the operators was taken into account, considering that they are allocated 60% to the inspection activity. The remaining time is allocated to non-value-added activities due to some losses regarding overheads. For this cost item, the worst case is represented by the company's decision to implement a more expensive strategy and therefore use specialized personnel (senior) for this activity, while in the best case there will be cheaper solution and therefore less specialized personnel (junior). In particular, the personnel cost refers to the daily cost of an electronic technician/maintenance technician (site). In the case where the personnel are highly specialized, the greater experience of the operator has been considered and therefore the item "Variation in personnel efficiency" has been introduced to emphasize that more specialized personnel need less time to perform the activity than less specialized (Equation 3.5).

$$Manual\ inspection\ cost\ [€/km] = \frac{P * C * A * G}{L}$$
$$P = Persons\ employed\ for\ manual\ inspection$$
$$C = Personnel\ cost\ [€/day]$$
$$A = Change\ in\ personnel\ efficiency$$
$$G = Entire\ line\ inspection\ yield\ with\ direct\ observations\ [days]$$
$$L = Line\ length[km]$$

Equation 3.5: *Manual inspection cost AS-IS [€/km]*

From the answers of the interviewees, it was possible to conclude that in general the yield of an operator carrying out a manual inspection on a pipeline in a flat area is 4 km/day, while in the mountains it is 2 km/day. In the case of pipelines, on the other hand, the operator's output on a pipeline is higher because the inspections turn out to be more linear as there are no vertical inspections and is therefore 3.5 km/day.

For direct observations, it is also necessary to consider the cost of transport. The cost of transport is calculated considering twice the length of the line, as the machine must follow the route that the observer is inspecting, considering the two-way trip. The route taken by the car, however, never matches the one taken by the observer, but is longer. This derives from the fact that in the plains, electricity grids and pipelines are not located along the car's route, but in the middle of fields or inhabited places, whereas in the mountains they are located in more confined places so moving from one point to another requires a longer movement in comparison to walking. The result is that if the stretch analysed by the personnel is flat (best case), the car travels twice the distance in the case of electricity grids, while they travel three times in the case of pipelines. If the stretch is in the mountains (worst case) then the distance is three times longer in the case of electricity grids, and four times in the case of pipelines. The difference in the two cases results from the interviews that were conducted; in fact, it turned out that the pipelines are located in more difficult places than in electric grids. Furthermore, it was not taken into account a greater increase in the route because, in highly dangerous and steep areas, inspections will preferably be carried out using helicopters for safety reasons. Furthermore, the route from the point where the car leaves to the beginning of the line was not taken into account, as the respondents defined it as negligible. Finally, this cost obviously depends on the cost of diesel, which is not a fixed cost, so a percentage variation was taken into account that depends on the variation in the price of diesel (Equation 3.6).

$$Transport\ cost\ [€/km] = \frac{C * A * M * 2L}{L}$$
$C = Diesel\ cost\ [€/km]$
$A = Change\ in\ diesel\ cost$
$M = Change\ in\ line\ length$
$L = Line\ length\ [km]$

Equation 3.6: *Transport cost AS-IS [€/km]*

From Equation 3.3 concerning extraordinary inspections, this cost can be attributed to the sum of several factors. For extraordinary inspections with the helicopter, a fixed fee of €5,000 per day was taken into account, which was the figure received from the interviews. Again, a percentage was introduced to represent the variation in cost that a company may have, as this cost depends on the agreements made with the company carrying out the inspection (Equation 3.7). The expenses for extraordinary inspections with personnel, on the other hand, follow a similar reasoning to the cost of inspection with personnel (Equation 3.8). In particular, the data on the number of extraordinary inspections were reported annually. To define the cost for an inspection cycle, the frequency that the company inspects the entire line was also considered. In fact, to determine the impact that this cost has on one kilometer of line, the annual cost was first multiplied by the frequency required to inspect the entire line and then divided by the length of the line.

$$Cost\ for\ extraordinary\ inspections\ by\ helicopter[€\ /km\ ] = \frac{T * C * A * F}{L}$$
$T = Extraordinary\ inspection\ time\ by\ helicopter\ [days/year]$
$C = Average\ helicopter\ extraordinary\ inspection\ cost[€/day]$
$A = Change\ in\ extraordinary\ inspection\ cost$
$F = Inspection\ frequency[years]$
$L = Line\ length[km]$

Equation 3.7: *Cost of extraordinary inspections by helicopter AS-IS [€/km]*

$$Cost\ of\ extraordinary\ inspections\ with\ personnel[€/km] = \frac{T * P * C * A * F}{L}$$
$T = Time\ of\ extraordinary\ manual\ inspection\ [days/year]$
$P = Persons\ employed\ for\ manual\ inspection$
$C = Personnel\ cost\ [€/day]$
$A = Change\ in\ personnel\ efficiency$
$F = Inspection\ frequency\ [years]$
$L = Line\ length\ [km]$

Equation 3.8: *Cost of extraordinary inspections with personnel AS-IS [€/km]*

For direct observations, it is also necessary to take into account the cost of the transport needed for the travel of the persons making the extraordinary inspection (Equation 3.9).

$$Extraordinary\ transport\ cost[€/km] = \frac{C * A * M * F * 2L}{L}$$

$C = Diesel\ cost\ [€/km]$
$A = Change\ in\ diesel\ cost$
$M = Change\ in\ line\ length$
$F = Inspectionfrequency[years]$
$L = Line\ length\ [km]$

Equation 3.9: *Extraordinary transport cost AS-IS[€/km]*

Finally, the safety cost depends on the average cost of an injury in Italy which is €4,667.00[7] per year per individual worker and a percentage variation depending on the variation that the cost of the employee may have (Equation 3.10). Again, the number of injuries is an annual figure and therefore the frequency has been included.

$$Cost\ of\ safety\ [€/km] = \frac{N * C * A * F}{L}$$

$N = Number\ of\ injured\ workers\ [persons/year]$
$C = Average\ injury\ cost\ in\ Italy\ [€/person]$
$A = Change\ in\ injury\ cost$
$F = Inspectionfrequency[years]$
$L = Line\ length\ [km]\ L = Line\ length\ [km]$

Equation 3.10: *Cost of safety AS-IS [€/km]*

Table 3.8 highlights the fixed factors that have just been analysed and the variable factors that differ from case to case. The variable factors depend both on company choices and the length of the line to be inspected.

AS-IS (Electric grid)	**Worst Case**	**Medium Case**	**Best Case**
Helicopter rental cost [€]			
Change in rental cost	1.05	1.00	0.95
Line length [km]			
Helicopter inspection cost [€/km]			
Persons employed for manual inspection			

[7] Quanto costa un infortunio sul lavoro indagine - Lisa Servizi

Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield for manual inspection [days]			
Line length [km]			
Manual inspection cost [€/km]			
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km]			
Line length [km]			
Transport cost [€/km]			
Total Operating costs [€/km]			
Extraordinary inspection time by helicopter [days/year]			
Average helicopter extraordinary inspection cost [€/day]	5,000	5,000	5,000
Change in extraordinary inspection cost	1.05	1.00	0.95
Inspection frequency [years]			
Line length [km]			
Cost for extraordinary inspections by helicopter [€/km]			
Time of extraordinary manual inspections [days/year]			
Persons employed for manual inspection			
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]			
Line length [km]			
Cost of extraordinary manual inspection [€/km]			
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km/year]			
Inspection frequency [years]			
Line length [km]			
Extraordinary transport cost [€/km]			
Cost of extraordinary inspections [€/km]			
Number of injured workers [persons/year]			
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]			
Line length [km]			

Cost of safety [€/km]	
Total AS-IS [€/km]	

Table 3.8: *Fixed cost voices in the AS-IS Case (electric grids)*

As far as the photovoltaic and wind power scenarios are concerned, the analysis of tangible factors shows some differences (Table 3.9).

In particular, the operating cost does not include the cost of the helicopter, as all the companies surveyed do not rely on this type of inspection at all, considering it too expensive for this type of infrastructure. The operating cost, in fact, only takes into account the cost of personnel to carry out infrastructure inspections manually.

Furthermore, the transport cost is not taken into account either, as it is not a differential cost between the AS-IS and TO-BE methodology. In fact, the distance travelled by the car is the same whether the inspection is done manually or with the drone. In fact, the only stretch travelled by the car is the one to reach the place where the inspections are carried out, and the inspections are then conducted on foot by the operators without any further travel by car (Equation 3.11).

$$Total\ AS-IS[€/MW] = Manual\ inspection\ cost\ [€/MW] + Cost\ of\ extraordinary\ manual\ inspection\ [€/MW] + Cost\ of\ safety\ [€/MW]$$

Equation 3.11: *Total AS-IS [€/MW]*

AS-IS (Solar panel)	**Worst Case**	**Medium Case**	**Best Case**
Persons employed for manual inspection			
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire solar park yield for manual inspection [days]			
Installed capacity [MW]			
Manual inspection cost [€/MW]			
Time of extraordinary manual inspections [days/year]			
Persons employed for manual inspection			
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]			
Installed capacity [MW]			
Cost of extraordinary manual inspection [€/MW]			
Number of injured workers [people/year]			
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]			

Installed capacity [MW]
Cost of safety [€/MW]
Total AS-IS [€/MW]

Table 3.9: *Fixed cost voices in the AS-IS Case (solar panels)*

3.3.3.1.2 Case TO-BE

In the TO-BE case, first the cost items for electric grids and pipelines will be analysed for completeness and then a comparison will be made on the photovoltaic and wind power items.

Inspection activity in the new scenario is currently carried out with the aid of drones, which totally eliminates the use of helicopters. As far as manual observation is concerned, this is also replaced by drone activity, with the exception of a few special cases in which it is necessary to maintain it, but which can be considered negligible.

Also in TO-BE, the three scenarios, worst case, medium case and best case, are defined, varying from the case with the most costly decisions to the case with the most cost-effective decisions.

The total cost is the sum of the investment cost, which is carried out every three years on average, the cost of the battery, the inspection cost of personnel with the drone, the expenses for extraordinary inspections, which are a non-recurring costs, and finally the safety costs (Equation 3.12).

$$\begin{aligned} Total\ TO - BE\ [€/km] \\ &= Investment\ cost\ [€/km] + Battery\ cost\ [€/km]\ + Operating\ cost\ [€/km] \\ &+ Cost\ of\ extraordinary\ inspections\ [€/km] + Cost\ of\ safety\ [€/km] \end{aligned}$$

Equation 3.12: *Total TO-BE [€/km]*

The investment cost refers to two expenses that the company has to incur on a non-constant basis. The first refers to the purchase cost of the drone; this expense should be repeated over the life cycle of the asset, which averages around three years. The second, on the other hand, refers to staff training, again a non-recurring cost and not on constant base (Equation 3.13).

$$Investment\ cost\ [€/km]\ = Drone\ cost\ [€/km] + Training\ cost\ [€/km]$$

Equation 3.13: *Investment cost TO-BE [€/km]*

The cost of batteries refers to the batteries that need to be purchased to have the entire line inspected and recharged (Equation 3.14).

$$Battery\ cost\ [€/km] = Battery\ purchase\ cost\ [€/km] + Battery\ charging\ cost\ [€/km]$$

Equation 3.14: *Battery cost TO-BE [€/km]*

Operating cost considers the cost of personnel for inspection the entire line with drones and the related transport cost (Equation 3.15).

$$Operating\ cost\ [€/km] = Cost\ of\ personnel\ inspection\ with\ drone\ [€/km] + Transport\ cost\ [€/km]$$

Equation 3.15: *Operating cost TO-BE [€/km]*

The cost of extraordinary inspections considers both the cost of performing them, i.e., the cost of extraordinary drone inspections, and the cost of transport associated with them, i.e., the cost of extraordinary transport (Equation 3.16).

$$Cost\ of\ extraordinary\ inspections\ [€/km] = Cost\ of\ extraordinary\ inspection\ with\ drone\ [€/km] + Extraordinary\ transport\ cost\ [€/km]$$

Equation 3.16: *Cost of extraordinary inspections TO-BE [€/km]*

The above-mentioned cost items are detailed below.

Focusing on the investment cost, the items that need to be analysed concern the cost of the drone and the cost of training. Regarding the cost of the drone, DJI's Matrice 300[8] drone with the Zenmuse P1[9] thermal camera was considered as the average cost of a drone with payloads for pipelines. Instead, for electric grids, it was also added another payload, i.e., LiDAR Zenmuse L1[10]. This type of drone is widely used by infrastructure inspection companies, as confirmed by the experts interviewed. The website of the manufacturer, DJI, was consulted for this cost.

The companies surveyed, however, use drones within their company that have different characteristics and therefore also different costs. For this reason, the definition of the drone purchase cost is influenced by a variable called "Price variation with payload", which impacts the average price of a drone including payload by +15% and -15% (Equation 3.17).

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[8] Acquista MATRICE 300 RTK - DJI Store

[9] DJI Zenmuse P1 - DJI Authorized Retail Store

[10] DJI Zenmuse L1 - DJI Authorized Retail Store

$$Drone\ cost\ [€/km] = \frac{D * C * A}{L}$$
$$D = Number\ of\ drones\ [drones]$$
$$C = Average\ cost\ of\ a\ drone\ with\ payload\ [€/drone]$$
$$A = Change\ in\ cost\ of\ a\ drone\ with\ payload$$
$$L = Line\ lenght\ [km]$$

Equation 3.17: *Drone cost TO-BE [€/km]*

As far as training is concerned, the company's choice lies in the type of training course to be given to its employees. In the Worst case, the decision was made to undertake a more comprehensive and thus more expensive training course, while in the best case a cheaper course was considered. For the cost of training, an average was made of the various drone pilot training courses offered on the market. In particular, following the experts' suggestion, the Italdron academy was taken as a reference[11] (Equation 3.18).

$$Training\ cost\ [€/km] = \frac{N * C}{L}$$
$$N = Number\ of\ trained\ persons\ [persons]$$
$$C = Training\ course\ cost\ [€/person]$$
$$L = Line\ lenght\ [km]$$

Equation 3.18: *Training cost TO-BE [€/km]*

The cost of purchasing batteries is related to the cost of the battery, which again can differ. In the worst case, i.e., the one in which one decides to buy a more high-end battery, the cost is around €800, whereas in the best case batteries are considered to cost around €600. This variation takes into account the different types of battery that can be applied to DJI's Matrice 300 drone, and as an average cost, the manufacturer DJI's Matrice 300 Series TB60 smart flight battery is considered to be around €700[12]. This cost is also influenced by the number of batteries required to perform the entire line inspection. In particular, a battery lasts on average 43 minutes and can be recharged 200 times after that the battery will start to be inefficient. Therefore, the calculation depends on these two parameters and the total duration of the inspection. In addition, the number of batteries required depends on the type of drone; in fact, the Matrix 300 drone was taken into account, which requires two batteries to fly (Equation 3.19). In addition, a variation in battery life was also considered by

[11] Home - Corsi Pilotaggio Droni ENAC - Italdron Academy
[12] Matrice 300 Series TB60 Intelligent Flight Battery - DJI

assuming that more expensive batteries are more efficient than others. This is emphasized by the "Percentage of variation in battery life" (Equation 3.20).

$$Number\ of\ necessary\ batteries\ = \frac{Total\ inspection\ time\ with\ drone\ [min]}{Average\ drone\ battery\ time[min] * Battery\ life\ cycle} \cdot 2$$

Equation 3.19: *Number of necessary batteries*

$$Battery\ purchase\ cost\ [€/km] = \frac{N * C * A}{L}$$

$N = Number\ of\ necessary\ batteries\ [batteries]$
$C = Drone\ battery\ cost\ [€/battery]$
$A = Change\ in\ time\ battery$
$L = Line\ lenght\ [km]$

Equation 3.20: *Battery purchase cost TO-BE [€/km]*

In addition to the cost of purchasing batteries, the cost of recharging them must also be considered. This turns out to be the major maintenance cost associated with the drone, while the others, according to experts, can be considered negligible. To calculate the cost of recharging, it is necessary to consider the cost of electricity consumption, which in Italy is around 0.361 €/kWh[13]. Obviously, this is not a fixed cost during the year, so a 5% 'Electricity Cost Variation' has been applied to take into account fluctuations in electricity prices. In addition, it is necessary to consider the time to recharge a TB60 300 Series Smart Flight Battery[14], which is approximately 65 minutes and the "Change in battery recharge", which considers a variation in the time to charge batteries of different qualities. This implies that more expensive and therefore higher quality batteries will have longer battery lives while lower quality batteries will have a shorter battery life. Finally, it is necessary to consider the energy consumption to recharge a battery, which, comparing different generators, is about 1 kW. The cost of recharging batteries is detailed in Equation 3.21.

$$Battery\ charging\ cost\ [€/km] = \frac{C * V * T * A * E * N}{L}$$

$C = Electricity\ consumption\ [€/kWh]$
$V = Change\ in\ electricity\ cost$
$T = Time\ to\ battery\ rechange\ [h]$
$A = Change\ in\ battery\ recharge$
$E = Power\ consumption\ for\ battery\ recharge[kW]$

[13] Quanto Costa un kWh di Energia Elettrica Oggi? | Marzo 2023 - Luce-gas.it
[14] Matrice 300 Series BS60 Intelligent Battery Station - DJI

$N = Number\ of\ necessary\ batteries$
$L = Line\ lenght\ [km]$

Equation 3.21: *Battery charging cost TO-BE [€/km]*

As far as the cost of inspection with personnel is concerned, the way of defining the cost is the same as in the AS-IS case. The difference in this cost lies in the fact that the operators no longer perform manual inspection activities but are dedicated to drone piloting activities. This can be seen from the fact that the salaries of the employees in the two cases are different. In this case, in fact, a cost of the junior pilot, senior pilot and an average cost between the two were defined and included in the three scenarios analysed (worst, best and medium case). In the worst case it was used a cost of 200 €/person which corresponds to the cost of a senior pilot and 150 €/person in the best case which corresponds to the cost of a junior pilot. A variation according to the efficiency of the personnel was included assuming that a senior pilot with a lot of experience would perform the task in a shorter time than the junior pilot. These figures were defined following a discussion with experts from the drone industry (Equation 3.22).

Moreover, it is important to underline that all these companies use drones that are flying in VLOS. In the case of pipelines and electric grids the possibility to fly in BVLOS could change with big differences the definition of decreasing of costs and time but nowadays the regulations do not premise the exploitation of this kind of fly.

$$Cost\ of\ personnel\ inspection\ with\ drone\ [€/km] = \frac{P * S * A * G}{L}$$

$P = Pilot\ for\ inspection$
$S = Pilot\ cost\ [€/day]$
$A = Change\ in\ personnel\ efficiency$
$G = Entire\ line\ inspection\ yield\ with\ drone\ [days]$
$L = Line\ lenght\ [km]$

Equation 3.22: *Cost of personnel inspection with drone TO-BE [€/km]*

For direct observations, moreover, the cost of transport in this case will be treated as a percentage reduction compared to the AS-IS case. Whereas previously the transport had to try to follow the grid line or pipeline that was being inspected, the interviewees now state that there is a reduction in the distance travelled as it is not necessary to follow the exact course of the line. This reduction, defined according to the respondents' answers, is around 30% (Equation 3.23).

$Transport\ cost\ [€/km] = C * R$
$C = AS - IS\ transport\ cost\ [€/km]$
$R = Percentage\ reduction$

Equation 3.23: Transport cost TO-BE [€/km]

Concerning extraordinary inspections, this cost takes into account both the cost to perform the inspections and the cost of transport. The cost of extraordinary inspections with a drone has been calculated using the same approach as that used to calculate the cost of personnel, with the only difference that the total time required for this activity will be less since they are non-recurring costs and therefore the activity will not be carried out constantly during the inspection period of the entire line. This calculation, moreover, is the same as in the AS-IS case, the only difference being that the salary for drone pilots is higher than in the AS-IS case (Equation 3.24).

$$Cost\ of\ extraordinary\ inspection\ with\ drone\ [€/km] = \frac{T * P * C * A * F}{L}$$

$T = Time\ of\ extraordinary\ inspections\ with\ drone\ [days/year]$

$P = Pilot\ for\ inspection$

$C = Pilot\ cost\ [€/day]$

$A = Change\ in\ personnel\ efficiency$

$F = Inspection\ frequency\ [years]$

$L = Line\ lenght\ [km]$

Equation 3.24: *Cost of extraordinary inspection with drone TO-BE [€/km]*

For extraordinary inspections, it is also necessary to take into account the cost of transport for the travel of the people doing the extraordinary inspection. In the TO-BE case, however, there is a percentage reduction that considers the fact that the drone simplifies the movements as it allows personnel not to follow the whole line as in the AS-IS case. This reduction coincides with the reduction in transport related to the operating costs analysed in the TO-BE case (Equation 3.25).

$$Extraordinary\ transport\ cost [€/km] = \frac{C * A * M * F * 2L * R}{L}$$

$C = Diesel\ cost\ [€/km]$
$A = Change\ in\ diesel\ cost$
$M = Change\ in\ line\ lenght$
$F = Inspection\ frequency\ [years]$
$R = Percentage\ reduction$
$L = Line\ lenght\ [km]$

Equation 3.25: *Extraordinary transport cost TO-BE [€/km]*

Finally, also in the TO-BE scenario it is necessary to consider the cost related to safety. This cost item is calculated in the same way as the safety cost in the AS-IS case, but the number of injuries is reduced by a variable percentage in the various scenarios. This percentage reduction in injuries, defined as a result of the interviews, varies from a decrease of 80% in the worst case to 90% in the best case (Equation 3.26).

$$Cost\ of\ safety\ [€/km] = \frac{N * R * C * A * F}{L}$$
$$N = Number\ of\ injured\ workers\ [persons/year]$$
$$R = Redution\ in\ the\ percentage\ of\ injured\ workers$$
$$C = Average\ injury\ cost\ in\ Italy\ [€/person]$$
$$A = Change\ in\ injury\ cost$$
$$F = Inspection\ freqeuncy\ [years]$$
$$L = Line\ lenght\ [km]$$

Equation 3.26: Cost of safety TO-BE [€/km]

Table 3.10 represents all the costs that have just been described and all the information that has been considered. In particular, the boxes that are not empty represent the fixed parameters in each case study and in the model in the case of electricity grids and pipelines, while those that are empty are specific to each case.

TO-BE (Electric grid)	**Worst Case**	**Medium Case**	**Best Case**
Number of drones [drones]			
Average cost of a drone with payload [€/drone]	29,268	29,268	29,268
Change in cost of a drone with payload	1.15	1.00	0.85
Line length [km]			
Drone cost [€/km]			
Number of trained persons [persons]			
Training course cost [€/person]	1,200	950	700
Line length [km]			
Training cost [€/km]			
Investment cost [€/km]			
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]			
Change in time battery	0.80	1.00	1.20
Line length [km]			
Battery purchase cost [€/km]			
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]			
Line length [km]			

Battery charging cost [€/km]			
Battery cost [€/km]			
Pilot for inspection			
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]			
Line length [km]			
Cost of personnel inspection with drone [€/km]			
AS-IS transport cost [€/km]			
Percentage reduction	0.70	0.70	0.70
Transport cost [€/km]			
Operating cost [€/km]			
Time of extraordinary inspections with drone [days/year]			
Pilot for inspection			
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]			
Line length [km]			
Cost of extraordinary inspection with drone [€/km]			
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km/year]			
Inspection frequency [years]			
Percentage reduction	0.70	0.70	0.70
Line length [km]			
Extraordinary transport cost [€/km]			
Cost of extraordinary inspections [€/km]			
Number of injured workers [persons/year]			
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]			
Line length [km]			
Cost of safety [€/km]			
Total BE-TO [€/km]			

Table 3.10: *Fixed cost voices in the TO-BE cases (Electric grids)*

The cases concerning the inspection of wind farms and solar panels are partially different.

The most important difference relates to the cost of transport. This is not taken into account for either routine drone inspections or extraordinary inspections as it is not a differential cost between the AS-IS and TO-BE methodology. The reasoning followed for this decision is the same as in the AS-IS case.

Another difference is found in the average cost of a drone with payloads in the case of photovoltaic. This is because although the drone used is the same, i.e., DJI's Matrice 300, and with the same cost, in this specific case the payload used is different. In fact, DJI's Zenmuse H20N[15] camera was considered with a cost of around €11,000.

The remaining cost items remain valid for solar and wind inspections.

As a result of the differences concerning the different solar and wind cases and models, the total cost of TO-BE will be different from the other two clusters. This is because the operational cost consists only of the cost of inspection with personnel, which, as already mentioned, refers to the fact that operators carry out piloting activities and not manual observation (Equation 3.27).

$$\begin{aligned} Total\ TO-BE\ (€/MW) &= Investment\ cost\ [€MW] + Battery\ cost\ [€/MW\ ] \\ &+ Cost\ of\ personnel\ inspection\ with\ drone\ [€/MW] \\ &+ Cost\ of\ extraordinary\ inspections\ [€/MW] + Cost\ of\ safety\ [€/MW] \end{aligned}$$

Equation 3.27: *Total TO-BE [€/MW]*

Table 3.11 is a summary of the data used to calculate the total TO-BE cost in the case of solar and wind. It includes within it fixed data for each case study and each model (those in the non-empty boxes) and specific data for each case study and each model (those in the filled boxes).

TO-BE (Solar panels)	**Worst Case**	**Medium Case**	**Best Case**
Number of drones			
Average cost of a drone with payload [€/drone]	22,483	22,483	22,483
Change in cost of a drone with payload	1.15	1.00	0.85
Installed capacity [MW]			
Drone cost [€/MW]			
Number of trained persons [persons]			
Training course cost [€/person]	1,200	950	700

[15] Zenmuse H20N - Visione oltre l'oscurità - DJI

L Installed capacity [MW]			
Training cost [€/MW]			
Investment cost [€/MW]			
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]			
Change in time battery	0.80	1.00	1.20
Installed capacity [MW]			
Battery purchase cost [€/MW]			
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]			
Installed capacity [MW]			
Battery charging cost [€/MW]			
Battery cost [€/MW]			
Pilot for inspection [persons]			
Pilot cost [€/(day*person)]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]			
Installed capacity [MW]			
Cost of personnel inspection with drone [€/MW]			
Time of extraordinary inspections with drone [days/year]			
Pilot for inspection			
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]			
Installed capacity [MW]			
Cost of extraordinary inspection with drone [€/MW]			
Number of injured workers [persons/year]			
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]			
Installed capacity [MW]			
Cost of safety [€/MW]			
Total BE-TO [€/MW]			

Table 3.11: *Fixed cost voices in the TO.BE cases (Solar panels)*

Once the different case study files were completed, the different general cases valid for each cluster were constructed. The general models will consider average data that are explanatory of a base case. In this way, companies wishing to evaluate the introduction of the new drone technology for infrastructure inspections in the field of utilities will be able to consult and verify this model in order to analyse the economic benefit derived from it.

3.3.3.1 Results of models

This section will analyze under each cluster the results in terms of time and cost related to a "type" case constructed from the information revealed during the interviews. In particular, all the various cost items that were defined within the various models will be explained. Finally, there will be a section focusing on the analysis of all the cases to get an overview of the different economic benefits within each cluster.

3.3.3.1.1 Electric grids

3.3.3.1.1.1 Case AS-IS

The first scenario considered in the model AS-IS, is that of using the helicopter and operators performing manual inspection in order to observe the entire electric grid. The costs that will be considered are those related to ordinary activity, extraordinary activity, and safety.

For this analysis, a symbolic electric line extension of 1,000 km was considered for simplicity of analysis. This extension refers to an average case and is not related to any of the companies surveyed.

The first ordinary cost considered is that related to the helicopter. This refers to the rental of the aircraft with an external company. The decision refers to the fact that all the case studies interviewed chose to enter into a relationship with an outside company to conduct inspections, probably because purchasing a helicopter is not cost-effective as an investment. Rental refers to the different feedback received related to electric grids and pipelines. Both clusters turn out to be in line with the decision to hire the helicopter through the establishment of long-term contracts or through annually reconfirmed contracts with partner companies. What resulted in fact is a cost that does not particularly vary from worst to best case. As can be seen, it ranges from 117 €/km down to 106 €/km (Table 3.12).

AS-IS (Electric grids)	Worst case	Medium case	Best case
Helicopter rental cost [€]	11,111.11	11,111.11	11,111.11

Change in rental cost	1.05	1.00	0.95
Line length [km]	1,000	1,000	1,000
Helicopter inspection cost [€/km]	**116.67**	**111.11**	**105.56**

Table 3.12: *Helicopter inspection cost (AS-IS Electric grids)*

The second cost considered is related to the manual activity performed by the operators. Almost all companies also consider the presence of two observers employed for this activity as a matter of occupational safety. As it was mentioned in the previous section (Creation of the model), it is necessary for one inspector to be supported by another operator so that if there should be any accidents at work, especially in isolated locations, they can be notified by the non-injured operator (Table 3.13).

Another factor that is in line with the electric grid cases and with the experts who were interviewed is yield. In particular, yields change depending on whether one is in more cramped or in flatter locations with fewer hazards. The yield of an operator on foot checking power grids in places with little narrowness is 4 km/day, while if it is more complicated places then it is considered 2 km/day. The differentiation that has been made between the different yields depends on the fact that to inspect a flat place do not have any obstacles that come up at the time of inspection, a situation that arises in the case of being in more complex places such as, for example, a forest (Table 3.13).

"Whole line inspection yield with direct observations" was defined through the average percentage of electric line placed in cramped or low-density housing locations and that for less hazardous locations. The result, obtained through the interviews conducted, considers 60% of line in complex areas and 40% in areas that present much less risk to human activity. This coincides with what was said in the previous section (3.3.3.1 Creation of the model) in that, for example, electric lines are placed in places where humans have a hard time getting to. Even for this item, the cost does not vary that much as it can range from 170 €/km to 153 €/km depending on the strategic decision one decides to implement (Table 3.13).

AS-IS (Electric grids)	**Worst case**	**Medium case**	**Best case**
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield for manual inspection [days]	666.67	666.67	666.67
Line length [km]	1,000	1,000	1,000
Manual inspection cost [€/km]	**170.00**	**166.67**	**153.33**

Table 3.13: *Manual inspection cost (AS-IS Electric grids)*

An additional cost considered is that of transportation. This is closely related to the fact that the operator follows the line and the vehicle moves with the observer. Companies have explained that the amount of road covered by the machine compared to that of the line is more. In particular, it turns out to be double or even triple. Therefore, for this type of inspection, the companies decided that places that are more difficult to reach and riskier to human safety will not be inspected on foot where it is possible (Table 3.14).

What can be seen from the analysis of the cost items just analyzed is the fact that the item related to transportation has very little impact, almost irrelevant. For this item, it will be much more interesting to compare with the TO-BE case in that a reduction in car use leads to a decrease in CO_2 emissions (Table 3.14).

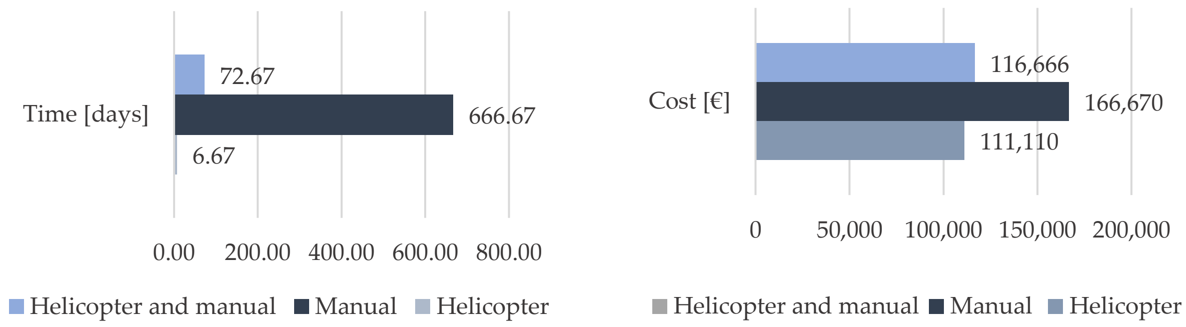
AS-IS (Electric grids)	**Worst case**	**Medium case**	**Best case**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km]	2,000	2,000	2,000
Line length [km]	1,000	1,000	1,000
Transport cost [€/km]	**0.44**	**0.35**	**0.27**

Table 3.14: *Transport cost (AS-IS Electric grids)*

The definition of the total operating cost depends on the amount of kilometers inspected by helicopter and that related to manual inspections. To define the optimal amount, the choices of the various companies were considered, and an average was created. Again, the differences between the case studies are not significant; in fact, it was noted that most of the inspection is done by helicopter, while the remainder by direct observations. This is probably due to the fact that inspection by helicopter is much faster while the operator to perform the same length would need much more time. In fact, the aircraft would be able to inspect 150 km of line in a working day, while the operator on average would only be able to inspect 3 km. What results is that on average 90% are inspected by helicopter and the remaining 10% by direct observations although the cost of manual inspection is lower (Graph 3.26).

As can be seen from Graph 3.26 if 1,000 km of line were taken into consideration, such as the one taken as a reference for the model shown, there are several scenarios that can be analyzed to try to understand what the company choices are. It turns out that manual inspection is very time consuming, although the operators that companies provide are not just 2 and so this number is very lump sum and will certainly be less in reality. This means that if you added up all the hours worked by the operators, you would get a very similar result. Instead, the less time-consuming methodology is the one that exploits the helicopter.

According to Graph 3.26, the use of single manual inspection turned out to be the costliest methodology while the other two result lower. The decision of companies is to use a combination of both methodologies. This is because they can exploit both as required and this allows for a diversification of costs by having both internal and external costs. Although the helicopter is more convenient in terms of time and cost, it has limitations in that it is not cost-effective for short duration inspections (Graph 3.26).



Graph 3.26: *Days and cost to inspect ordinary 1,000 km of electric grid with traditional methodologies*

Next, extraordinary inspections were considered. What emerges is that companies do this type of inspection when needed. The need arises either from an alert from the system or if they think it is convenient to go for an inspection on a part of the line that is expected to have anomalies to the asset or that the asset may be threatened by the growth of vegetation surrounding it. It is also important to point out that in the case of extraordinary inspections, companies act differently. There are companies that prefer to inspect only at the point of the alert and others that prefer to inspect the surrounding line as well. The model considers a medium case between these two scenarios.

In order to better understand how much of the line is inspected overtime, it was necessary to understand how often the entire line is observed. In this case, both companies stated that each section of line is observed every two years.

Extraordinary inspections with helicopters are not considered by the companies as this activity is particularly costly. It has been claimed and subsequently confirmed in the sustainability reports that on average 15% of the line is inspected in a year; therefore, over the two-year period in total 30% of the line is inspected. As can be noted from Table 3.15 this cost is around 10 €/km.

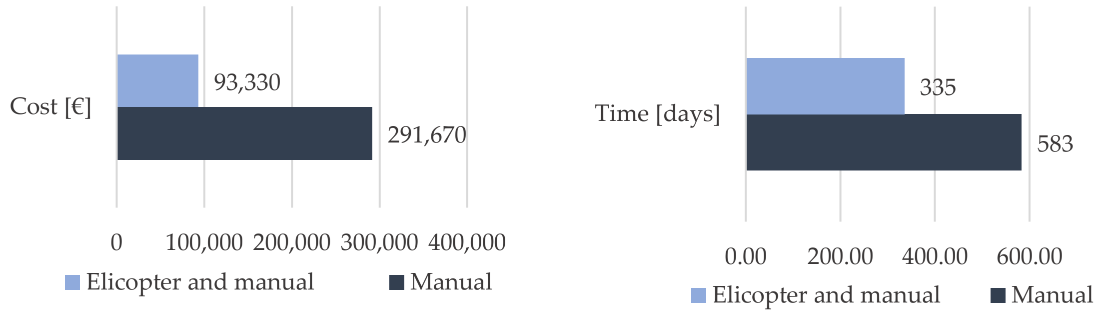
On the other hand, extraordinary manual inspections are much more frequent and are carried out in the same way as ordinary ones thus with two operators on site. Observations of this type occur mainly along the part of the line that is in places that are more difficult to reach and therefore are present in places that are more "problematic" for both the operator and the line itself. The definition of the days required for a company depends on the percentage of line they manage to inspect in extraordinary per year. The part of the line inspected during the inspection period (2 years) on average is around 40% of the length line. In this case this cost item is around 83 €/km (Table 3.15).

AS-IS (Electric grids)	Worst case	Medium case	Best case
Extraordinary inspection time by helicopter [days/year]	1	1	1
Average helicopter extraordinary inspection cost [€/day]	5.000	5.000	5.000
Change in extraordinary inspection cost	1.05	1.00	0.95
Inspection frequency [years]	2	2	2
Line length [km]	1,000	1,000	1,000
Cost for extraordinary inspections by helicopter [€/km]	**10.50**	**10.00**	**9.50**
Time of extraordinary manual inspections [days/year]	166.67	166.67	166.67
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	2	2	2
Line length [km]	1,000	1,000	1,000
Cost of extraordinary manual inspection [€/km]	**85.00**	**83.33**	**76.67**

Table 3.15: *Cost of extraordinary inspection (AS-IS Electric grids)*

Thus, it can be inferred that companies carry out two processes in parallel. The first related to routine inspection in which much more helicopter is used and a small part manual inspection and the second, extraordinary inspection, in which manual inspection is preferred to helicopter inspection. Comparing the various types of inspection and considering the example of 1,000 km of line, it can be seen that the manual inspection activity is the most expensive and the most time spending, while the hybrid solution is more convenient (Graph 3.27).

It should also be noted that the possibility of using the helicopter for this type of activity is not an option that is highly considered by companies. The reason for this stems from the fact that the observations take place on affected sections of the line. This would mean spending €5,000 each time a section of line has to be inspected and thus would drastically increase the total cost of the activity. Therefore, companies will use the helicopter at the time when they have more kilometers to inspect in extraordinary and not for activities aimed at a few kilometers (Graph 3.27).



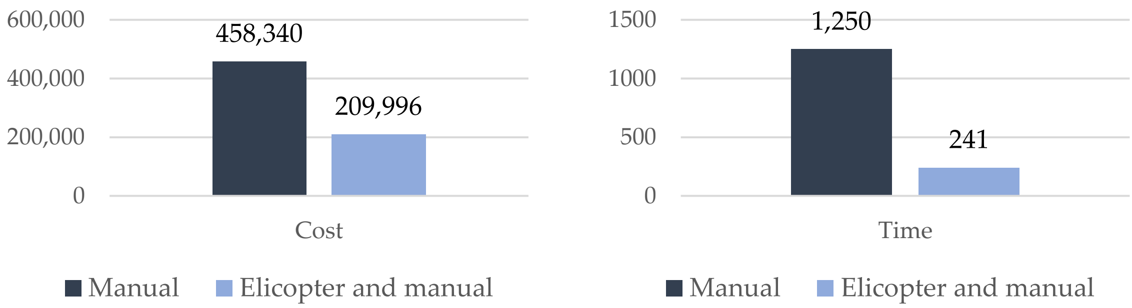
Graph 3.27: *Days and cost to inspect extraordinary 1,000 km of electric grid with different methodologies (AS-IS Electric grids)*

By analyzing the total cost and time related to inspection, it can be seen that the solution adopted by the companies is the most cost-effective and time efficient.

The solution of using only a helicopter is not a feasible scenario to undertake, for the reasons stated above.

The fully manual solution on the other hand is very time-consuming, of course these figures are calculated with the presence of only two operators. Companies, in fact, do not have only two operators and therefore in reality the time considered is not "true". What needs to be emphasized here is that the view the operators have is not complete so there is a lack of a top-down view to identify certain anomalies and have 360-degree information. In addition, helicopter data collection allows companies to gather information to be able to make more accurate analyses in the future as well (Graph 3.28).

For these reasons, the solution of using multiple methodologies in parallel in this case is more advantageous even at the expense of cost.



Graph 3.28: *Days and cost to inspect totally 1,000 km of electric grid with traditional methodologies*

Finally, monetary outputs related to injuries have also been considered. As detailed in the section Advantages, manual observation of infrastructure has a very high associated risk to the worker. All the companies confirmed that they had not experienced any serious accidents at work for this activity and had an injury index below 1%. Comparing then the data that was provided, we estimated that the number of people injured is around 0.6% per year. This means that considering the Equation 3.28 in the case of the 1,000 km inspected there will be an average of 6 people injured.

$$People\ injured\ in\ an\ average\ year = 0.006 * Line\ lenth$$

Equation 3.28: *People injured in an average year*

Thus, the cost for injuries results is 56 €/km (Table 3.16).

AS-IS (Electric grids)	Worst case	Medium case	Best case
Number of injured workers [persons/year]	6	6	6
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	2	2	2
Line length [km]	1,000	1,000	1,000
Cost of safety [€/km]	**58,80**	**56,00**	**53,20**

Table 3.16: *Cost of safety (AS-IS Electric grids)*

The total cost of helicopter inspections and manual observations, thus using the traditional methodology, turns out to range from about 276 €/km to 249 €/km (Table 3.17).

AS-IS (Electric grid)	Worst Case	Medium Case	Best Case
Helicopter inspection cost [€/km]	116.67	111.11	105.56
Manual inspection cost [€/km]	170.00	166.67	153.33
Transport cost [€/km]	0,44	0,35	0,27
Total Operating costs [€/km]	**122.04**	**116.70**	**110.36**
Cost for extraordinary inspections by helicopter [€/km]	10.5	10.00	9.50
Cost of extraordinary manual inspection [€/km]	85.00	83.33	76.67
Extraordinary transport cost [€/km]	0.09	0.07	0.05
Cost of extraordinary inspections [€/km]	**95.59**	**93.40**	**86.22**
Cost of safety [€/km]	**58.80**	**56.00**	**53.20**
Total AS-IS [€/km]	**276.44**	**266.11**	**249.78**

Table 3.17: *Total cost of AS-IS case of electric grids*

3.3.3.1.1.2 Case TO-BE

This section is going to evaluate what is the new solution with drones and in what amount this new technology brings benefits within electric line companies in economic terms.

The first costs considered are those related to the investment that a company faces; thus, those related to the purchase of drones and that related to training.

The majority of the case studies favor the use of owned drones rather than outsourcing the activity (as was the case with helicopters). Defining the ideal number of UAVs that a company interested in introducing this new technology should purchase depends, with reference to the model, on the kilometers inspected by the company. It appears from the case studies that it would be optimal to have one drone for every 500 km of line. In the case illustrated (1,000 km) two drones are needed.

Regarding the choice of drone and payload, the model involves the use of DJI's Matrice 300 drone with an associated thermal camera and a LiDAR. Many of the interviewees said that they use this drone and payload for their own inspections. In addition, the two drone specialists also confirmed the optimality of the choice. The number of UAVs referred to does not consider a backup element, as it is considered an unreasonable and unnecessary investment. Indeed, it could happen that the drone would be idle for years, at which point there would be new models and the backup drone would be obsolete. Also, the useful life of a drone is about 5 years so after this time period companies change their UAVs (Table 3.18).

Regarding the cost of training, this is provided for each operator who will then have to fly the drone and has an average cost of €950 per person. The number of people trained depends on the drones purchased. It turns out that each drone is accompanied by two pilots. In this case the cost associated with training turns out to be around 4 €/km (Table 3.18).

The total Investment cost of these two expenses is around 62 €/km (Table 3.18).

TO-BE (Electric grid)	Worst Case	Medium Case	Best Case
Number of drones [drones]	2	2	2
Average cost of a drone with payload [€/drone]	29,268	29,268	29,268
Change in cost of a drone with payload	1.15	1.00	0.85
Line length [km]	1,000	1,000	1,000
Drone cost [€/km]	**67.32**	**58.54**	**49.76**
Number of trained persons [persons]	4	4	4
Training course cost [€/person]	1,200	950	700
Line length [km]	1,000	1,000	1,000
Training cost [€/km]	**4.80**	**3.80**	**2.80**
Investment cost [€/km]	**72.12**	**62.34**	**52.56**

Table 3.18: *Investment cost (TO-BE Electric grids)*

A new cost, not present in the AS-IS case, is related to drone batteries. Specifically, to the cost of battery purchase and that of battery recharging.

The purchase cost depends first and foremost on business decisions; there are more or less performing batteries that therefore have different costs. Also, it should be considered that DJI's Matrice 300 drone needs 2 batteries at a time to fly. Taking into consideration a battery with average characteristics it can be seen that the cost of the latter does not have such a significant impact on the cost of the business itself resulting 11 €/km (Table 3.19).

The cost of battery charging as can be seen from Table 3.19 has very little impact. The particularity here lies in the fact that companies prefer to arrive at inspection sites with their batteries already charged. This, in addition to being an advantage in terms of organization, is also an advantage in terms of the environment, since, instead of charging them with the energy produced by the machine and thus through fuel, electric power is used.

TO-BE (Electric grid)	**Worst case**	**Medium case**	**Best case**
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]	16	16	16
Change in time battery	0.80	1.00	1.20
Line length [km]	1,000	1,000	1,000
Battery purchase cost [€/km]	**10.24**	**11.20**	**11.52**
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]	16	16	16
Line length [km]	1,000	1,000	1,000
Battery charging cost [€/km]	**0.0052**	**0.0062**	**0.0071**
Battery cost [€/km]	**10.25**	**11.21**	**11.53**

Table 3.19:*Battery cost (TO-BE Electric grids)*

The total operating costs in this scenario are composed only of the cost items related to drone inspection and that of transportation.

As for operators, again there will be two people employed to perform this activity. In fact, all the companies interviewed are in line with this thinking and each employ two operators for this activity. In order to define this cost, it was necessary to understand the daily output of a drone. Specifically, the interviewees, and subsequently also the two drone specialists, stated that on average a drone can inspect 9 to 11 km per day. The variation always depends on the type of environment one is in so they will decrease as the complexity of the surrounding environment in which the electric grids are located increases. Again, the transportation cost is very insignificant and still reduced compared to the AS-IS case. This 30 % reduction in transport is due to the fact that being able to remain stationary at one point allows companies to decrease the amount of roads to be traveled (Table 3.20).

TO-BE (Electric grid)	**Worst case**	**Medium case**	**Best case**
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]	166.67	166.67	166.67
Line length [km]	1,000	1,000	1,000
Cost of personnel inspection with drone [€/km]	**56.67**	**58.33**	**57.50**
AS-IS transport cost [€/km]	0.44	0.35	0.27
Percentage reduction	0.70	0.70	0.70
Transport cost [€/km]	**0.31**	**0.25**	**0.19**
Operating cost [€/km]	**56.98**	**58.58**	**57.69**

Table 3.20: *Operating cost (TO-BE Electric grids)*

Extraordinary inspections, even in the case of drones represent a parallel process to ordinary inspections. Over the course of a year, it has been estimated that 40% of electric grids are inspected. In this case, however, the need does not arise from problems that are reported as a result of alerts due to line failure but are reported from the data of the drones themselves. In addition, as has been stated many times already, drones are able to detect many more alerts than the old methodology, and this then allows them to go back to the site to verify the problem and in case figure out the type of problem so that they can then take actions.

The other factor to consider when defining the cost of extraordinary inspection per kilometer is that of frequency. The frequency of inspection manages to be increased significantly; companies on average manage to inspect the entire line every 9 months. This, in fact, leads to several benefits on the economic level as well, stemming from the benefits related to data quality (Quality of inspections) which, however, have not been considered in this model. As can be seen, extraordinary drone inspections and the related transportation cost have a very limited cost of 18 €/km (Table 3.20).

TO BE (Electric grid)	**Worst case**	**Medium case**	**Best case**
Time of extraordinary inspections with drone [days/year]	66.67	66.67	66.67
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.75	0.75	0.75
Line length [km]	1,000	1,000	1,000
Cost of extraordinary inspection with drone [€/km]	**17.00**	**17.50**	**17.25**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km/year]	800	800	800
Inspection frequency [years]	0.75	0.75	0.75

Percentage reduction	0.70	0.70	0.70
Line length [km]	1,000	1,000	1,000
Extraordinary transport cost [€/km]	**0.09**	**0.07**	**0.06**
Cost of extraordinary inspections [€/km]	**17.09**	**17.57**	**17.31**

Table 3.21: *Extraordinary inspection (TO-BE Electric grids)*

On the other hand, as far as safety is concerned, the possibility of reducing the risk and increasing the safety of inspection activities has also caused a decrease in injuries. Specifically, this number can be reduced from a maximum of 80% to a minimum of 90% by significantly decreasing not only the associated risk but also the cost of safety to about 3 €/km (Table 3.22).

TO BE (Electric grid)	Worst case	Medium case	Best case
Number of injured workers [persons/year]	6	6	6
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	0.75	0.75	0.75
Line length [km]	1,000	1,000	1.000
Cost of safety [€/km]	**4.41**	**3.15**	**2.00**

Table 3.22: *Cost of safety (TO-BE electric grids)*

Thus, the total cost related to the introduction of drones to carry out the inspection of electric grids results to be about 90 €/km. Moreover, it can be seen from the table that the total cost without investment in the worst case is the lowest scenario due to the efficiency of senior pilots and also thanks to the better typology of batteries.

Considering also the investment cost, it would result in a total of 153 €/km for the first inspection, which would still remain lower than in the AS IS case (Table 3.23).

TO-BE (Electric grid)	Worst Case	Medium Case	Best Case
Drone cost [€/km]	67.32	58.54	49.76
Training cost [€/km]	4.80	3.80	2.80
Investment cost [€/km]	**72.12**	**62.34**	**52.56**
Battery purchase cost [€/km]	10.24	11.20	11.52
Battery charging cost [€/km]	0.0053	0.0063	0.0071
Battery cost [€/km]	**10.25**	**10.21**	**10.53**
Cost of personnel inspection with drone [€/km]	56.67	58.33	57.50
Transport cost [€/km]	0.31	0.25	0.19
Operating cost [€/km]	**58.98**	**58.58**	**57.69**
Cost of extraordinary inspection with drone [€/km]	17.00	17.50	17.25
Extraordinary transport cost [€/km]	0.09	0.07	0.06
Cost of extraordinary inspections [€/km]	**17.09**	**17.57**	**17.31**
Cost of safety [€/km]	**4.41**	**3.15**	**2.00**

Total BE-TO [€/km]	**160.84**	**152.84**	**141.07**
Total TO-BE without investment	**88.72**	**90.51**	**88.51**

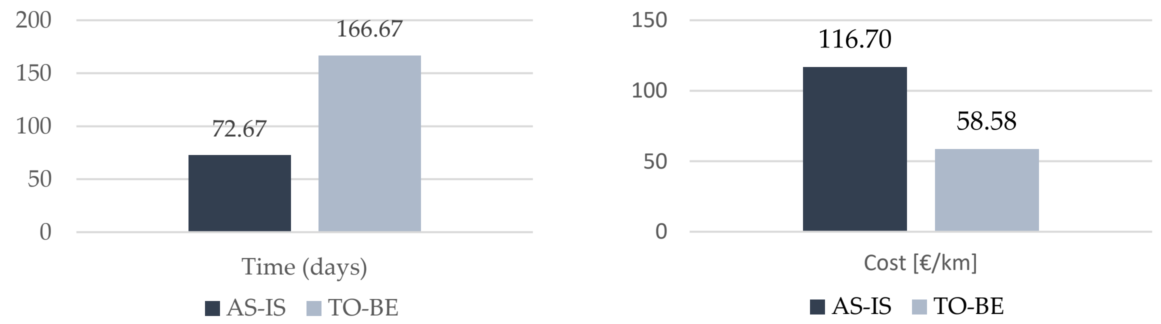
Table 3.23: *Total TO-BE (Electric grids)*

3.3.3.1.1.3 Comparison between AS-IS and TO-BE

The first analysis that carry out comparing between the two cases, AS-IS and TO-BE, are the costs and operational times by considering the average cases of both scenarios.

Considering the case under consideration, it can be seen that at the time level the routine inspection of the entire line does not need many days and that in reality the drone time is longer than the combined helicopter and manual inspection. This figure may in fact be misleading from what is expected. The reason for this result depends on the fact that the helicopter manages to decrease the inspection time significantly since it can observe 150 km in a working day while the drone only 9/11 km. In addition, the helicopter covers 90% of the line, instead, manual inspections, that are more time consuming, are exploited for the rest of the line (10%).

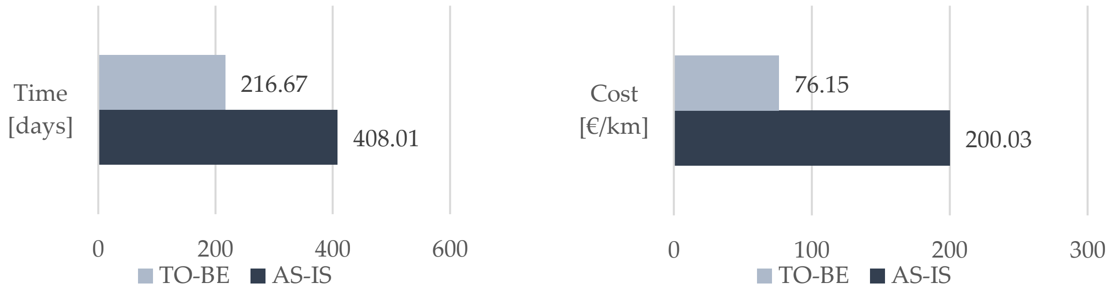
What can be seen, however, is that the operating costs are markedly different. While the cost in the AS-IS scenario turns out to be close to 117 €/km in the TO-BE case (without investment) turns out to be close to 59 €/km, this translates into a percentage reduction of about 50% (Graph 3.29). This means that the use of the helicopter and manual inspection is definitely not cost-effective but is slightly more time-efficient (Graph 3.29).



Graph 3.29: *Time and cost for operational inspection in the AS-IS and TO-BE scenarios (Electric grids)*

To get a clearer view, it is necessary to consider both processes running in parallel, and thus operational and extraordinary inspections.

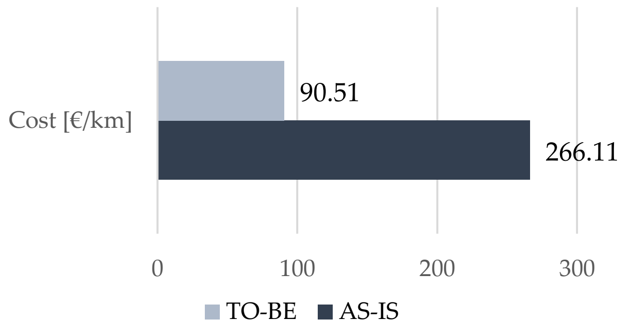
From Graph 3.30 it can be seen that the time required for the activity with drones is reduced by 47%. This led companies to increase the frequency by more than double, from observations once every two years to once every nine months. Moreover, the kilometers inspected in a year in the TO-BE case are higher than the ones in the AS-IS. In particular, in the AS-IS companies are able to inspect 1350 km/year, while in the TO-BE around 1650 km/year. The consequence of this improvement is an impact in the maintenance costs since one is able to achieve so many savings at the economic level (Graph 3.30). In addition, it can be obtained an economic benefit. To inspect one kilometer of line, a company is able to achieve an even greater reduction than that which is achieved only at the operational level. Thus, in this case, there is a reduction of 62% (Graph 3.30).



Graph 3.30: *Time and cost to inspect in ordinary and extraordinary in the AS-IS and TO-BE scenarios (Electric grids)*

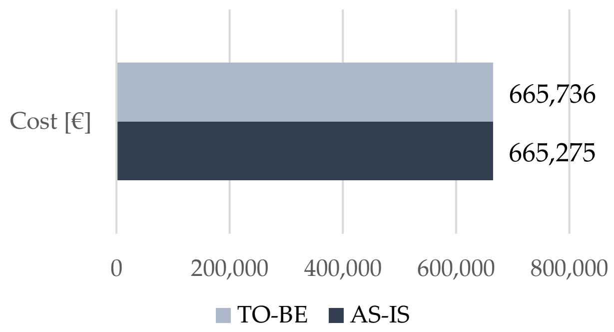
Since it is intended to study all the costs that can be associated with both activities, it is going to analyzed what are all the costs that are attributable to the two case scenarios and then it is to consider a fixed time period to also evaluate the investment in the TO-BE case and thus the costs related to training and drone purchase.

From the Graph 3.31 it can be seen that the total cost of the inspection still turns out to be, with all costs considered in the model, a much lower cost than with the old methodology. The savings results in about 66% (Graph 3.31).



Graph 3.31: *Total cost in the AS-IS and TO-BE scenarios (Electric grids)*

Considering instead a defined time interval, the five years of drone investment, and the 1,000 km of line, it can be seen from Graph 3.32 that the costs related to this type of inspection are more or less the same. It is important to emphasise that in this case the number of inspections carried out is much higher than in the TO-BE case, in fact, during the period considered in the AS-IS case the electric grids are inspected 2.5 times while in the TO-BE case 6.67 times, i.e. the inspections are almost tripled. Furthermore, it is important to consider that there are savings costs that are not currently included in the drone scenario. These certainly include the possibility of preventive maintenance, which makes the solution cost-effective. Finally, two payloads have been considered for electric grids that are very expensive and are not always used by all companies (Graph 3.32).



Graph 3.32: *Evaluation of the investment (Electric grids)*

3.3.3.1.2 Pipelines

3.3.3.1.2.1 Case AS-IS

The case of pipelines is very similar to that of electric grids. In fact, it can be seen that the two assets are not so different so only those parts of the analysis that differentiate pipelines with power grids will be considered and analyzed in detail.

In addition, 1,000 km of line will also be considered for the definition of the generic case.

Regarding the operational costs, it can be seen from Table 3.24 that the cost of the helicopter has not changed and is the same as in the case of electric grids since in any case the km inspected in a day remain fixed, the contracts are the same in cost and no different tasks are required than in the case of inspection on electric grids (Table 3.24).

AS-IS (Pipelines)	**Worst Case**	**Medium Case**	**Best Case**
Helicopter rental cost [€]	11,111.11	11,111.11	11,111.11
Change in rental cost	1.05	1.00	0.95
Line length [km]	1,000	1,000	1,000
Helicopter inspection cost [€/km]	**116.67**	**111.11**	**105.56**

Table 3.24: *Helicopter inspection cost (AS-IS Pipelines)*

Different is the case with manual inspections. In this case, the two operators employed for the task manage to increase their yield. Based on what has been said by companies and also confirmed by drone specialists, it has been estimated that the average yield, considering both the presence of problematic and non-problematic sections, is 3,5 km/day. The reason for this increase depends on the fact that pipeline inspection for operators is a less time consuming activity since it does not involve vertical inspection like that of electric grids for this reason they are able to increase the yield and therefore the manual inspection cost is lower than that of electric grids with a Medium case of about 119 €/km compared to 167 €/km in the case of electric grids (Table 3.25).

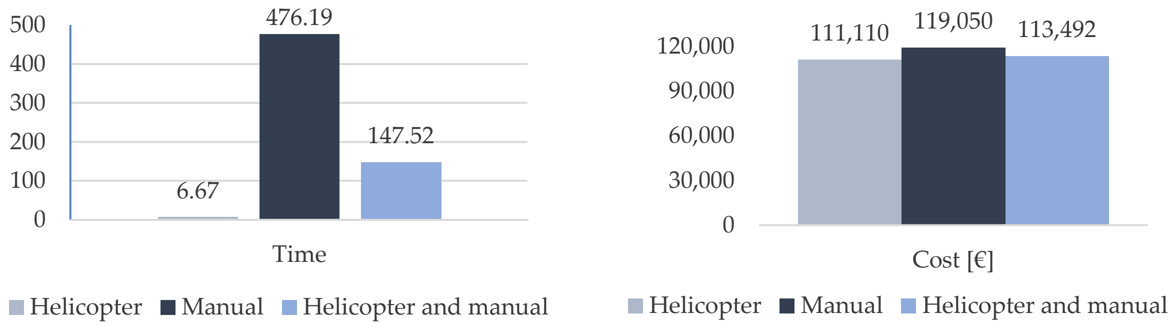
Again, the cost of transportation does not particularly vary, the only difference found is that in the pipeline cases, the stretch of road traveled is longer than in the case of the electric grids since they turn out to be located in more cramped locations than the grids (Table 3.25).

AS-IS (Pipelines)	Worst Case	Medium Case	Best Case
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield for manual inspection [days]	476.19	476.19	476.19
Line length [km]	1,000	1,000	1,000
Manual inspection cost [€/km]	**121.43**	**119.05**	**109.52**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	4.00	3.50	3.00
Total route travelled by car [km]	2,000	2,000	2,000
Line length [km]	1,000	1,000	1,000
Transport cost [€/km]	**0.59**	**0.49**	**0.40**

Table 3.25: *Manual inspection and transport cost (AS-IS Pipelines)*

Regarding the percentage inspected by helicopter and that by direct observations, the interviews showed that this percentage differs with that of electric grids. In fact, it turns out that 70% are inspected with aircraft and the rest with direct observations.

The inspection time with the helicopter is very low and that the time needed by the operator, on the other hand, is much higher. Instead, the costs are more or less similar. The decision that was made by the companies turns out to be an average case between the two solutions and surely this is because there is not one solution that prevails over the other also because the companies do not have only cost as a driver (Graph 3.33).



Graph 3.33: *Days and cost to inspect ordinary 1,000 km of pipeline with traditional methodologies*

As for extraordinary inspections, here the companies' course of action follows a slightly different path from that of electric grids because they have a regulatory requirement to be looked at twice each year. This has definitely led companies to act differently.

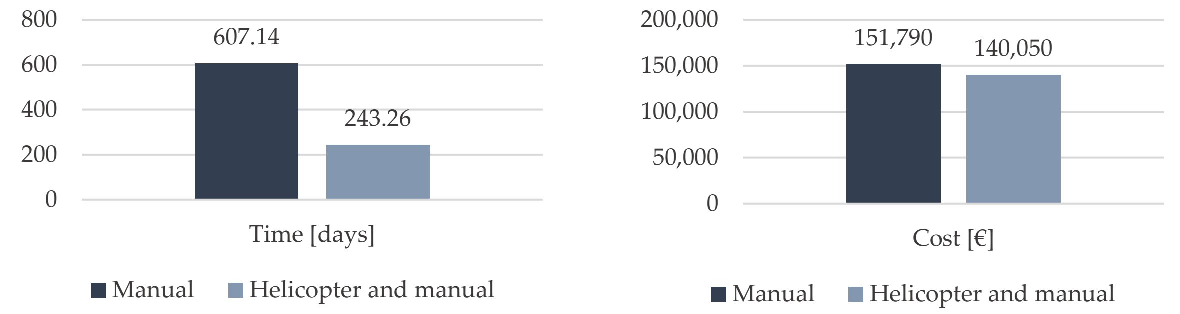
The helicopter is used to look at twice the line over the course of a year. Basically it is used to inspect 15% of the line. On the other hand, manual inspection is found to be useful to inspect 40% of the line over a year (Table 3.26).

AS-IS (Pipelines)	**Worst case**	**Medium case**	**Best case**
Extraordinary inspection time by helicopter [days/year]	1	1	1
Average helicopter extraordinary inspection cost [€/day]	5.000	5.000	5.000
Change in extraordinary inspection cost	1.05	1.00	0.95
Inspection frequency [years]	0.5	0.5	0.5
Line length [km]	1,000	1,000	1,000
Cost for extraordinary inspections by helicopter [€/km]	**2.63**	**2.50**	**2.38**
Time of extraordinary manual inspections [days/year]	190.48	190.48	190.48
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.5	0.5	0.5
Line length [km]	1,000	1,000	1,000
Cost of extraordinary manual inspection [€/km]	**24.29**	**23.81**	**21.90**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	4.00	3.50	3.00
Total route travelled by car [km/year]	800	800	800
Inspection frequency [years]	0.5	0.5	0.5
Line length [km]	1,000	1,000	1,000
Extraordinary transport cost [€/km]	**0.12**	**0.10**	**0.08**
Cost of extraordinary inspections [€/km]	**27.03**	**26.41**	**24.36**

Table 3.26: *Cost of extraordinary inspection (AS-IS Pipelines)*

From Graph 3.34 it is possible to make a comparison of what are the time and costs related to extraordinary and routine inspection for the case considered in the model. In particular, it is possible to observe how an entirely manual solution is not time-effective and it is not cost-efficient in monetary terms. The solution that has been chosen by the companies also involves the use of the helicopter, this is because in addition to having a positive impact on costs it allows the companies to have a 360-degree view of the health of the asset.

The solution involving inspection entirely by aircraft was not considered because extraordinary inspections by this method are too expensive because, the areas that are to be observed in this type of inspection are not very extensive and therefore the economic expenditure required by the helicopter would not be justified.



Graph 3.34: *Days and cost to inspect totally 1,000 km of pipeline with traditional methodologies*

Finally, there is the cost related to safety for workers. In this case it can be seen that the number of injured workers is higher than what is seen in the case of power grids. Probably the reason is due to the fact that the kilometers inspected in one case and the other are different and for pipelines they are greater. In fact, in the case of 1,000 km, if for electric networks 50 km are inspected in ordinary in a year and 200 in overtime, in the case of pipelines 600 km are inspected in ordinary and 400 in overtime. It has been reported that the injury rate is approximately 1,2% in this case. The reason is definitely related to the fact that they inspect so much line with direct observations so being a risky activity this leads to accidents (Table 3.27).

AS-IS (Pipelines)	**Worst case**	**Medium case**	**Best case**
Number of injured workers [persons/year]	12	12	12
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	0.5	0.5	0.5
Line length [km]	1,000	1,000	1,000
Cost of safety [€/km]	**29.40**	**28.00**	**26.60**

Table 3.27: *Cost of safety (AS-IS Pipelines)*

The total cost of carrying out an inspection with the traditional methodology turns out to be between 175 €/km and 156 €/km approximately. What can be noted is that it turns out to be definitely lower than that of electric grids (Table 3.28).

AS-IS (Pipelines)	Worst Case	Medium Case	Best Case
Helicopter inspection cost [€/km]	116.67	111.11	105.56
Manual inspection cost [€/km]	121.43	119.05	109.52
Transport cost [€/km]	0.59	0.49	0.40
Total Operating costs [€/km]	**118.27**	**113.64**	**106.87**
Cost for extraordinary inspections by helicopter [€/km]	2.63	2.50	2.38
Cost of extraordinary manual inspection [€/km]	24.29	23.81	21.90
Extraordinary transport cost [€/km]	0.12	0.10	0.08
Cost of extraordinary inspections [€/km]	**27.03**	**26.41**	**24.36**
Cost of safety [€/km]	**29.40**	**28.00**	**26.60**
Total AS-IS [€/km]	**174.70**	**168.05**	**157.83**

Table 3.28: *Total cost of AS-IS case of pipelines*

3.3.3.1.2.2 Case TO-BE

The TO BE case of pipelines, again turns out to be very similar to that of electric grids. As was mentioned earlier the activity being considered is inspecting "similar" assets in that they extend in length.

As far as investment costs are concerned these are the same as those defined for the electrical case. So, the companies are using a DJI 300 matrix drone with thermal camera every 500 km of line and training 2 people for each drone purchased (Table 3.29).

TO-BE (Pipelines)	Worst Case	Medium Case	Best Case
Number of drones [drones]	2	2	2
Average cost of a drone with payload [€/drone]	16,639	16,639	16,639
Change in cost of a drone with payload	1.15	1.00	0.85
Line length [km]	1,000	1,000	1,000
Drone cost [€/km]	**38.27**	**33.28**	**28.29**
Number of trained persons [persons]	4	4	4
Training course cost [€/person]	1,200	950	700
Line length [km]	1,000	1,000	1,000
Training cost [€/km]	**4.80**	**3.80**	**2.80**
Investment cost [€/km]	**43.07**	**37.08**	**31.09**

Table 3.29: *Investment cost (TO-BE Electric grids)*

As for batteries, the batteries needed in this case are six. The main reason for this difference lies in the fact that the drone's performance is greater because by avoiding vertical analysis it can inspect an average of 10,5 km/day, thus allowing for a decrease in the number of batteries needed.

This factor impacts on the costs related to battery purchase and those of battery cost. Again, companies prefer to arrive on site with charged batteries and then are recharged at the base via electricity (Table 3.30).

TO-BE (Pipelines)	Worst case	Medium case	Best case
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]	14	14	14
Change in time battery	0.80	1.00	1.20
Line length [km]	1,000	1,000	1,000
Battery purchase cost [€/km]	**8.96**	**9.80**	**10.08**
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]	14	14	14
Line length [km]	1,000	1,000	1,000
Battery charging cost [€/km]	**0.0046**	**0.0055**	**0.0062**
Battery cost [€/km]	**8.96**	**9.81**	**10.09**

Table 3.30: *Battery cost (TO-BE Electric grids)*

As for the operational cost, again it is the sum of the drone inspection cost and the transportation cost (Table 3.31). Notably, the pilots needed for an inspection always turn out to be two, but the time needed to inspect the line is less when compared to the power line. The reason is always based on the fact that the drone yield is no longer 10 km/day (Electric grid case) but 10.5 km/day (Table 3.31).

Regarding extraordinary inspections, the interviews showed that the entire pipeline line is inspected in extraordinary. The increase in the percentage inspected in a year depends on the fact that drones are able to detect more alerts and thus more inspections are completed. This of course has greater feedback in terms of cost but it certainly has a feedback in terms of increased preventive maintenance and so there will be savings due to reductions in corrective maintenance (Table 3.31).

TO-BE (Pipelines)	Worst case	Medium case	Best case
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]	158.73	158.73	158.73
Line length [km]	1,000	1,000	1,000
Cost of personnel inspection with drone [€/km]	**54.38**	**55.90**	**55.04**

AS-IS transport cost [€/km]	0.59	0.49	0.40
Percentage reduction	0.70	0.70	0.70
Transport cost [€/km]	**0.41**	**0.34**	**0.28**
Operating cost [€/km]	**54.38**	**55.90**	**55.04**
Time of extraordinary inspections with drone [days/year]	63.49	63.4	63.49
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.50	0.50	0.50
Line length [km]	1,000	1,000	1,000
Cost of extraordinary inspection with drone [€/km]	**10.79**	**11.11**	**10.95**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	4.00	3.50	3.00
Total route travelled by car [km/year]	800	800	800
Inspection frequency [years]	0.50	0.50	0.50
Percentage reduction	0.70	0.70	0.70
Line length [km]	1,000	1,000	1,000
Extraordinary transport cost [€/km]	**0.08**	**0.07**	**0.06**
Cost of extraordinary inspections [€/km]	**10.88**	**11.18**	**11.01**

Table 3.31: *Extraordinary and operative cost (TO-BE Pipelines)*

The total cost of drone inspection results, without the investment, is 81 €/km for pipelines. A result that is certainly much lower than that in the AS IS (Table 3.32).

TO-BE (Pipelines)	Worst Case	Medium Case	Best Case
Drone cost [€/km]	38.27	33.28	28.29
Training cost [€/km]	4.80	3.80	2.80
Investment cost [€/km]	**43.07**	**37.08**	**31.09**
Battery purchase cost [€/km]	8.96	9.80	10.08
Battery charging cost [€/km]	0.0046	0.0055	0.0062
Battery cost [€/km]	**8.96**	**9.81**	**10.09**
Cost of personnel inspection with drone [€/km]	53.97	55.56	54.76
Transport cost [€/km]	0.41	0.34	0.28
Operating cost [€/km]	**54.38**	**55.90**	**55.04**
Cost of extraordinary inspection with drone [€/km]	10.79	11.11	10.95
Extraordinary transport cost [€/km]	0.08	0.07	0.06
Cost of extraordinary inspections [€/km]	**10.88**	**11.18**	**11.01**
Cost of safety [€/km]	**5.88**	**4.20**	**2.66**
Total TO-BE [€/km]	**123.17**	**118.16**	**109.88**
Total TO-BE without investment [€/km]	**80.10**	**81.08**	**78.80**

Table 3.32: *Total cost TO-BE (Pipelines)*

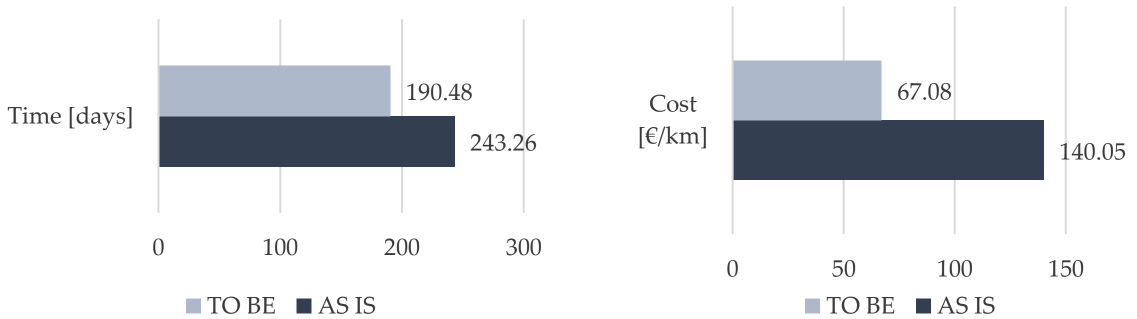
3.3.3.1.2.3 Comparison between AS-IS and TO-BE

Considering what are the times and costs related to ordinary and extraordinary inspection activities, it can be seen that the differences between the two cases are particularly important.

In particular, as far as time is concerned, it should be remembered that it is calculated considering only the work of two workers and that the activity will certainly be carried out in parallel by several operators. This data, however, can underline how the introduction of drones is actually convenient in terms of time and also more flexible in certain cases (Graph 3.35). Companies, in fact, decide to use the helicopter for their ordinary inspections because they are already aware that it will have to inspect the entire line while it is not used for extraordinary ones because there is no certainty of inspecting an amount of kilometers necessary for an aerial intervention.

The introduction of drones, on the other hand, in addition to being much more cost-effective than the manual one, also allows us to internalize the activity and use drones even for small stretches, unlike airplanes, and thus is more flexible.

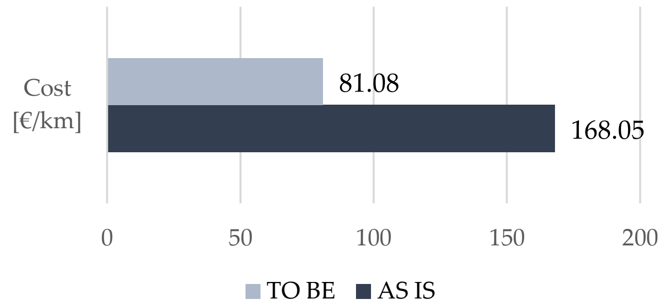
Regarding operational and extraordinary costs, it can be seen that, as in the case of electric grids, there are important savings. The percentage reduction that can be observed is about 52% (62% for electric grids) (Graph 3.35).



Graph 3.35: *Time and cost related to ordinary and extraordinary inspection in AS-IS and TO-BE scenarios (Pipelines)*

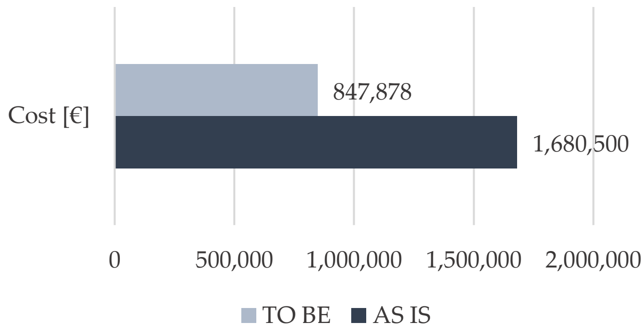
Considering all the costs that can be associated with the activity, excluding the investment cost for drone inspection, there will be a significant reduction in costs, similar to that anticipated already in the case of power grids.

Specifically, a reduction of about 52% will be achieved, compared to 66% for electric grids. However, the result obtained is clear evidence of the benefit that drones bring to this type of activity. Furthermore, it should always be considered that this is not the only benefit that companies can rely on, and this value will be greater as the model created is not inclusive of all the maintenance-level savings that can be achieved (Graph 3.36).



Graph 3.36: *Total costs in the AS-IS and TO-BE scenarios (Pipelines)*

Finally, it was aimed to analyze what is the total benefit by also considering the investment cost. Taking into consideration the 1,000-line kilometers and five years as the horizon time (useful life of the drones), it was again possible to see even with the investment the economic benefit from the inclusion of UAVs, about 50% (Graph 3.37)



Graph 3.37: *Evaluation of the investment (Pipelines)*

3.3.3.1.3 Solar panels

3.3.3.1.3.1 Case AS-IS

The behavior of the various solar companies with regard to operational cost is traced back to the direct inspections that are carried out on the solar panels. Specifically, for this type of inspection, it was stated that the helicopter is not used. The activity is carried out by two operators who together inspect the asset. Specifically, from the different case studies, later also validated by drone specialists, it was found that one observer manages to inspect 1 MW every 5 hours on average. This thus translates to a yield of 1,6 MW/day. The cost of manually inspecting one MW is thus found to be between 266 €/MW and 240 €/MW.

What can be noted is that the cost of transportation is not present. This was not taken into account because all costs that could be differential from one case and another were considered, and the cost of transportation turns out to be the same. In addition, as also seen for the two previous cases, the cost of transportation would not be so influential as to go to the extent of distorting the analysis that is being done, and thus would turn out to be a very insignificant cost (Table 3.33).

AS-IS (Solar panels)	Worst case	Medium case	Best case
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield for manual inspection [days]	1,041.67	1,041.67	1,041.67
Installed capacity [MW]	1,000	1,000	1,000
Manual inspection cost [€/MW]	**265.63**	**260.42**	**239.58**

Table 3.33: *Manual inspection cost (AS-IS Solar panels)*

As a result of the interviews, all cases related to the inspection of solar panels claimed to carry out the observations on the entire park once a year for this reason the frequency of inspections in the created model was considered to be one year. Specifically, during this period the ordinary inspection is carried out, while for what concerns the extraordinary inspection the companies claimed to inspect 10% of the line in extraordinary every year (Table 3.34).

AS-IS (Solar panels)	Worst case	Medium case	Best case
Time of extraordinary manual inspections [days/year]	104.17	104.17	104.17
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	1	1	1
Installed capacity [MW]	1,000	1,000	1,000
Cost of extraordinary manual inspection [€/MW]	**26.56**	**26.04**	**23.96**

Table 3.34: *Cost of extraordinary inspection (AS-IS Solar panels)*

Although the previously discussed cases are not comparable in monetary terms with the current one, because inspections are done in totally different manners, it can be seen that for solar parks much less is inspected. This is probably due to the fact that the other types of assets need more inspection. This inspection activity on electric grids and pipelines is not only aimed at inspecting the health of the asset, as it is for solar, but also needs to observe how the vegetation around the asset grows and make assessments if there is a "threat" to the health of the infrastructure.

In addition, none of the companies stated that they use helicopters as a traditional tool for inspection. This could stem from the fact that since they are a particularly important cost to bear, it makes sense to introduce them if there are long stretches to be inspected. So, the way solar farms are structured probably makes more sense to use manual inspection alone.

The number of injuries for this activity results in an average of 2 people per year. This figure was defined by the interventions of the different companies. Notably, this is also in line with the analysis of intangibles in Intangible analysis since this activity is not high risk for the observer. Manual observation does not involve special hazards such as there may be for other infrastructures because the operator is not in highly dangerous locations and does not have to, for example, be harnessed while performing the activity. So as could be expected this cost item does not have a significant impact on the total cost of the activity itself (Table 3.35).

AS-IS (Solar panels)	**Worst case**	**Medium case**	**Best case**
Number of injured workers [persons/year]	2	2	2
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	1	1	1
Installed capacity [MW]	1,000	1,000	1,000
Cost of safety [€/MW]	**9.80**	**9.33**	**8.87**

Table 3.35: *Cost of safety (AS-IS Solar panels)*

In conclusion, in the AS-IS case for the inspection of solar panels, it still turns out that the cost per MW is not a small cost, but on the contrary, this is around 296 €/MW for what concerns the average case and has been estimated to be up to 302 €/MW. The composition of this cost, as it has been just explained, is fundamentally burdened by manual inspections which are therefore particularly onerous (Table 3.36).

AS-IS (Solar panels)	Worst Case	Medium Case	Best Case
Manual inspection cost [€/MW]	265.63	260.42	239.58
Cost of extraordinary manual inspection [€/MW]	26.56	26.04	23.96
Cost of safety [€/MW]	9.80	9.33	8.87
Total AS-IS [€/MW]	**301.99**	**295.79**	**272.41**

Table 3.36: *Total AS-IS (Solar panels)*

3.3.3.1.3.2 Case TO-BE

The new perspective, consisting of the introduction of drones, no longer involves the use of manpower for manual inspections, but only for piloting the drones.

The investment cost in this case also consists of the cost of training plus the cost of purchasing the drones.

The various interviewees of the solar park case studies and specialists stated that on average a drone is needed for every 750 MW. Thus, for example, in the considered case of 1,000MW, 1.33 drones would be needed, therefore, two drones were considered necessary to perform the task (Table 3.37).

The drone preferred by the companies in this case also turns out to be DJI's Array 300, but with the difference that a different payload is required to complete the inspection of these types of assets. The decision fell for the different case studies on a dual camera, i.e., a payload with a high-resolution camera (Table 3.37).

As far as the cost of training is concerned, again two people are needed for an inspection (Table 3.37).

TO-BE (Solar panels)	Worst Case	Medium Case	Best Case
Number of drones [drones]	2	2	2
Average cost of a drone with payload [€/drone]	22,483	22,483	22,483
Change in cost of a drone with payload	1.15	1.00	0.85
Installed capacity [MW]	1,000	1,000	1,000
Drone cost [€/MW]	**51.71**	**44.97**	**38.22**
Number of trained persons [persons]	4	4	4
Training course cost [€/person]	1,200	950	700
Installed capacity [MW]	1,000	1,000	1,000
Training cost [€/MW]	**4.80**	**3.80**	**2.80**
Investment cost [€/MW]	**56.51**	**48.77**	**41.02**

Table 3.37: *Investment cost (TO-BE Solar panels)*

As far as the cost of the batteries is concerned, it was estimated, considering the time required to complete the inspection, that 8 batteries are needed. Furthermore, these respondents also claimed to arrive on site with the batteries already charged. In this case, the cost for batteries is around 6 €/MW (Table 3.38).

TO-BE (Solar panels)	Worst case	Medium case	Best case
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]	8	8	8
Change in time battery	0.80	1.00	1.20
Installed capacity [MW]	1,000	1,000	1,000
Battery purchase cost [€/MW]	**5.12**	**5.60**	**5.76**
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]	8	8	8
Installed capacity [MW]	1,000	1,000	1,000
Battery charging cost [€/MW]	**0.0026**	**0.0031**	**0.0036**
Battery cost [€/MW]	**5.12**	**5.60**	**5.76**

Table 3.38: *Battery cost (TO-BE Solar panels)*

The cost of ordinary inspections depends on the cost of the pilots and the duration that the inspections require. This activity is carried out by two operators at the same time that together use the drone for inspection. In particular, the result of the interviews is that one drone can inspect 1MW in 30 minutes, thus 16MW in one working day. It turns out that in the worst case, senior personnel will spend about 35.50 €/MW, in the medium 36,50 €/MW and in the best case about 36 €/MW (Table 3.39).

TO-BE (Solar panels)	Worst case	Medium case	Best case
Pilot for inspection [persons]	2	2	2
Pilot cost [€/(day*person)]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]	104.17	104.17	104.17
Installed capacity [MW]	1,000	1,000	1,000
Cost of personnel inspection with drone [€/MW]	**35.42**	**36.46**	**35.94**

Table 3.39: *Operating cost (TO-BE Solar panels)*

As far as extraordinary inspections are concerned, solar panel companies claim to inspect half of their facilities in a year. Furthermore, the companies' decision following the introduction of drones was to double the inspection frequency. What emerges is that in this case, companies inspect everything once every six months and, in parallel, a 20% of the park is inspected due to presence of alerts. So, taking this case as an example, 2,200 MW are inspected in one year, so the panels are inspected 2.2 times in one year (Table 3.40).

TO-BE (Solar panels)	Worst case	Medium case	Best case
Time of extraordinary inspections with drone [days/year]	20.83	20.83	20.83
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.50	0.50	0.50
Installed capacity [MW]	1,000	1,000	1,000
Cost of extraordinary inspection with drone [€/MW]	**3.54**	**3.65**	**3.59**

Table 3.40: *Extraordinary inspection (TO-BE Solar panels)*

Finally, the cost related to safety is very small indeed. Already in the case of AS-IS, a low cost can be seen as the number of injuries is very low. Given the substantial decrease that occurs with the introduction of drones on inspection-related risks, there is also a considerable decrease in the cost related to injuries (Table 3.41). As well as being a benefit in economic terms for the activities, this is a positive aspect for the work in terms of safety. In fact, during the interviews the companies insisted much more on the importance of the risks associated with the activity rather than the decrease in the accident cost.

TO-BE (Solar panels)	Worst case	Medium case	Best case
Number of injured workers [persons/year]	2	2	2
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	0.50	0.50	0.50
Installed capacity [MW]	1,000	1,000	1.000
Cost of safety [€/MW]	**0.98**	**0.70**	**0.44**

Table 3.41: *Cost of safety (TO-BE Solar panels)*

The total cost of the activity following the introduction of drones decreases. It can be seen that the total costs without considering the investment amount to approximately 46 €/MW (Table 3.42).

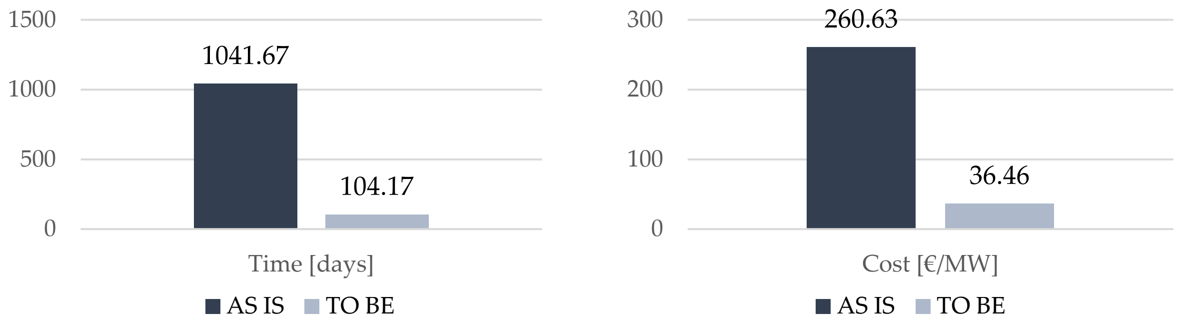
TO-BE (Solar panels)	Worst Case	Medium Case	Best Case
Drone cost [€/MW]	51.71	44.97	38.22
Training cost [€/MW]	4.80	3.80	2.80
Investment cost [€/MW]	**51.51**	**48.77**	**41.02**
Battery purchase cost [€/MW]	5.12	5.60	5.76
Battery charging cost [€/MW]	0.0026	0.0031	0.0035
Battery cost [€/MW]	**5.12**	**5.60**	**5.76**
Cost of personnel inspection with drone [€/MW]	**35.42**	**36.46**	**35.94**
Cost of extraordinary inspection with drone [€/MW]	**3.54**	**3.65**	**3.59**
Cost of safety [€/MW]	**0.98**	**0.70**	**0.44**
Total BE-TO [€/MW]	**101.57**	**95.17**	**86.76**
Total TO-BE without investment [€/MW]	**45.06**	**46.41**	**45.74**

Table 3.42: *Total TO-BE (Solar panels)*

3.3.3.1.3.3 Comparison between AS-IS and TO-BE

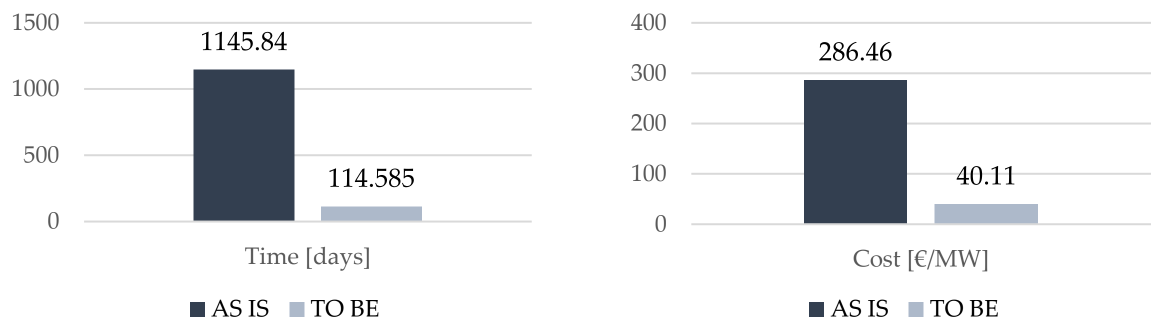
The introduction of drones for the inspection of solar panels certainly brings an economic benefit, as can be seen from Graph 3.38. In particular, looking at the time required to perform the inspection on a park producing 1,000 MW, it can be seen that the decrease in terms of days is substantial, reaching a reduction of 90% (Graph 3.38).

As far as operating costs are concerned, a considerable decrease can also be seen here, by about 86%. The reason for this decrease is substantially due to the reduction in the time required for the activity, as it can actually be seen that the cost of a drone pilot is higher than that of an AS IS case operator, and this is why the reductions are different (Graph 3.38).



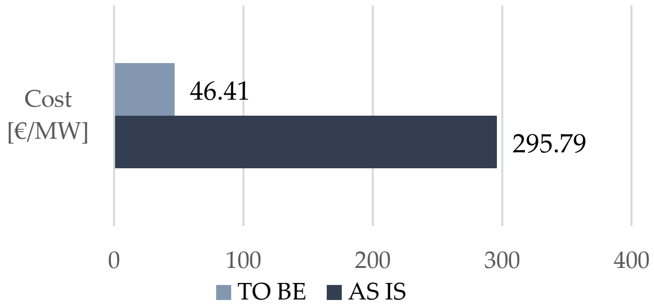
Graph 3.38: *Operating time and cost in AS-IS and TO-BE scenarios (Solar panels)*

Considering the inspection part of the costs, i.e., the ordinary inspection and the extraordinary inspection, the decrease in time is the same as the percentage noted when considering only operational time and thus amounts to 90%. This number is very close to those of the other clusters. On the other hand, as far as costs are concerned, here the decrease also remains constant with the result of operating costs and thus a reduction of 86% (Graph 3.39).



Graph 3.39: *Extraordinary and operating time and cost in AS-IS and TO-BE scenarios (Solar panels)*

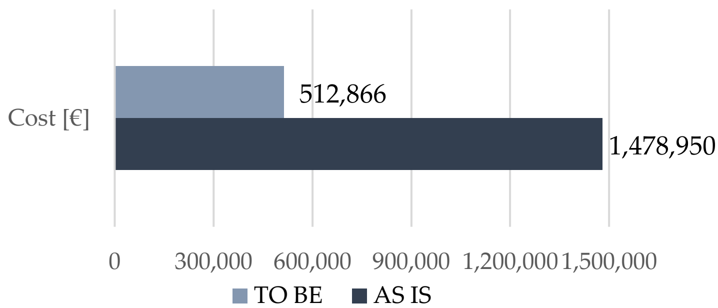
As far as the total cost of inspection is concerned, excluding investment costs, it is clear from the graph that this new technology in monetary terms is really worthwhile. The savings that a company can achieve are considerable, and according to what has been gathered from companies is around 84%. It is to be considered that this saving will increase because, as has already been mentioned, all those indirect costs that generate costs that the company will no longer have to face, such as corrective maintenance costs (Graph 3.40).



Graph 3.40: *Total cost in AS-IS and TO-BE scenario (Solar panels)*

Graph 3.41 shows the cost difference between the AS-IS and TO-BE cases over a five-year period (drone life cycle). This is useful to assess whether the investment in the new technology could be justified and whether it would not result in a higher cost considering the purchase cost of UAVs.

Although the savings in this case amount to 65%, which is much lower than the reductions seen so far, it must be remembered that if in the AS-IS case five inspections can be carried out, in the TO-BE case these inspections increase, and furthermore, the possibility of increasing the efficiency and quality of the activity allows companies to increase their ability to identify damage and act preventively (Graph 3.41).



Graph 3.41: *Evaluation of the investment (Solar panels)*

3.3.3.1.4 Wind turbines

3.3.3.1.4.1 Case AS-IS

The case of inspection for wind turbines, as already mentioned, is very similar to that of solar panels. In particular, the total cost refers to the installed power and therefore all macro-cost items will be calculated in €/MW.

The operational inspection cost item refers only to the manual inspection cost item. The interviews showed that the different case studies perform the activity with two operators. These, in one working day, manage to inspect four turbines per day.

Furthermore, since the average power of a turbine conserving the companies inspected is 2 MW/turbine, the output in a working day is 8 MW without considering overhead times. In our case, therefore, with 1,000 MW installed, the number of days needed to inspect the entire wind farm is approximately 209 (Table 3.43).

This means that a company will spend about 52 €/MW to inspect the wind farm operationally (Table 3.43).

AS-IS (Wind turbines)	Worst Case	Medium Case	Best Case
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire solar park yield for manual inspection [days]	208.33	208.33	208.33
Installed capacity [MW]	1,000	1,000	1,000
Manual inspection cost [€/MW]	**59.38**	**52.08**	**43.75**

Table 3.43: *Manual inspection cost (AS-IS Wind turbines)*

Again, extraordinary inspections are mentioned. In particular, it was found that 10% of the installed power will be inspected during one year. Thus, in the case under consideration, 21 days will be dedicated to the extraordinary inspection of turbines during one year. The companies stated that this activity is carried out once a year and that therefore the wind farm is observed in an operational manner once a year and then in an extraordinary manner when alarms occur. The cost of extraordinary inspections is around 5 €/MW (Table 3.44).

AS-IS (Wind turbines)	Worst Case	Medium Case	Best Case
Time of extraordinary manual inspections [days/year]	20.83	20.83	20.83
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	1	1	1
Installed capacity [MW]	1,000	1,000	1,000
Cost of extraordinary manual inspection [€/MW]	**5.31**	**5.21**	**4.79**

Table 3.44: *Extraordinary cost (AS-IS Wind turbines)*

Finally, as far as the cost related to injuries is concerned, this is quite high compared to the total cost of the activity. In fact, it can be seen that the number of injuries in a year averages 6 operators. Again, this is not a number that is impressive since, as already mentioned in Paragraph x.x, the activity in question is risky for the operator, who is required to travel to the top of the turbine in order to inspect it completely. This cost amounts to approximately 28 €/MW (Table 3.45).

AS-IS (Wind turbines)	Worst Case	Medium Case	Best Case
Number of injured workers [people/year]	6	6	6

Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	1	1	1
Installed capacity [MW]	1,000	1,000	1,000
Cost of safety [€/MW]	**29.40**	**28.00**	**26.60**

Table 3.45: *Cost of safety (AS-IS Wind turbines)*

The total cost for wind turbines inspections in the AS IS case is 85 €/MW, which is much lower than in the cases handled so far (Table 3.46).

AS-IS (Wind turbines)	**Worst Case**	**Medium Case**	**Best Case**
Manual inspection cost [€/MW]	59.38	52.08	43.75
Cost of extraordinary manual inspection [€/MW]	5.31	5.21	4.79
Cost of safety [€/MW]	29.40	28.00	26.60
Total AS-IS [€/MW]	**94.09**	**85.29**	**75.14**

Table 3.46: *Total AS-IS (Wind turbines)*

3.3.3.1.4.2 Case TO-BE

The new scenario proposed in the wind energy sector is to use one drone for every 500 MW installed, which means that companies use one drone for every 250 turbines approximately. The most commonly used drones also in this case are DJI's Array 300, while the payload installed on them is a thermal chamber, the same as in the case of electric grids and pipelines (Table 3.47). The total cost of purchasing the drone will therefore be 33 €/MW (Table 3.47).

The cost of training, on the other hand, is again based on the fact that for each drone there are two people who can use it with a cost per MW of around €4 (Table 3.47).

TO-BE (Wind turbines)	**Worst Case**	**Medium Case**	**Best Case**
Number of drones	2	2	2
Average cost of a drone with payload [€/drone]	16,639	16,639	16,639
Change in cost of a drone with payload	1.15	1.00	0.85
Installed capacity [MW]	1,000	1,000	1,000
Drone cost [€/MW]	**38.27**	**33.28**	**28.29**
Number of trained persons [persons]	4	4	4
Training course cost [€/person]	1,200	950	700
Installed capacity [MW]	1,000	1,000	1,000
Training cost [€/MW]	**4.80**	**3.80**	**2.80**
Investment cost [€/MW]	**43.07**	**37.08**	**31.09**

Table 3.47: *Investment cost (TO-BE Wind turbines)*

The cost of the batteries, on the other hand, considers, as in the other cases, the need for the Matrice 300 drone to have two batteries installed and the number of batteries required. This depends on the time needed to inspect the wind park and, for example, in our case 6 batteries are needed to complete the inspection. The cost of the batteries therefore amounts to approximately 4 €/MW. Again, companies prefer to arrive at the workplace with the batteries already charged and only in extreme cases recharge them by car. It therefore turns out that the cost of battery charging is very low and not very relevant as it is less than 1 cent (Table 3.48).

TO-BE (Wind turbines)	Worst Case	Medium Case	Best Case
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]	**6**	**6**	**6**
Change in time battery	0.80	1.00	1.20
Installed capacity [MW]	1,000	1,000	1,000
Battery purchase cost [€/MW]	**3.84**	**4.20**	**4.32**
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]	6	6	6
Installed capacity [MW]	1,000	1,000	1,000
Battery charging cost [€/MW]	**0.0020**	**0.0023**	**0.0027**
Battery cost [€/MW]	**3.84**	**4.20**	**4.32**

Table 3.48: *Battery cost (Wind turbines)*

The inspections in the different case studies are carried out by two drones, who can observe 10,67 turbines per day, i.e. 21 MW in one working day. In the specific case, 1,000 MW of wind farm requires 79 days to complete the inspection of the wind farm. From the model, it can be seen that the cost of operational inspection amounts to 27 €/MW (Table 3.49).

On the other hand, even in this case, extraordinary inspections are necessary. One of the benefits that can be gained is an increase in the quality of inspections, and thus the possibility of better identifying damage and critical points. This can also be seen in this model as extraordinary inspections are carried out on 15% of the fleet in a year, compared to 10% in the case of AS IS. In addition, the frequency of inspections also increases. The interviews showed that companies inspect the entire fleet every five months. The cost for extraordinary inspections is very low and amounts to about 4 €/MW (Table 3.49).

TO-BE (Wind turbines)	Worst Case	Medium Case	Best Case
Pilot for inspection [persons]	2	2	2
Pilot cost [€/(day*person)]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]	78.13	78.13	78.13

Installed capacity [MW]	1,000	1,000	1,000
Cost of personnel inspection with drone [€/MW]	**26.56**	**27.34**	**26.95**
Time of extraordinary inspections with drone [days/year]	11.72	11.72	11.72
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.42	0.42	0.42
Installed capacity [MW]	1,000	1,000	1,000
Cost of extraordinary inspection with drone [€/MW]	**1.65**	**1.70**	**1.68**

Table 3.49: *Ordinary and extraordinary cost (TO-BE Wind turbines)*

Finally, with regard to injured personnel, as in the other cases, the cost sees an important decrease. This cost falls from 28 €/MW to around 2 €/MW. This makes us realise that the number of injured persons decreases considerably (Table 3.50).

TO-BE (Wind turbines)	Worst Case	Medium Case	Best Case
Number of injured workers [persons/year]	6	6	6
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	0.42	0.42	0.42
Installed capacity [MW]	1,000	1,000	1.000
Cost of safety [€/MW]	**2.44**	**1.74**	**1.10**

Table 3.50: *Cost of safety (TO-BE Wind turbines)*

The total cost in the TO-BE case turns out to be around 35 €/MW without considering the necessary investment cost to be made about every five years (Table 3.51).

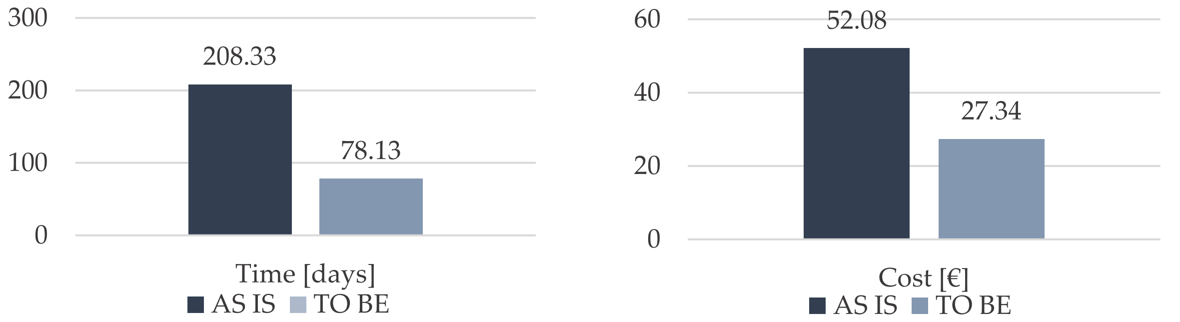
TO-BE (Wind turbines)	**Worst Case**	**Medium Case**	**Best Case**
Drone cost [€/MW]	38.27	33.28	28.29
Training cost [€/MW]	4.80	3.80	2.80
Investment cost [€/MW]	**43.07**	**37.08**	**31.09**
Battery purchase cost [€/MW]	3.84	4.20	4.32
Battery charging cost [€/MW]	0.0020	0.0023	0.0027
Battery cost [€/MW]	**3.84**	**4.20**	**4.32**
Cost of personnel inspection with drone [€/MW]	**26.56**	**27.34**	**26.95**
Cost of extraordinary inspection with drone [€/MW]	**1.65**	**1.70**	**1.68**
Cost of safety [€/MW]	**2.44**	**1.74**	**1.10**
Total TO BE [€/MW]	**77.57**	**72.07**	**65.14**
Total BE-TO without investment [€/MW]	**34.50**	**34.99**	**34.06**

Table 3.51: *Total TO-BE (wind turbines)*

3.3.3.1.4.3 Comparison between AS-IS and TO-BE

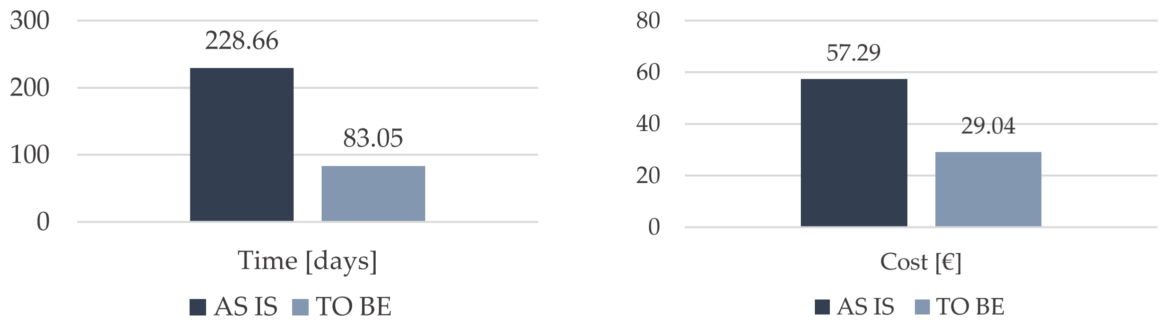
The case of turbines is a case of a separate nature, with smaller reductions than in the cases seen so far.

With regard to operational inspection and the time associated with it, it can be seen that there is a decrease: it is possible to move from 2 hours to 45 minutes per turbine. This means that a decrease of about 63% in time can be achieved. On the other hand, as far as costs are concerned a 48% reduction can be observed. These results depend on the fact that the cost of the drone pilots is higher than that of the operators and therefore the savings will always be smaller than the costs and not proportional (Graph 3.42).



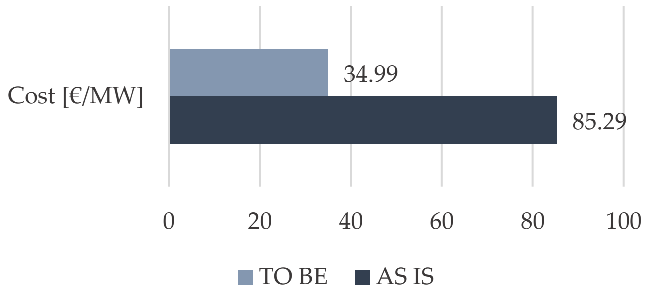
Graph 3.42: *Operating time and cost in AS-IS and TO-BE scenarios (wind turbines)*

Taking ordinary and extraordinary inspections into account, it can be seen that savings can be achieved based on time are about 63% and the ones regarding costs are about 49% (Graph 3.43).



Graph 3.43: *Ordinary and extraordinary time and cost in the AS-IS and TO-BE scenarios (Wind turbines)*

From the Graph 3.44 can be seen that the costs in the TO-BE case are lower than in the AS-IS. In particular, the reduction that is possible to obtain, without considering the investment, is about a 59%.

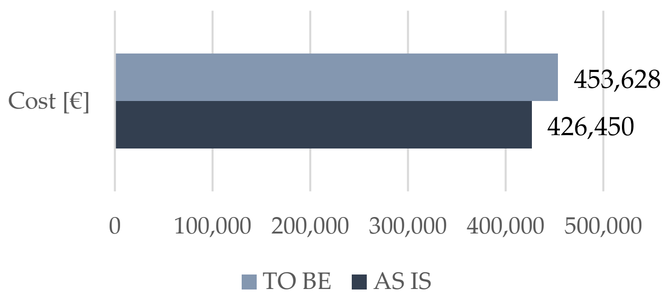


Graph 3.44: *Total cost in the AS-IS and TO-BE scenarios (Wind turbines)*

Considering the case illustrated in the model, the five-year useful life of the drone will be examined to assess the investment.

Turning out to be a more particular case, it can be observed that the difference between the two costs is not so substantial. In fact, it turns out that the two costs differ by 6%. Of course, it has to be considered that this increase will be smaller as more savings are expected as a result of the introduction of drones mainly due to quality issues.

Furthermore, it must be remembered that two completely identical cases are not being compared. In the TO-BE case, more and more MWs are inspected overtime than in the AS-IS because one of the benefits of introducing this new technology is the possibility to better identify damages, so this leads to more inspections of the infrastructure. A final factor is the question of frequency: inspections in the case of AS-IS take place every year, whereas in the new scenario they take place every four months. This certainly leads to an increase in costs, as shown in Graph 3.45 but as this is not the only driver to be taken into consideration, in the totality of the solution the option of introducing drones cannot be discarded in advance.



Graph 3.45: *Evaluation of investment (Wind turbines)*

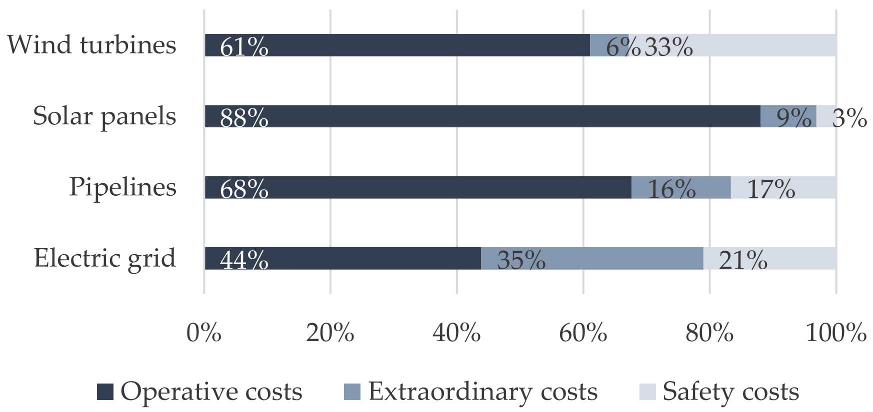
3.3.3.1.5 Cluster analysis

The analysis that has just been carried out is useful in order to understand what savings companies would be able to achieve with the above-mentioned cost items, without considering the possible savings that could be achieved with the various benefits resulting from the introduction of technology. This section will compare the different models created.

First, it is aimed to investigate how costs are distributed in the different scenarios considered.

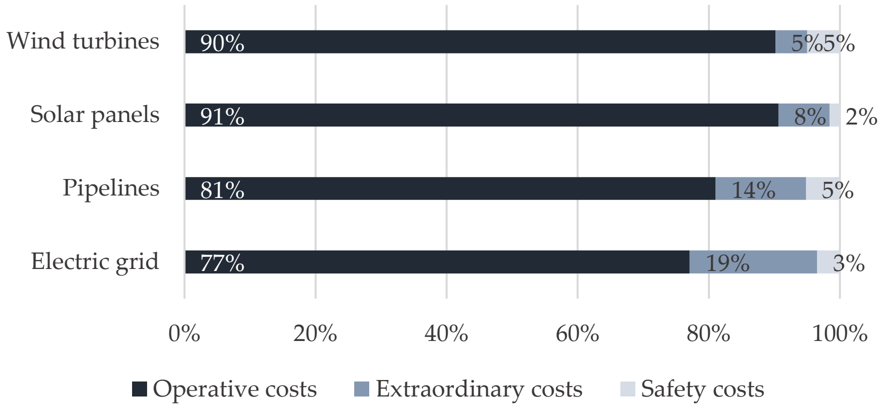
The data on which the analysis is carried out, in terms of line length and installed power, are those for the different models, i.e., 1,000 km for electric grids and pipeline clusters and 1,000 MW for solar and wind power.

Taking the AS-IS case into consideration, it can be seen from Graph 3.46 that the operating activity is the cost with the greatest impact on the activity. Different behaviour, on the other hand, can be seen with regard to the other two macro-cost items. Each case has a different behaviour. In the case of electric grids, the cost of safety and extraordinary inspection are slightly different with a variation of 14%. In the case of pipelines these two cost items are balanced and have almost equal incidence. It is important to note that the cost of safety for these two cases result close to 20% of the total. The difference comes from the costs related to the operational and extraordinary costs: for pipelines the first one is higher than the second one while for electric grids they are closer to each other. The case of solar and turbines, on the other hand, behave differently. In the solar case, the cost of safety does not affect the total so much because, as mentioned already, the activity has a lower risk than the other cases. For turbines, on the other hand, the opposite occurs; the safety cost has a very high incidence on the total because the operators are required to carry out the inspection activities at height (Graph 3.46).



Graph 3.46: *Distribution of the main costs in the AS-IS case by the different infrastructures*

In the TO-BE case, on the other hand, it can be seen that the operating costs, relating to the cost of the battery and inspection, have the greatest impact on the total cost of the activity. In particular, it can be noted that the two clusters of electric grids and pipelines find that this cost affects about 80% of the total, while the other two clusters note an incidence of about 90%. With regard to the other costs, extraordinary and safety costs, it can be noted that the first two clusters (electric grids and pipelines) find a 4% cost for safety and a 16% cost for extraordinary inspections, while the other two clusters (solar and wind) find a 7% cost for injuries and a 3% cost for extraordinary inspections (Graph 3.47).



Graph 3.47: *Distribution of the main costs in the TO-BE case by the different infrastructures*

Another aspect to be investigated is a comparison of the different time and cost savings between the AS-IS case and the TO-BE case.

It can be seen from Table 3.52 that each case has its own behaviour.

Electric grids show an important decrease in the case of time and cost when comparing the expense of an inspection between one methodology and another. This proportion is zero when evaluating the investment because the frequency of inspections in the TO-BE case is increased. It is important to consider that, this reduction will be more significant as additional cost savings must be considered. In the case of pipelines, companies can gain significant reductions in costs both considering only one inspection and the investment over the 5-year life of the drone. on the other hand, time reduction is not as important as cost reduction.

From Table 3.52 it can be seen that in the case of solar panels and turbines, the decrease is very high in terms of both cost (86% in solar and 49% in wind) and time (90% in solar and 63% in wind). As far as the investment is concerned, on the other hand, this is worthwhile in the case of solar with a reduction of 65%, whereas it is apparently not worthwhile in the case of wind power. The reason stems from the fact that wind power increases the frequency of inspection by 300% while wind power by

200%. In addition, it must always consider those cost savings that result from the introduction of drones and which will therefore take the solution from disadvantageous to advantageous even with an increase in the frequency of inspections.

	Reduction of operative and extraordinary time	Reduction of total costs	Reduction of total costs in 5 years
Electric grids	47%	62%	0%
Pipelines	22%	52%	50%
Solar panels	90%	86%	65%
Wind turbines	63%	49%	-6%

Table 3.52: *Percentage of reduction of costs, time and total costs considering the investment*

In order to better understand the advantages obtained from the introduction of drones, it was decided to study the differences between the different yields. What can be seen from Table 3.53 is that the time reductions for the turbine case is the smallest respect the other cases and, in particular, for solar panels the increase of yield is really higher than in the case of wind turbines. For electric grids and pipelines, the relative yields in both scenarios are similar (Table 3.53).

	AS-IS yield	TO-BE yield	Yield Increasing
Electric grids	2.8 [km/day]	9.8 [km/day]	3.5
Pipelines	3.5 [km/day]	10.5 [km/day]	3
Solar panels	1.6 [MW/day]	16 [MW/day]	10
Wind turbines	8 [MW/day]	21.33 [MW/day]	2.66

Table 3.53: *Yield in the AS-IS and TO-BE cases by the different infrastructures inspected*

At this point, for the clusters for which it is economically advantageous to introduce the technology, i.e., pipelines and solar panels, it is interesting to carry out additional analysis to understand the minimum amount of km and MW to be inspected to justify the investment in UAVs. In addition, the case of electric grids is also considered, as it can be analysed whether the use of manual inspection as a traditional methodology may be more costly than the use of drones for inspection.

In the case of electric grids, since the investment results apparently non convenient only one cases was considered. Firstly, the critical point at which it is better to use one technology than another in AS-IS were first defined. The Equation 3.29 is intended to investigate the maximum amount of line where only manual inspection should be used.

$$0{,}9 * X = 150 \rightarrow X = 170\text{km}$$

Equation 3.29: *Critical point (electric grids)*

The objective of this analysis is to identify, based on the assumptions made within the model, for which types of companies it makes sense to introduce the new technology and for which it makes sense to keep the old one. Four scenarios were considered and the optimal solutions for each scenario were investigated.

In the scenario for electric lines, it was considered the case where the company, with up to a maximum of 170 km of line, operates with only manual inspections in the AS-IS case and in the TO-BE case it operates with only one drone because, as mentioned above, it makes sense to purchase one drone for every 500 km of line and consequently train 2 people (Equation 3.30).

$$\frac{5}{2} * [166.67 * X + 145.83 * X + 56{,}00 * X] \geq \frac{5 * 90.51 * X}{0{,}75} + 29{,}268 * 1 + 2 * 950 \quad if X < 17$$

Equation 3.30: *Inequation to define the minimum line length to insert drones (electric grids)*

The first scenario is only cost-effective if you have a power line longer than 98 km and not greater than 170 km (Equation 3.31).

$$317.85 * X \geq 31{,}168 \quad \rightarrow \; X \geq 98.05 \qquad\qquad if \; X < \; 170$$

Equation 3.31: *Result of the inequation to define the minimum line length to insert drones (electric grids)*

Also in the case of pipelines, the critical points where it is better to use one technology than another in AS-IS were first defined.

Equation 3.32 represents the maximum amount of line where it makes sense to use manual inspection alone, as for shorter lengths the helicopter is inconvenient. Equation 3.33 is intended to investigate the maximum amount of line in which it makes sense to use both technologies, manual and helicopter, for operational inspections only and for extraordinary inspections the use of direct observations only.

$$0{,}7 * X = 150 \; \rightarrow \; X = 214 \; km$$

Equation 3.32: *First critical point (Pipelines)*

$$0{,}15 * X = 150 \; \rightarrow X = 1.000 \; km$$

Equation 3.33: *Second critical point (Pipelines)*

At this point, having identified the optimal solutions to be used in the AS-IS case, it is possible to assess when it is convenient to discard traditional methodologies and introduce drones.

The first scenario, in which the company covers a maximum of 214 km, considers in the AS-IS case only manual inspections and in the TO-BE case only drone inspections as only one UAV needs to be purchased up to 500 km and consequently, it is necessary to train 2 people (Equation 3.34).

In the second and third scenarios, both helicopter and direct observations for ordinary inspections and direct observations for extraordinary inspections are considered in the AS-IS case. In TO-BE, on the other hand, the number of drones used, and consequently the persons trained, are different depending on the amount of line observed (Equation 3.34).

In the fourth scenario, on the other hand, in the AS-IS case, both methodologies are used for each type of inspection, whereas in the TO-BE the number of drones considered is 3 and consequently 6 people trained (Equation 3.34).

$$
\begin{cases}
\frac{5}{0.5} * [(119.05 + 0{,}49) * X + 32.74 * X + 28 * X] \geq \frac{5 * 81.08 * X}{0{,}5} + 16{,}639 * 1 + 2 * 950 & if X < 214 \\
\frac{5}{0{,}5} * [113.64 * X + 32.74 * X + 28 * X] = \frac{5 * 81.08 * X}{0{,}5} + 16{,}639 * 1 + 2 * 950 & if\ 214 \leq X > 500 \\
\frac{5}{0{,}5} * [113.64 * X + 26{,}41 * X + 28 * X] = \frac{5 * 81.08 * X}{0{,}5} + 16{,}639 * 2 + 4 * 950 & if\ 500 \leq X > 1{,}000 \\
\frac{5 * 168.05 * X}{0{,}5} = \frac{5 * 81.08 * X}{0{,}5} + 16{,}639 * 3 + 6 * 950 & if\ X \geq 1{,}000
\end{cases}
$$

Equation 3.34: *Inequations to define the minimum line length to insert drones within different scenarios (pipelines)*

From these results, what can be seen is that in the last three cases, the equation is always verified, i.e., when a company has more than 214 km of pipelines, it is cost-effective to introduce UAVs for inspection activities. On the other hand, if the company has less than 214 km of pipelines, it is cost-effective to introduce drones if and only if the pipelines cover more than 18.68 km in length (Equation 3.35).

$$
\begin{cases}
992 * X \geq 18{,}539 \rightarrow X \geq 18.68 & if\ X < 214 \\
933 * X \geq 18{,}539 \rightarrow X \geq 19.87 & if\ 214 \leq X > 500 \\
869.7 * X \geq 37{,}078 \rightarrow X \geq 42.63 & if\ 500 \leq X \geq 1{,}000 \\
869.7 * X \geq 55{,}617 \rightarrow X \geq 63.95 & if\ X > 1{,}000
\end{cases}
$$

Equation 3.35: *Results of inequations to define the minimum line length to insert drones within different scenarios (pipelines)*

In the case of solar, only one critical point was considered, as a helicopter is not used for this type of inspection. In fact, the evaluation was limited to comparing the traditional methodology of manual observations with the new drone technology. In particular, it was intended to assess the scenario where only one drone was needed and the scenario where two drones were needed. The interviewees who were taken into consideration argued that it would be necessary to have one drone for every 750MW of power (Equation 3.36).

$$\begin{cases} 295.79 * X * \frac{5}{1} \geq 46.41 * X * \frac{3}{0,5} + 22.483 * 1 + 2 * 950 \quad if\ X < 750MW \\ 295.79 * X * \frac{3}{1} \geq 46.41 * X * \frac{5}{0,5} + 22.483 * 2 + 4 * 950 \quad if\ X \geq 750M \end{cases}$$

Equation 3.36: *Inequations to define the minimum line length to insert drones within different scenarios (solar panels)*

The objective here is again to identify the minimum amount of power generated by solar panels for which it makes sense to introduce the use of UAVs. The result of this analysis shows that for power outputs above 48 MW, investment in the new technology is justified by cost savings (Equation 3.37).

$$\begin{cases} 1{,}014.85 * X \geq 24.383 \quad \rightarrow X \geq 24.06\ MW \quad if\ X < 750MW \\ 1{,}014.85 * X \geq 48.766 \quad \rightarrow X \geq 48.05\ MW \quad if\ X \geq 750MW \end{cases}$$

Equation 3.37: *Results of inequations to define the minimum line length to insert drones within different scenarios (solar panels*

4. Conclusions

This chapter gives a general overview of the results obtained in previous sections and explores the theoretical and managerial implications that this research brings to the literature and specifically to companies that operate in the utility sector and perform the activity of inspecting their infrastructure. Next, the limitations of the study and future research that can be done for this valour are investigated.

4.1 Overview

The phenomenon of technology substitution is expanding more and more due to the development of new technologies that bring benefits over traditional technologies. Among these new technologies are drones, which have been introduced in several areas from infrastructure and major works to arts and culture, from health care and pharmaceuticals to entertainment and media, from utilities to public administration.

The adoption of drones stems from the significant benefits of enabling businesses to improve and streamline their processes and operations. Drones are taking on roles that were previously performed using other technologies or entirely manually. This new technology does not always completely replace the previously used technology or labor, but in many cases, it is an integrated and complementary solution.

The aim of this work is to provide an overview of the potential and critical issues of UAVs through an in-depth analysis of the advantages and disadvantages associated with their use. Analyzing the benefits helps explain why drones are being used to replace other technologies or people. While conducting a critical analysis is not only for the integrity and objectivity of the research, it helps to understand why drones are not completely replacing previous methods but are being used as complementary technologies or in support of humans. The analysis will then delve into the different application domains in more detail, highlighting the specific benefits, from qualitative and quantitative point of view, and key points of them and the activities they replace.

The novelty brought by this research lies in the fact that in this way it is possible to understand what benefits this new technology brings to all sectors from both intangible and tangible perspectives. To do this, it was necessary the study proposes an extensive literature analysis. 98 scientific papers have been individually selected and studied. With this analysis, it has been possible to understand which are the main benefits and criticalities that are related to the different macro areas studied and the different activities performed by drones.

Although the literature is extensive, some partially unexplored gaps and some aspects needing additional treatment have been identified. One of the most critical gaps identified was the absence of papers research that consider the benefits and criticalities of using drone technology in a general scope considering all application areas. In fact, many of them describe a main case within the empirical study, making the results obtained scarcely applicable to other areas and sectors.

Moreover, most of this research make only minor references to the advantages or disadvantages that could arise as a result of replacing or integrating old methodologies with drones.

In addition, the articles analyzed, in many cases, do not provide precise and tangible data on which an objective comparison can be made regarding the use of two different technologies in performing out an activity. So, these scientific papers were limited to describing the new method and mentioning in a non-exhaustive way what are advantages and disadvantages without going into too much detail. This makes it particularly difficult to be able to identify what are the benefits and criticalities of the technology even in application areas that have been less studied.

Finally, among the areas that have been less analysed, there is the role of the utility sector. There is a lack of papers that compare the use of drones compared to previous technologies. Thus, it is more difficult to capture what are the benefits and criticalities of the technology by separating them from the business cases analysed by the specific paper. It is therefore necessary to understand which are the advantages and disadvantages, both tangible and intangible, compared to traditional technologies of using drones in the utility field and those that are one-offs. The focus of the research is on utility infrastructure inspection activity as it is the one of greatest application for this field.

These three macro aspects are the main key points that the two research questions aim to investigate. They have been formulated as follows:

RQ1: *What are the main areas of application of drone technology in different sectors and in the utility field?*

RQ2: *What are the benefits and criticalities of using drones to replace or flank a traditional technology for inspection activity in the utility sector?*

Two different methods are used to answer to these research questions and create an empirical contribution.

To answer the first question, a census was created that considers news reported on the use of drones in different applications. To create the census file, several factors were ranked for each news item, explained in the Methodology chapter. In order to understand the major areas of drone application, all application areas and their areas of application were analyzed. Next, a focus was made on the utility sector.

To answer the RQ2, a multi-case studies approach was chosen. Ten cases in the utility sector belonging to four different infrastructure type (electric grid, pipelines, solar panels, and wind turbines) were the focus of the empirical analysis and were studied in-depth through semi-structured interviews. Their contribution has allowed the authors to get in touch with the broad panorama of the utilization of drones in the infrastructure inspection activity in the utility field and to understand the benefits and criticalities belonging to this business from the qualitative and quantitative point of view.

The data obtained was analyzed in two different ways. The data were divided into two sections: intangible analysis, that consider all the factors that are not connected with quantifiable information, and tangible analysis, that include time and cost information. These two analyses allow to understand which factors really impact the decision of a company in the utility field to adopt drone technology for infrastructure inspection activities. The second, moreover, allowed to create a cost model for each type of infrastructure so that companies can consult it, and by entering their own data, evaluate the cost-effectiveness of the solution.

The remainder of the chapter will be structured as follows. Initially, the theoretical and managerial implications will be presented. Subsequently, the limitations and probable avenues for future developments will be announced.

4.2 Theoretical implications

The research adds value to the literature by bringing important theoretical contributions.

First, the literature review increases the knowledge about technology substitution with drones by summarizing the various contributions schematically and rigorously in a single framework. The unique contribution provided to the literature is enriched by the added value created by the overview of the benefits and criticalities provided by drone (Literature review). Starting from recognizing the advantages and disadvantages of the technology in different sectors, it was possible to create an overview of which of these can be considered at a general level.

One of the primary benefits of using drones is the reduction in manpower required for various tasks [101]. Automation enables only necessary human intervention, minimizing labor costs [59, 102].Even in cases where human presence is necessary, integration with drones has been found to improve task quality [42]. Drones are particularly useful in areas with a shortage of manpower [95].

The reduced need for human labor translates into cost savings for businesses using drone technology, especially in replacing manual labor [13]. Autonomous systems also minimize training costs by eliminating the need for low-skill labor [103]. Drones are also more cost-effective than other technologies, with lower investment and operating costs [53, 69].

The use of drones has also significantly reduced the time required to complete professional tasks, particularly those performed manually [87, 59]. This has led to increased productivity in various industries, such as monitoring, transportation, and inspection frequency [43, 5, 95, 65].

This reduction in time and costs is also translate in an increase of the frequency of the activity performed. By reducing these factors, companies are more inclined, for example, to increase the number of inspections performed, thereby increasing the quality of the activity.

Drone technology has been shown to not only reduce the time it takes to complete tasks but also improve their quality. One example of a drone-optimized activity is the acquisition of images for analysis, which provides real-time information with high spatial resolution and more data than those provided by other technologies [104, 91, 40, 47, 5, 28].

Drones also have the advantage of having high mobility, flexibility and greater spatial extent, increasing precision and allowing access to remote and hard-to-reach areas [71, 97].

Safety is another benefit, as drones can perform dangerous activities without putting humans at risk, especially in enclosed spaces or during environmental disasters [34, 108, 73, 107].

Additionally, drones can minimize environmental impact by reducing noise and physical disturbance on flora and fauna, as well as carbon emissions during transportation [9, 25, 42].

Drones come with both advantages and limitations, some of which may be regulatory or operational.

The drone industry is governed by multiple regulations and entities, which companies must refer to depending on the country of use. For instance, regulatory entities include FAA in America, EASA in Europe, and ENAC in Italy. These authorities may limit their scope and require companies to apply for flight approval from several entities, leading to a lengthened waiting time [5, 73].

Additionally, weather conditions can limit drone flights, especially in unstable or stormy weather, due to their small size. For example, it is difficult to fly in rainy or windy conditions [109, 38].

Furthermore, it's crucial to consider that drones have limited battery life, which affects their range and flight time. As a result, they may need to pause operations to recharge or limit their area of coverage [93, 38, 45, 104].

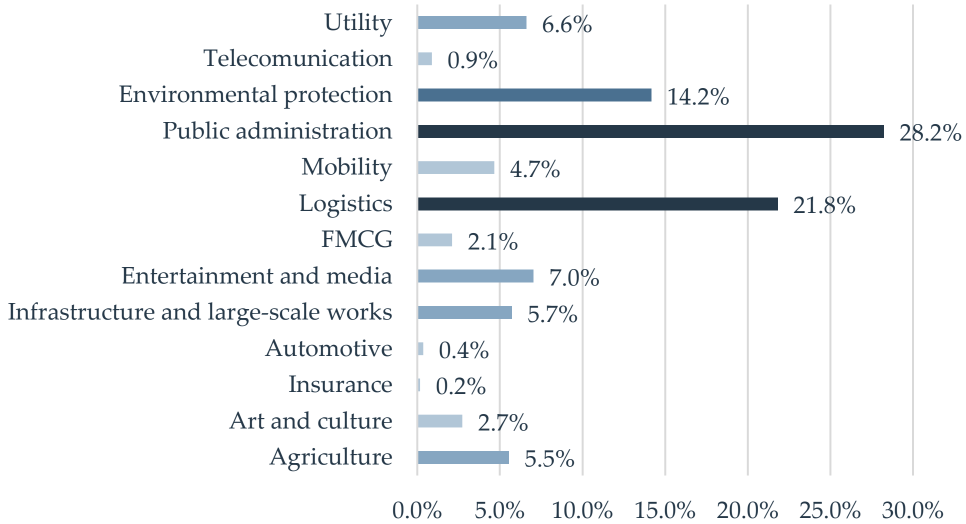
Another value added to the literature is the distinction of benefits and criticalities into quantitative and qualitative aspects. The former, which can be expressed in monetary terms, relate to time and cost, specifically in the context of drone technology replacing traditional methods. The contribution consists in defining a model with all the primary costs related to the inspection activity for each infrastructure studied (Electric grids, pipelines, solar panels and wind turbines). On the other hand, qualitative or intangible benefits and criticalities pertain to factors that cannot be easily accounted for but have a significant impact on business operations. In this case it was defined the various factors that impact positively or negatively on the inspection activity and then was considered how much each factor impacts on the activity. In the case of drones, positive factors include improved analysis quality, enhanced safety during operations, reduced environmental impact, and the ability to reach remote locations. However, regulatory, battery, and weather-related issues pose critical challenges (Table 4.1).

	Qualitative		Quantitative	
Benefits	Safety of the activity Reaching remote places	Quality of analysis Environmental	Costs	Time
Criticalities	Regulations Weather conditions	Batteries	Costs	Time

Table 4.1: *Classification of benefits and criticalities*

A second contribution that has been made to the literature is found in the response to RQ1. Specifically, an overview was established of how the technology is evolving in recent years, which countries are doing more research and utilization, which sectors are making the most use of it, and for which types of activities it covers the most in each sector.

Data indicates that the public administration sector has the highest number of surveyed cases at 28%, but the majority of these are on-offs cases. Public administration has a low percentage of cases covered in literature, possibly due to drone technology's infrequent use in the sector. This sector is followed by logistics at 22%, and environmental protection at 14%. Other sectors have a significantly lower percentage of surveyed cases, below 7%. Despite only having a 15% surveyed case rate, environmental protection is the third-highest area studied, so the interest is very high as it can be seen in literature. Agriculture only has a 6% surveyed case rate, likely due to extensive prior research in precision agriculture. Public administration has a low percentage of cases covered in literature, possibly due to drone technology's infrequent use in the sector (Graph 4.1).



Graph 4.1: *Distribution of census cases (1,137) by macro sectors*

Moreover, the majority of cases are distributed along the last years of analysis, and most of these are experimentations. This means that interest in this technology is increasing, and the potential of UAVs is still being discovered. Most companies continue to invest in research related to the introduction of drones in various fields and their presence is concentrated in Europe with a percentage of 51% followed by America with 24%.

Subsequently, a third contribution to the literature was also made. The research aims to narrow the field to utility, since it appeared to be a sector not studied in the literature, especially the activity of infrastructure inspection. Several companies in the sector were interviewed to do this.

The benefits and criticalities of these companies were analyzed through a multi-case empirical analysis. This analysis is divided according to the type of infrastructure inspected and between tangible and intangible aspects.

While maintaining a qualitative perspective, through the comparison with the individual companies, scores on a scale from 0 to 5 were assigned to each benefit and criticality described. This made it possible to draw up a ranking of importance among the various factors according to different infrastructure inspected. This quantitative evaluation was considered relevant as an empirical contribution to create order among the many factors mentioned and focused on those of most significant interest. Below, depending on the infrastructure inspected, it is reported the average ratings assigned to benefits (Table 4.2).

	Electric grids	**Pipelines**	**Solar panels**	**Wind turbines**
Environmental impact	5	5	1,5	1,5
Reaching problematic places	4	4,5	1,5	3
Safety for workers	5	5	3,25	5
Inspection frequency	5	1	3,5	4
Quality of inspection	4	5	5	5

Table 4.2: *Intangible benefits for different infrastructures*

As can be seen, the quality of the inspections is the factor that has found in all fields a rather high value, this surely is a driver that companies take into consideration when making the choice to use this new methodology. Workers' safety certainly impacts a lot as well, in fact it allows to reduce the risks of injuries related to the inspection of dangerous or problematic places. Frequency, on the other hand, finds a low value only among pipelines that have not increased it. Regarding the environmental impact, on the other hand, it is very important for those infrastructures that previously used the helicopter for this activity (Table 4.2).

From this information it can be seen what the relationships are between the various benefits. Firstly, drones have contributed to environmental benefits without any impact on other advantages. Secondly, drones have enabled companies to reach inaccessible areas, thereby increasing worker safety and reducing risks associated with the activity. This has also improved inspection frequency and efficiency. Thirdly, drones have reduced the time taken for inspections, allowing companies to increase inspection frequency. Finally, digitization and improved data quality have facilitated better asset prediction and damage identification, enabling preventive intervention. However, in the case of solar installations, drones do not offer the benefit of accessing problematic locations, as they are typically not located in challenging areas. Similarly, for pipelines, while drones reduce inspection time, there is no added value in increasing inspection frequency (Figure 4.1).

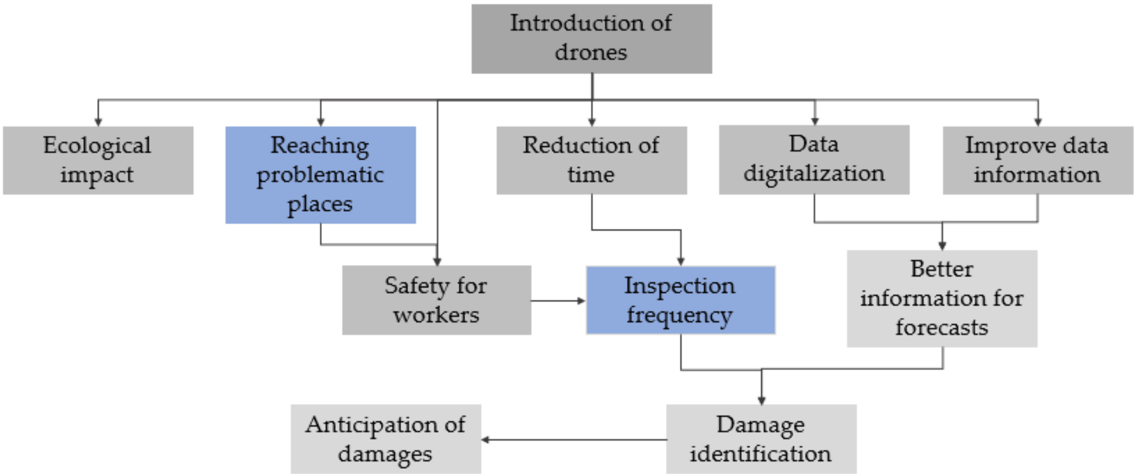


Figure 4.1: *Relations between the different benefits of introducing drones*

Next, it can be analyzed how much impact the critical issues have:

	Electric grid	Pipelines	Solar panels	Wind turbines
Batteries	3	3	2,5	2
Weather conditions	2	2	2	2
Investment in personnel training	2,5	2,5	2	2
Regulations	4,5	5	2,25	2,5

Table 4.3: *Intangible criticalities for different infrastructures*

Among these, it is possible to note that no factor is particularly limited for the application. The only criticality was found in the cases of pipelines and those of electric grids in terms of regulations. In fact, the lines extend for several kilometers and having less stringent authorizations in terms of space and time could be an advantage (Table 4.3).

A fourth contribution that can be made to literature is that of tangible data.

The information from the multi-case studies approach was first used to understand what differential cost items influenced the use of drones for inspections in the utility sector and then to create a cost model related to each type of infrastructure (Tangible analysis). This model identified what the differential cost items were between the previous technologies used for inspections and drones. In the AS-IS situation, the macro cost items identified refer to operational costs, cost for extraordinary inspections, and injury costs. In the TO-BE situation, investment cost, battery cost, operational cost, cost for extraordinary inspections, and injury cost were identified. These items were detailed and explained in Analysis.

The innovation that was made, and not present, in the literature was to numerically quantify the time and costs related to the different infrastructures inspected by making a comparison between the previous methodology and the use of UAVs (Tangible analysis). From this, it was possible to find that drones not only provide very important intangible benefits, but also manage to translate into cost-effectiveness for most infrastructure.

4.1 Managerial implications

The findings of this study have several implications for utility company managers, who can gain valuable lessons and insights.

Specifically for each type of infrastructure, an analysis was conducted to summarize the tangible and intangible benefits of using drones for inspection activity. In addition, thanks to the cost models created, companies can consult it and with their own data, figure out how much they can save in replacing their previous technology with drones. The model is detailed in Tangible analysis.

Results of benefits are schematized below and divided by each type of infrastructure inspected.

Electric grid:

		AS-IS	TO-BE
Environmental benefits		Low	High
Reaching problematic places		Low	High
Safety for operators		Low	High
Quality of inspection		Low	High
Time	Frequency	Low (2 years)	High (9 months)
	Yield	2-4 km/day	9-11 km/day
Costs		266.11 €/km	90.51 €/km

Table 4.4: Electric grids benefits

As can be seen from Table 4.4, electric grids have a high environmental impact as in the TO-BE case helicopters are completely replaced by drones that emit less CO2 and reduce noise pollution.

In addition, they allow easier access to inconvenient places, consequently also reducing the risk for operators as they do not have to go into dangerous places (Table 4.4).

Quality is one of the key aspects, as the analysis that can be done with drones is much more precise and also allows the reduction from some costs related to maintenance (Table 4.4).

In terms of time, the frequency of inspection increases by 62.5 %, which allows the line to be inspected multiple times so that there is a proactive attitude in identifying damage. The increase in frequency is made possible by the fact that the yield improves from 2-4 km/day to 9-11 km/day (Table 4.4).

With this data, it was possible to calculate the total cost to inspect a kilometer of line once with the AS-IS methodology and the new TO-BE technology. As can be seen, the cost reduction amounts to about 66% (Table 4.4).

Pipelines:

		AS-IS	TO-BE
Environmental benefits		Low	High
Reaching problematic places		Low	High
Safety for operators		Low	High
Quality of inspection		Low	High
Time	Frequency	Same (6 months)	Same (6 months)
	Yield	3.5 km/day	10.5 km/day
Costs		168.05 €/km	81.08 €/km

Table 4.5: Pipelines benefits

For pipelines, the benefits provided are similar to power grids in that the methodologies used in AS-IS and TO-BE situations are the same (Table 4.5).

The main differences are at the time level. In fact, although the new technology makes it possible to greatly increase the yield in inspections, this does not lead, as in the previous case, to an increase in frequency. This is because these are two different infrastructures with different needs, and in this case companies would not get a benefit in increasing the number of inspections (Table 4.5).

In terms of cost, the benefit is consistent and brings a reduction of about 52% (Table 4.5).

Solar panels:

		AS-IS	TO-BE
Environmental benefits		Low	Low
Reaching problematic places		Low	Low
Safety for operators		Medium	Medium
Quality of inspection		Low	High
Time	Frequency	Low (1 year)	High (6 months)
	Yield	1.6 MW/day	16 MW/day
Costs		295.79 €/MW	46.41 €/MW

Table 4.6: Solar panels benefits

Regarding the solar panels, the environmental benefit is not significant compared to the AS-IS situation because helicopters were not previously used and thus is considered negligible (Table 4.6).

Despite the flexibility and mobility characteristics of UAVs, in this case the solar panels are not located in difficult-to-access places so reaching problematic locations is not critical in this situation. As a result, safety for operators is also average (Table 4.6).

In terms of time, however, the benefits are significant with a 50% increase in frequency and a 900% increase in yield (Table 4.6).

This improvement is also realized in terms of cost with a reduction of 84% (Table 4.6).

Inspection quality, on the other hand, is a benefit also found here as the ability to inspect more frequently and more accurately allows the company to act in a preventive rather than corrective manner (Table 4.6).

Wind Turbines:

		AS-IS	TO-BE
Environmental benefits		Low	Low
Reaching problematic places		Low	Medium
Safety for operators		Low	High
Quality of inspection		Low	High
Time	Frequency	Low (1 year)	High (5 months)
	Yield	8 MW/day	21.33 MW/day
Costs		85.29 €/MW	34.99 €/MW

Table 4.7: Wind turbines benefits

As in the case of solar panels, given AS-IS methodologies, the environmental impact with the new technology is not relevant (Table 4.7).

On the other hand, with regard to inconvenient locations in some cases, it is necessary to observe the turbines at height, and this is facilitated by the use of drones that prevent operators from slinging and climbing on the turbines to do this activity. As a result, safety and the number of injuries are also positively impacted (Table 4.7).

For time, it can be seen that the frequency increases by about 60 % and the yield improves significantly from a value of 8 MW/day to a value of 21 MW/day (Table 4.7).

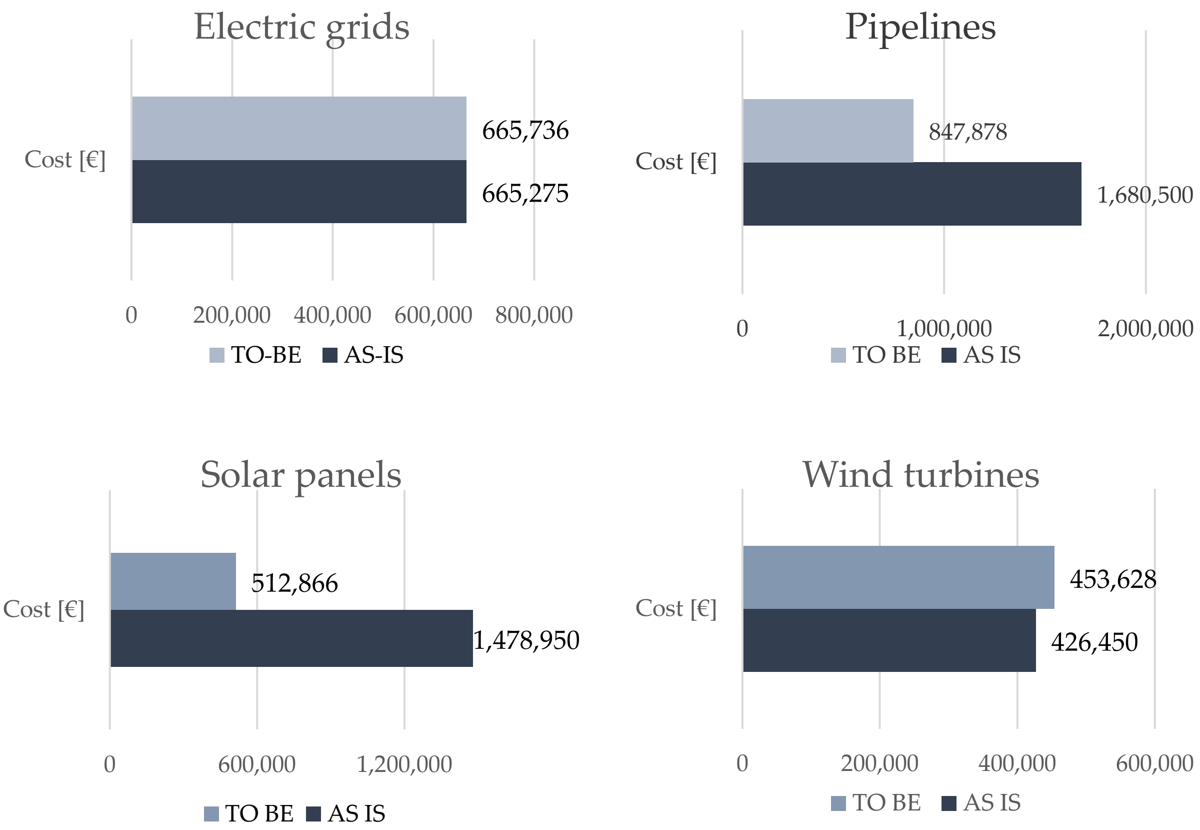
Cost reduction is also present here, although to a lesser extent, and is 59% (Table 4.7).

In addition, to better understand the economic impact over time of the introduction of the new technology, an analysis of the costs incurred by companies was conducted over 5 years, i.e., the useful life of the drone.

As can be seen from Graph 4.2, the greatest economic benefits resulting from the introduction of drones are in the case of pipelines and solar panels, with cost reductions of 50% and 65%, respectively.

As for electric grids, the costs in the AS-IS case and the TO-BE case are about the same. In this case, the reasons why an improved situation is not present are that the frequency of inspections increases greatly, from an infrastructure inspected 2.5 times every five years to 6.67 times. In addition, companies interviewed for electric grids have rather high investment costs given by using more payloads to achieve higher inspection quality, and this inevitably leads to additional savings that were not considered (Graph 4.2).

Finally, with regard to wind turbines, it can be seen that the investment is not completely cost-effective as it has a cost increase of 6%. Again, the frequency of inspections is greatly increased, and the investment cost is high compared to the costs found in the AS-IS case. Of course, this makes it possible to improve operations and identify damage well in advance so that preventive maintenance can be done and consequently reduce costs at the company level (Graph 4.2).



Graph 4.2: *Evaluation of five-year investment for different infrastructures*

Thus, it is possible to conclude that the introduction of technology can be considered beneficial in several respects from both intangible and tangible points of view.

4.2 Limitation and future research

The previous paragraphs have offered valuable insights on the theoretical and managerial aspects of analyzing the benefits and challenges of substituting drones in various sectors, particularly in companies that use this technology for infrastructure inspection in the utility industry. However, there are certain limitations which could be addressed in future research.

Firstly, the census conducted to explore the distribution of application cases is primarily based on articles from Italian specialist and generalist publications, which has resulted in a bias towards a European and Italian perspective. To avoid this, future research should expand the search to include news from other countries and continents to ensure unbiased results.

Secondly, the sample size is limited to only 10 Italian companies in the utility field, which may hinder the generalization of insights gained due to a small number of interviewees and the national-specific context. Additionally, the study only includes four different types of infrastructure, leaving out some infrastructures and not analyzing any industry in-depth. To overcome these limitations, future research should expand the sample of companies and include other infrastructures and countries in the survey.

Thirdly, the methodology used in this study is prone to subjectivity. The systematic literature review conducted at the beginning may not have been comprehensive due to the subjective criteria used for analyzing titles, abstracts, and full papers. Additionally, the perspective of the respondents may also be subjective, which is a potential limitation. A portion of the analysis is based on intangible factors, hence, future research should employ quantitative methods to validate the benefits obtained through qualitative analysis and delve deeper to comprehend the magnitude of these advantages.

Another limitation must be mentioned in the quantitative model. The model provides a medium case built on the perspective of companies interviewed. Due to the fact that the sample is not large, it is possible that the choices of other companies can be different. Differences may arise both in inspection methodologies, which may be different in the as-is and to-be case, and in the company's strategic choices that influence, for example, the percentage of line to be inspected. Therefore, future research should expand the sample of companies and verify the correspondence of the choices before applying the model to other business.

Moreover, although a quantitative model was created regarding the costs incurred in infrastructure inspection activities, a limitation of this research is that additional economic savings resulting from the introduction of the drone were not quantified. In particular, the savings that result from higher inspection quality and reduced maintenance costs were not introduced. So, future research can investigate the presence of additional economic savings that result from this technology and quantify those already identified.

It is also important to note that the studied model considers the VLOS flight mode and consequently cannot be fully applied to companies using BVLOS mode. Future research can study the differences between these two modes and update the model to be used by companies flying BVLOS mode.

Finally, this research examined the current state of the technology. Future research can focus on the evolution of drone characteristics and their impact for this study in both qualitative and quantitative benefits.

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B. Appendix A

Census

Nome	Macro-settore	Micro-settore	Ambito 1	Ambito 2	Ambito 3	Stato avanzamento	Anno	Data	Continente	Paese (di utilizzo)	Azienda/ente utilizzatore	Provider del servizio	Altri attori coinvolti	Modello di drone	Categoria operazione
Schiebel Partners with Earthrace for Global Environment and Wildlife Protection	Salvaguardia ambientale	Fauna	Sicurezza e sorveglianza	Azioni di sorveglianza pubblica	Sorveglianza di attività illegali	Operativo	2022	31-ago-22	America	Isole Galapagos	Earthrace Conservation	Schiebel	n.d.	CAMCOPTER S-100	UAS
Droni per portare il segnale mobile nelle zone remote del Galles	Telecomunicazioni	Celle telefoniche	Erogazione	Emissione segnali	Emissione rete internet	Annuncio	2022	03-nov-22	Europa	Regno Unito	Snowdonia Aerospace Centre	n.d.	Virgin Media O2	n.d.	n.d.
Vietnam farmers adopt XAG agricultural drone to reduce the cost of rice production	Agricoltura	Campi	Erogazione	Rilascio materiali	Supporto alla lavorazione delle colture	Sperimentazione	2022	30-ago-22	Asia	Vietnam	agricoltori del Vietnam	DigiDrone	n.d.	XAG	n.d.
Cyprus Launches Drones to Monitor Turkish Gas Drilling	Utility	Oil&Gas	Sicurezza e sorveglianza	Azioni di sorveglianza pubblica	Sorveglianza di attività illegali	Sperimentazione	2019	22-ott-19	Europa	Cipro	Cyprus government	Aerostar Tactical UAS (TUAS)		n.d.	n.d.
German Airways, Wingcopter collaborate to deploy drones for offshore deliveries	Utility	Energie rinnovabili	Trasporto	Consegna di strumenti o materiali	Consegna last-mile	Annuncio	2022	01-apr-22	Europa	Germania	German Airways	Wingcopter	n.d.	Wingcopter 198	n.d.

C. Appendix B

Interviews

The aim of this thesis is to analyze the benefits and criticalities that arise with the adoption of drones in the utility sector during inspection of infrastructure.

Motivations behind the introduction of drone technology in infrastructure inspection

1. How was inspection activity carried out prior to the introduction of drones, and what needs prompted you to use drones to conduct this activity?
2. What type of drone did you decide to introduce within your company? What payloads characterize your drone?

Benefits gained from the use of drone technology in infrastructure inspection

1. What benefits have you found after using drones for inspection purposes?

TIME

2. How much time was needed for inspection before the introduction of the drone? How much time is needed as a result of the introduction of the drone?
3. How long does it take you to inspect the entire infrastructure complex with drones and without drones?
4. How many inspections were done per day before the introduction of drone? What was the frequency of inspections?
5. How many inspections are done per day as a result of drone introduction? What is the frequency of drone inspections?
6. Has the time saved allowed human resources to be allocated to other business activities, and which ones?

COST

7. How many people were employed to carry out this activity without drones? How many after the introduction of the drone?
8. How much cost savings in inspection operations can be attributed to the introduction of the technology?

9. What costs have you been able to eliminate/decrease with the introduction of drones?

INCONVENIENT LOCATIONS

10. Thanks to drones, is possible to reach places that are difficult to access and dangerous?
11. What kind of benefits has this brought for your business?

SAFETY

12. What were the hazards that could be faced without the use of drones?
13. Are you able to reduce the risks associated with the activity?
14. As you are able to reduce the risks associated with the activity, what types of costs are you able to eliminate/reduce? How high is the resulting economic benefit?

ENVIRONMENTAL IMPACT

15. What is the reduction in environmental impact as a result of using drones compared to helicopters or other technologies? What are the resulting environmental benefits?

QUALITY/ACCURACY

16. What kind of data are collected during the inspection?
17. Does the drone enable you to acquire information that was previously difficult or impossible to acquire? What kind of information? What advantage did this provide?
18. If images were previously acquired through other technologies what improvements have you noticed in the images and data acquired through drones in terms of quality and accuracy?
19. Do you make use of storage databases for these data? Do you use platforms for ex post processing of these data?

Critical issues obtained from the use of drone technology in infrastructure inspection

1. Has it been necessary to obtain specific approvals from regulatory bodies to conduct drone inspections of your infrastructure? How does this affect business?
2. Is the use of drone technology affected by weather conditions? How might these affect drone image and video collection?
3. What is the impact of drone battery life on inspection activity? What alternative solutions have you deployed to counter this critical issue?
4. In addition to the technological investment, was it necessary to invest in staff training or hire specialized personnel?

Additional questions

Electric grid inspection by helicopter + direct observations

1. What is the rental price of a helicopter? How much line can you inspect as a result of the rental?
2. How much percentage of the line do you inspect with the helicopter and how much with direct observations?
3. How many extraordinary helicopter inspections conducted in an average year? How many days does an extraordinary inspection last?
4. How many days per year do you dedicate to extraordinary helicopter inspection?
5. How many extraordinary inspections with direct observations conducted in an average year? How many days does an extraordinary inspection last?
6. How many days per year do you dedicate to extraordinary inspection by direct observations?
7. How often do you inspect the entire electric grid?
8. How many observers are injured over an average year?

Electric grid Inspection with Drone

1. How many drones do you plan to purchase to inspect the entire line?
2. How many people do you plan to train for power grid inspection? If not planned, for what reason?
3. Do you foresee a reduction in the transportation cost due to a reduction in the stretch of road to be traveled? If yes, approximately by how much?
4. How often do you plan to inspect the power line with drones?
5. How many extraordinary inspections per year do you expect as a result of drone introduction (in days)?
6. How many extraordinary inspections with direct observations do you expect to conduct in an average year? How many days do you think an extraordinary inspection will last?
7. Do you anticipate a percentage reduction in this cost from the annual cost? If yes, by how much?
8. Do you anticipate that there will be a percentage reduction in injured observers per year? If yes, approximately by how much?

Pipelines Inspection conducted by helicopter + direct observations

1. How many km of line (pipelines) do you inspect in Italy?

2. How many km of line (pipelines) do you have in total in Italy?
3. How much of the line do you inspect by helicopter and how much by direct observations?
4. What is the rental price of a helicopter? How much line do you manage to inspect as a result of the rental?
5. How many people were needed to make a direct observation?
6. How many kilometers of line do you manage to inspect by direct observations in one day?
7. How often did you inspect the pipelines?
8. How many extraordinary helicopter inspections were made on average in a year? How many days did an extraordinary inspection last?
9. How many days per year did you devote to extraordinary helicopter inspection?
10. How many extraordinary inspections with direct observations did you conduct in an average year? How many days did an extraordinary inspection last?
11. How many days per year did you devote to extraordinary inspection by direct observations?
12. How many observers were injured over an average year?

Pipelines inspection conducted by drone

1. How many drones do you have available to carry out this activity?
2. How many people have been trained to carry out this activity?
3. How many people are involved during an inspection (people flanking a drone in an inspection?
4. How many kilometers per day are you able to inspect with a drone?
5. How often do you plan to inspect pipelines with drones? (Frequency)
6. Have you noticed a reduction in the cost of transportation due to a reduction in the stretch of road to be traveled? If yes, approximately by how much?
7. How many extraordinary inspections per year do you perform with drones on average? How many days does an extraordinary inspection last?
8. How many days per year are devoted to extraordinary drone inspection?
9. How many extraordinary inspections with direct observations are conducted in an average year? How many days do you think an extraordinary inspection will last?
10. Have you experienced a reduction in annual direct observations? If yes, by how much

11. Do you anticipate that there will be a percentage reduction in injured observers per year? If yes, approximately by how much?

Solar panel inspection direct observations

1. How many MW do you generate with your solar panels in Italy?
2. How many people were needed to conduct a direct observation?
3. How many MWs were you able to inspect in one working day through direct observations?
4. How often did you inspect your solar panels?
5. How many extraordinary inspections through direct observations did you make in an average year? How many days did an extraordinary inspection last?
6. How many days per year did you devote to extraordinary inspection by direct observation?
7. How many observers were injured over an average year?

Solar panel inspection by drone

1. How many drones do you have available to carry out this activity?
2. How many people have been trained to carry out this activity?
3. How many people are involved during an inspection (number of people flanking a drone in an inspection)?
4. How many extraordinary inspections per year are performed with drones on average? How many days does an extraordinary inspection last?
5. How many days per year are devoted to extraordinary drone inspection?
6. How many extraordinary inspections with direct observations conducted in an average year? How many days do you think an extraordinary inspection will last?
7. Have you experienced a reduction in annual direct observations? If yes, by how much
8. Do you anticipate that there will be a percentage reduction in injured observers per year? If yes, approximately by how much?

Wind turbines inspection direct observations

1. How many turbines are there in Italy?
2. How many MW does an average turbine produce?
3. How many people were needed to conduct a direct observation?

4. How much time was needed to inspect a turbine by direct inspection (Yield)?
5. How often did you inspect wind turbines?
6. How many extraordinary inspections through direct observations did you conduct in an average year? How many days did an extraordinary inspection last?
7. How many days per year did you devote to extraordinary inspection by direct observation?
8. How many observers were injured over an average year?

Wind turbines inspection by drone

1. How many drones do you have available to carry out this activity?
2. How many people have been trained to carry out this activity?
3. How many people are involved during an inspection (number of people flanking a drone during a single inspection)?
4. How often do you inspect turbines with the introduction of drones?
5. How many extraordinary inspections per year do you perform with drones on average? How many days does an extraordinary inspection last?
6. How many days per year are devoted to extraordinary drone inspection?
7. How many extraordinary inspections with direct observations are conducted in an average year? How many days do you think an extraordinary inspection will last?
8. Have you experienced a reduction in annual direct observations? If yes, by how much
9. Do you anticipate that there will be a percentage reduction in injured observers per year? If yes, approximately by how much?

Information about intangible data

This Table C.1 collects all the information on the different advantages found in the various cases.

	Type of infrastructure	Increase of frequency	Increase of safety	Quality of inspections	Ecological impact	Reaching problematic places
Case A	Electric grid	5	5	3	5	4
Case B	Electric grid	5	5	5	5	4
Case C	Pipelines	1	5	5	5	4
Case D	Solar panels	4	3	5	2	1
Case E	Wind turbines	4	5	5	2	3
Case F	Solar panels	4	3	5	1	1
Case G	Wind turbines	4	5	5	1	3
Case H	Pipelines	1	5	5	5	5
Case I	Solar panels	4	3	5	1	1
Case J	Solar panels	2	4	5	2	3

Table C.1: *Information about benefits by the different cases*

This Table C.2 collects all the information on the different criticalities found in the various cases.

	Type of infrastructure	Batteries	Regulations	Weather conditions	Personnel investment
Case A	Electric grid	3	5	2	3
Case B	Electric grid	3	4	2	2
Case C	Pipelines	3	5	2	2
Case D	Solar panels	3	3	2	2
Case E	Wind turbines	2	3	2	2
Case F	Solar panels	3	2	2	2
Case G	Wind turbines	2	2	2	2
Case H	Pipelines	3	5	2	3
Case I	Solar panels	3	2	2	1
Case J	Solar panels	1	2	2	1

Table C.2: *Information about criticalities by the different cases*

Information about tangible data

Electric grids

Table C.3 refers to the AS-IS model for company that inspect electric grids.

AS-IS (Electric grids)	Worst case	Medium case	Best case
Helicopter rental cost [€]	11,111.11	11,111.11	11,111.11
Change in rental cost	1.05	1.00	0.95
Line length [km]	1,000	1,000	1,000
Helicopter inspection cost [€/km]	**116.67**	**111.11**	**105.56**
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield for manual inspection [days]	666.67	666.67	666.67
Line length [km]	1,000	1,000	1,000
Manual inspection cost [€/km]	**170.00**	**166.67**	**153.33**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km]	2,000	2,000	2,000
Line length [km]	1,000	1,000	1,000
Transport cost [€/km]	**0.44**	**0.35**	**0.27**
Total Operating costs [€/km]	**122.04**	**116.70**	**110.36**
Extraordinary inspection time by helicopter [days/year]	1	1	1
Average helicopter extraordinary inspection cost [€/day]	5.000	5.000	5.000
Change in extraordinary inspection cost	1.05	1.00	0.95
Inspection frequency [years]	2	2	2
Line length [km]	1,000	1,000	1,000
Cost for extraordinary inspections by helicopter [€/km]	**10.50**	**10.00**	**9.50**
Time of extraordinary manual inspections [days/year]	166.67	166.67	166.67
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	2	2	2
Line length [km]	1,000	1,000	1,000
Cost of extraordinary manual inspection [€/km]	**85.00**	**83.33**	**76.67**
Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km]	2,000	2,000	2,000
Line length [km]	1,000	1,000	1,000

Transport cost [€/km]	**0.44**	**0.35**	**0.27**
Cost of extraordinary inspections [€/km]	**95.59**	**93.40**	**86.22**
Number of injured workers [persons/year]	6	6	6
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	2	2	2
Line length [km]	1,000	1,000	1,000
Cost of safety [€/km]	**58,80**	**56,00**	**53,20**
Total AS-IS [€/km]	**276.44**	**266.11**	**249.78**

Table C.3: *Total cost in the AS-IS situation for inspection of electric grids*

Table C.4 refers to input data for the AS-IS model of electric grids (Table C.3).

Line length [km]	1000
Line length high population density [km]	400
Line length low population density [km]	600
Helicopter rental cost [€/km]	111.11
Frequency of inspection [years]	2
Daily yield in the mountains with direct observations [km/day]	2
Daily yield in the plains with direct observations [km/day]	4
Entire line inspection yield with direct observations [days]	666.67
Extraordinary inspection cost by helicopter [€/day]	5,000
People employed for manual inspection	2
Junior personnel cost [€/gg]	100
Senior personnel cost [€/gg]	150
Average personnel cost [€/gg]	125
Average accident cost in Italy [€/year]	4,667
Km inspected with extraordinary inspections [km/year]	200
Time of manual extraordinary inspections [dd/year]	166.67
Diesel cost [€/km]	0.07

Table C.4: *Input data for AS-IS model (Electric grids)*

Table C.5 refers to the TO-BE model for company that inspect electric grids.

TO-BE (Electric grid)	**Worst case**	**Medium case**	**Best case**
Number of drones [drones]	2	2	2

Average cost of a drone with payload [€/drone]	29,268	29,268	29,268
Change in cost of a drone with payload	1.15	1.00	0.85
Line length [km]	1,000	1,000	1,000
Drone cost [€/km]	**67.32**	**58.54**	**49.76**
Number of trained persons [persons]	4	4	4
Training course cost [€/person]	1,200	950	700
Line length [km]	1,000	1,000	1,000
Training cost [€/km]	**4.80**	**3.80**	**2.80**
Investment cost [€/km]	**72.12**	**62.34**	**52.56**
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]	16	16	16
Change in time battery	0.80	1.00	1.20
Line length [km]	1,000	1,000	1,000
Battery purchase cost [€/km]	**10.24**	**11.20**	**11.52**
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]	16	16	16
Line length [km]	1,000	1,000	1,000
Battery charging cost [€/km]	**0.0052**	**0.0062**	**0.0071**
Battery cost [€/km]	**10.25**	**11.21**	**11.53**
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]	166.67	166.67	166.67
Line length [km]	1,000	1,000	1,000
Cost of personnel inspection with drone [€/km]	**56.67**	**58.33**	**57.50**
AS-IS transport cost [€/km]	0.44	0.35	0.27
Percentage reduction	0.70	0.70	0.70
Transport cost [€/km]	**0.31**	**0.25**	**0.19**
Operating cost [€/km]	**56.98**	**58.58**	**57.69**
Time of extraordinary inspections with drone [days/year]	66.67	66.67	66.67
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.75	0.75	0.75
Line length [km]	1,000	1,000	1,000
Cost of extraordinary inspection with drone [€/km]	**17.00**	**17.50**	**17.25**

Diesel cost [€/km]	0.07	0.07	0.07
Change in diesel cost	1.05	1.00	0.95
Change in line length	3.00	2.50	2.00
Total route travelled by car [km/year]	800	800	800
Inspection frequency [years]	0.75	0.75	0.75
Percentage reduction	0.70	0.70	0.70
Line length [km]	1,000	1,000	1,000
Extraordinary transport cost [€/km]	**0.09**	**0.07**	**0.06**
Cost of extraordinary inspections [€/km]	**17.09**	**17.57**	**17.31**
Number of injured workers [persons/year]	6	6	6
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	0.75	0.75	0.75
Line length [km]	1,000	1,000	1.000
Cost of safety [€/km]	**4.41**	**3.15**	**2.00**
Total BE-TO [€/km]	**160.84**	**152.84**	**141.07**
Total TO-BE without investment	**88.72**	**90.51**	**88.51**

Table C.5: *Total cost in the TO-BE situation for inspection of electric grids*

Table C.6 refers to input data for the TO-BE model (Table C.5).

Number of drones	2
DJI 300 matrix drone cost [€/drone]	11,147
Cost 2 payload [€/payload]	18,121
Junior drone pilot cost [€/day]	150
Senior drone pilot cost [€/day]	200
Medium drone pilot cost [€/day]	175
Daily inspection yield min [km/day]	9
Daily inspection yield max [km/day]	11
Entire line inspection yield with drone [days]	166.67
Frequency of inspection with drone [years]	0.75
Time of extraordinary inspections with drone [dd/year]	66.67
Km inspected with extraordinary drone inspections [km/year]	400
Average duration of a drone [min]	43
Entire line inspection yield with drone [min]	62,400
Battery life cycle	200
No. of batteries	8
Drone battery cost min [€/battery]	600

Drone battery cost max [€/battery]	800
Average drone battery cost [€/battery]	700
Electricity consumption [€/kWh]	0.361
Time to recharge a battery [h]	1.08
Energy consumption to recharge a battery [kW]	1

Table C.6: *Input data for TO-BE model (Electric grids)*

Pipelines

Table C.7 refers to input data for the AS-IS model of pipelines.

Line length [km]	1,000
Helicopter rental cost [€/km]	111.11
Frequency of inspection [years]	2
Daily yield with direct observations [km/day]	3.5
Entire line inspection yield with direct observations [days]	476.19
Extraordinary inspection cost by helicopter [€/day]	5,000
People employed for manual inspection	2
Junior personnel cost [€/gg]	100
Senior personnel cost [€/gg]	150
Average personnel cost [€/gg]	125
Average accident cost in Italy [€/year]	4,667
Km inspected with extraordinary inspections [km/year]	200
Time of manual extraordinary inspections [dd/year]	190.48
Diesel cost [€/km]	0.07

Table C.7: *Input data for AS-IS model (pipelines)*

Table C.8 refers to input data for the TO-BE model of pipelines.

Number of drones	**2**
DJI 300 matrix drone cost [€/drone]	11,147
Cost payload [€/payload]	5,492
Junior drone pilot cost [€/day]	150
Senior drone pilot cost [€/day]	200
Medium drone pilot cost [€/day]	175
Daily inspection yield [km/day]	10.5
Entire line inspection yield with drone [days]	158.73
Frequency of inspection with drone [years]	0.5

Time of extraordinary inspections with drone [dd/year]	63.49
Km inspected with extraordinary drone inspections [km/year]	400
Average duration of a drone [min]	43
Entire line inspection yield with drone [min]	54,857.14
Battery life cycle	200
No. of batteries	7
Drone battery cost min [€/battery]	600
Drone battery cost max [€/battery]	800
Average drone battery cost [€/battery]	700
Electricity consumption [€/kWh]	0.361
Time to recharge a battery [h]	1.08
Energy consumption to recharge a battery [kW]	1

Table C.8: *Input data for TO-BE model (pipelines)*

Solar panels

Table C.9 refers to the AS-IS model for company that inspect solar panels.

AS-IS (Solar panels)	**Worst case**	**Medium case**	**Best case**
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield for manual inspection [days]	1,041.67	1,041.67	1,041.67
Installed capacity [MW]	1,000	1,000	1,000
Manual inspection cost [€/MW]	**265.63**	**260.42**	**239.58**
Time of extraordinary manual inspections [days/year]	104.17	104.17	104.17
Persons employed for manual inspection	2	2	2
Personnel cost [€/day]	150	125	100
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	1	1	1
Installed capacity [MW]	1,000	1,000	1,000
Cost of extraordinary manual inspection [€/MW]	**26.56**	**26.04**	**23.96**
Number of injured workers [persons/year]	2	2	2
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	1	1	1
Installed capacity [MW]	1,000	1,000	1,000
Cost of safety [€/MW]	**9.80**	**9.33**	**8.87**
Total AS-IS [€/MW]	**301.99**	**295.79**	**272.41**

Table C.9: *Total cost in the AS-IS situation for inspection of solar panels*

Table C.10 refers to input data for the AS-IS model (Table C.9).

Installed power [MW]	1,000
Frequency of inspection [years]	1
Daily yield with direct observations [MW/day]	1.6
People employed for manual inspection	2
Junior personnel cost [€/gg]	100
Senior personnel cost [€/gg]	150
Average personnel cost [€/gg]	125
Average accident cost in Italy [€/year]	4,667
MW inspected with extraordinary inspections [MW/year]	100
Time of manual extraordinary inspections [days/year]	104.17

Table C.10: *Input data for AS-IS model (solar panels)*

Table C.11 refers to the TO-BE model for company that inspect solar panels.

TO-BE (Solar panels)	**Worst case**	**Medium case**	**Best case**
Number of drones [drones]	2	2	2
Average cost of a drone with payload [€/drone]	22,483	22,483	22,483
Change in cost of a drone with payload	1.15	1.00	0.85
Installed capacity [MW]	1,000	1,000	1,000
Drone cost [€/MW]	**51.71**	**44.97**	**38.22**
Number of trained persons [persons]	4	4	4
Training course cost [€/person]	1,200	950	700
Installed capacity [MW]	1,000	1,000	1,000
Training cost [€/MW]	**4.80**	**3.80**	**2.80**
Investment cost [€/MW]	**56.51**	**48.77**	**41.02**
Drone battery cost [€/battery]	800	700	600
Number of necessary batteries [batteries]	8	8	8
Change in time battery	0.80	1.00	1.20
Installed capacity [MW]	1,000	1,000	1,000
Battery purchase cost [€/MW]	**5.12**	**5.60**	**5.76**
Electricity consumption [€/kwh]	0.36	0.36	0.36
Change in electricity cost	1.05	1.00	0.95
Time to battery rechange [€/battery]	1.08	1.08	1.08
Change in time battery	0.80	1.00	1.20
Power consumption for battery recharge [kW]	1	1	1
Number of necessary batteries [batteries]	8	8	8
Installed capacity [MW]	1,000	1,000	1,000
Battery charging cost [€/MW]	**0.0026**	**0.0031**	**0.0036**

Battery cost [€/MW]	**5.12**	**5.60**	**5.76**
Pilot for inspection [persons]	2	2	2
Pilot cost [€/(day*person)]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Entire line inspection yield with drone [days]	104.17	104.17	104.17
Installed capacity [MW]	1,000	1,000	1,000
Cost of personnel inspection with drone [€/MW]	**35.42**	**36.46**	**35.94**
Time of extraordinary inspections with drone [days/year]	20.83	20.83	20.83
Pilot for inspection	2	2	2
Pilot cost [€/day]	200	175	150
Change in personnel efficiency	0.85	1.00	1.15
Inspection frequency [years]	0.50	0.50	0.50
Installed capacity [MW]	1,000	1,000	1,000
Cost of extraordinary inspection with drone [€/MW]	**3.54**	**3.65**	**3.59**
Number of injured workers [persons/year]	2	2	2
Reduction in the percentage of injured workers	0.20	0.15	0.10
Average injury cost in Italy [€/person]	4,667	4,667	4,667
Change in injury cost	1.05	1.00	0.95
Inspection frequency [years]	0.50	0.50	0.50
Installed capacity [MW]	1,000	1,000	1.000
Cost of safety [€/MW]	**0.98**	**0.70**	**0.44**
Total BE-TO [€/MW]	**101.57**	**95.17**	**86.76**
Total TO-BE without investment [€/MW]	**45.06**	**46.41**	**45.74**

Table C.11: *Total cost in the TO-BE situation for inspection of solar panels*

Table C.12 refers to input data for the TO-BE model (Table C.11Table C.5).

Number of drones	**2**
DJI 300 matrix drone cost [€/drone]	11,147
Cost payload [€/payload]	11,336
Junior drone pilot cost [€/day]	150
Senior drone pilot cost [€/day]	200
Medium drone pilot cost [€/day]	175
Daily inspection yield [MW/day]	16
Entire line inspection yield with drone [days]	104.17
Frequency of inspection with drone [years]	0.5
Time of extraordinary inspections with drone [dd/year]	20.83
MW inspected with extraordinary drone inspections [MW/year]	200
Average duration of a drone [min]	43

Entire line inspection yield with drone [days]	33,000
Battery life cycle	200
No. of batteries	4
Drone battery cost min [€/battery]	600
Drone battery cost max [€/battery]	800
Average drone battery cost [€/battery]	700
Electricity consumption [€/kWh]	0.361
Time to recharge a battery [h]	1.08
Energy consumption to recharge a battery [kW]	1

Table C.12: *Input data for TO-BE model (solar panels)*

Wind turbines

Table C.13 refers to input data for the AS-IS model.

Number of turbines	**500**
Average power of one turbine [MW/turbine]	2
Installed power [MW]	1000
Frequency of inspection [years]	1
Daily yield with direct observations [turbines/day]	4
People employed for manual inspection	2
Junior personnel cost [€/gg]	100
Senior personnel cost [€/gg]	150
Average personnel cost [€/gg]	125
Average accident cost in Italy [€/year]	4667
Turbines inspected with extraordinary inspections [turbines /year]	50
Time of manual extraordinary inspections [days/year]	20,83

Table C.13: *Input data for AS-IS model (solar panels)*

Table C.14 refers to input data for the TO-BE model .

Number of drones	**2**
DJI 300 matrix drone cost [€/drone]	11147
Cost payload [€/payload]	5492
Junior drone pilot cost [€/day]	150
Senior drone pilot cost [€/day]	200

Medium drone pilot cost [€/day]	175
Daily inspection yield [turbines/day]	10,67
Entire line inspection yield with drone [days]	78,125
Frequency of inspection with drone [years]	0,415
Time of extraordinary inspections with drone [dd/year]	11,72
Turbines inspected with extraordinary drone inspections [turbines/year]	75
Average duration of a drone [min]	45
Entire line inspection yield with drone [days]	23900,63
Battery life cycle	200
No. of batteries	3
Drone battery cost min [€/battery]	600
Drone battery cost max [€/battery]	800
Average drone battery cost [€/battery]	700
Electricity consumption [€/kWh]	0,361
Time to recharge a battery [h]	1,08
Energy consumption to recharge a battery [kW]	1

Table C.14: *Input data for TO-BE model (wind turbines)*

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Acknowledgements

The completion of this thesis signifies the culmination of a long and enriching journey of personal and cultural growth.

Throughout these five years, the Politecnico di Milano has been an invaluable constant, facilitating not only our professional development but also our growth as individuals, instilling in us the values of determination, respect, and responsibility which we will carry with us for the rest of our lives.

We wish to extend our heartfelt gratitude to the professors who have accompanied us on this journey, imparting their wisdom and humanity. Our advisor and co-advisor, Vincenzo Butticè and Paola Olivares, deserve a special mention for their trust and opportunity in allowing us to write this thesis and for always being available for discussion and exchange.

Another big thank you is for the Department of Drones and Advanced Air Mobility Observatory of the Politecnico di Milano that allowed us to explore this interesting topic with constant support.

We would also like to thank our families and friends for their unwavering support throughout this journey.

Lastly, we acknowledge ourselves for traversing this path together with great determination and perseverance, and the joy of achieving our goal alongside a trusted companion is priceless.

Debora and Giada