



Innovation and Capacity building

in Agricultural Environmental and Rural UAV Services



ICAERUS

D1.3: Comparative Analysis and Needs Report Version A

WP1: Drone Landscape Analysis

Responsible Author: Ms Viara Bojkova (NSWR)



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EU Project Advisor	Alessandra Sasso
Project Coordinator	Spyros Fountas
Address	75 Iera Odos, 11855 Athens, GR Agricultural University of Athens
Reply to	sfountas@aia.gr

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Reply to	vgbojkova@noosware.com
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Contributors	Dr. Despoina Filiou (OU), Stratos Arampatzis (NSWR), Elena Shkurti (NSWR), Dr. Aikaterini Kasimati (AUA), Prof. João Valente (WU), Jurrian Doornbos (WU), Mackenie Baert (FSH); Use Case Leaders: Paola Oses (NMN); Vasilis Psiroukis (AUA), Adrien Lebreton (IDELE), Kęstutis Skridaila (ART), Kostas Grigoriadis (GS)
Reviewer(s)	Mario Petkovski (AGFT)

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Participants		Contact
Agricultural University of Athens (AUA), Greece	 AGRICULTURAL UNIVERSITY OF ATHENS ΓΕΩΠΟΝΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ	Spyros Fountas sfountas@aual.gr
Wageningen University (WU), Netherlands	 WAGENINGEN UNIVERSITY & RESEARCH	João Valente joao.valente@wur.nl
Foodscale Hub (FSH), Greece	 FOODSCALE HUB	Grigoris Chatzikostas gchatzikostas@gmail.com
Noosware BV (NSWR), Netherlands	 noosware — cloud intelligence —	Efstratios Arampatzis sa@noosware.com
GeoSense IKE (GS), Greece	 beyond GeoSense standards	Dimitrios Ramnalis ramnalis@geosense.gr
Noumena Design Research Education SL (NMN), Spain	 noumena	Aldo Sollazzo aldo@noumena.io
Institut De l'Elevage (IDELE), France	 INSTITUT DE L'ELEVAGE idele	Jean-Marc Gautier jean-marc.gautier@idele.fr
ART21 UAB (ART), Lithuania	 art21	Laurynas Jukna laurynas@art21.lt
Ecological Interaction (EI), Estonia	 ECOLOGICAL INTERACTION MERGING MODERN TECHNOLOGY AND TRADITIONAL SYSTEMS 生態互動	Jonathan Minchin jonathan@ecologicalinteraction.org
Hellenic Crop Protection Association (HCPA), Greece	 HCPA HELLENIC CROP PROTECTION ASSOCIATION	Francesca Ydraiou fydraiou@esyf.gr
Agrifood Lithuania DIH (AFL), Lithuania	 AgriFood Lithuania	Valdas Rapševičius vrapsevicius@gmail.com
AgFutura Technologies (AGFT), North Macedonia	 AgFutura TECHNOLOGIES	Blagoja Mukanov blagoja.mukanov@agfutura.com
The Open University (OU), United Kingdom	 The Open University	Giacomo Carli giacomo.carli@open.ac.uk

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Expert opinion on deliverable/ Comment	Steps towards addressing it (Partner)
<i>Revised Executive Summary</i>	Added (NSWR)
<i>Add OECD Report “Competition and Innovation: a theoretical perspective” (2023) to the discussion</i>	The introduction and other parts of the D1.3 were updated taking into consideration the OECD report. The link is: https://www.oecd.org/competition/the-relationship-between-competition-and-innovation.htm (NSWR)
<i>Schumpeter - Arrow debate: the ICAERUS positioning</i>	This was already implicitly stated in the Conclusion, p. 83 - 84. A more explicit statement will be added to the Introduction and Concluding remarks on p. 81-82. The author has commented on the failure of competitive markets when it comes to the invention of digital goods and how the work of WP1 contributes to dealing with and resolving such weaknesses. Also building a network of stakeholders for each Use Case in T1.1 provides collaborative opportunities to a group of partners to stimulate innovations in the agricultural domain via network effects and economies of scale. (NSWR)
<i>Chapter 2 - literature review, was it done? Please add some explanation</i>	Addressed with references to the two key pieces of work. A justification is also offered. (OU)
<i>"two Ventures" - introduce the study and cross references</i>	A reference is added to the work that researched the 'two ventures' (OU)
<i>Table 1, 4 and 5 - why are they not harmonised?</i>	These three tables in D1.3 on p. 16, 26 and 28 are utilised for different purposes in both chapters 2 and 3. The first table presents an academic typology of applications and is based only on research of the US market. Similarly, table 5 presents market needs and applications but covers global markets (not only the US), so the statistical basis varies from the one in table 1. And table 4 doesn't present any typology of applications but rather maturity of different categories. In this respect, there are similarities only between table 1 and table 5, however they still can't be harmonised because table 1 relies on data pre-2020 while table 5 extrapolates and is based on market expectations from now on until 2040. (NSWR)
<i>Section 3 “Market needs and Technological global trends” - relevance</i>	The sequence of materials between chapter 3 "Market Needs and technological global trends" and chapter 4 "Comparative analysis of

	stakeholders' needs by case and technological solutions" is quite logical and complementary - chapter 3 sets the analysis of use cases in chapter 4 in a broader context of the development of drone technology & applications, on one side, and market needs and expectations, on the other side. A couple of sentences explaining the aims of chapter 3 was added at the outset on p. 29 and some comments were made at the end of chapter 3. (NSWR)
<i>Table 15 indicates "drone spraying" under fixed wings</i>	Table 15 on (p. 60) in no way indicates that the UC2 drone spraying is under the category "fixed wings". The table has to be read horizontally, not vertically. All components written in a row are only objects and this is explained in the text. (NSWR)
<i>Table 17 - "weather station"payload to drones</i>	Added sentence. (WU)
<i>Drone spraying is less explored because of regulations - any scientific reports from Asia</i>	Updated text to emphasise on the limited research conducted specifically in an EU context. "He, X. (2018). Rapid development of unmanned aerial vehicles (UAV) for plant protection and application technology in China. Outlooks on Pest Management, 29 (4), 162-167. Bonds, J. A., Pai, N., Hovinga, S., Stump, K., Haynie, R., Flack, S., & Bui, T. (2024). Spray Drift, Operator Exposure, Crop Residue and Efficacy: Early Indications for Equivalency of Uncrewed Aerial Spray Systems with Conventional Application Techniques. Takekawa, J. Y., Hagani, J. S., Edmunds, T. J., Collins, J. M., Chappell, S. C., & Reynolds, W. H. (2023). The Sky is Not the Limit: Use of a Spray Drone for the Precise Application of Herbicide and Control of an Invasive Plant in Managed Wetlands. Remote Sensing, 15(15), 3845." (AUA)
<i>Statement on "at a worse accuracy"</i>	Fixed wording to "lower" (WU)
<i>Should it not be lower or lesser accuracy?</i>	The same as above (WU)

Executive Summary

Innovation is an essential engine of advanced economies, taken as a driver of growth and long-term productivity in economic theory. Economists, strategists, and scientists have long sought to comprehend what drives innovation as a model to explain the differential growth rates of firms, nations, and regions. Various theoretical frameworks have been built as knowledge blocks that elaborate on developments of new technology and how this leads to technological change at an industry or firm level.

The ICAERUS project as a Research & Innovation Action (RIA) under the Horizon Europe programme aims to introduce drone innovations in five different use cases to improve productivity, sustainability, and competitiveness of European member-states' economies. Most prominently, the technicalities of all cases demonstrate the modern alternatives to the conventional methods in agriculture and rural development such as:

- ✓ **UC1:** radical innovation in the viticulture segment of the vineyard industry in Tarragona (Spain) that aims to demonstrate the capacity of drones in disease and plant stress identification as well as weed detection in vineyards.
- ✓ **UC2:** an optimisation experimental case in precision crop protection that aims to test and assess spraying configurations for optimal drone applications in the university's open-field conditions in Attika (Greece).
- ✓ **UC3:** an experimental breakthrough in the livestock farming segment of the agricultural industry in south of France aiming to evaluate drone solutions for monitoring different grazing cattle and sheep systems to reduce the case's labour intensity.
- ✓ **UC4:** an experimental breakthrough that aims to monitor ecosystems and assess biodiversity and wildlife population in the forest terrains of Lithuania. It evaluates the capacity of drones to manage or prevent the expansion of infectious diseases affecting both feral and domestic animals.
- ✓ **UC5:** radical innovation in the aerial supply chain industry that designs and offers an automatic "drone delivery fleet management system" to operate three different types of drones for delivering various payload parcels along different routes in rural settlements (North Macedonia).

Taking the multi-purpose drone applications approach, this deliverable 1.3 *Comparative Analysis and Needs Report* shapes the first report of T1.3 *Comparative Analysis and Needs* of Work Package 1. Its objective is to conduct a comparative analysis of stakeholders' needs surveyed in T1.1 *Understanding the Drone Market* with technological drone solutions by project's use cases collected in T1.2 *Stock-taking of Drone Technologies*. It provides a taxonomy for the comparison as it entangles **the market and technological dimensions** of the embedded methodology of WP1 *Drone Landscape Analysis* and offers a wider foundation for making conclusions and recommendations. It has accumulated a knowledge basis to support the innovative stages through which the UCs have to move forward. In addition, the report researched the market needs and technological trends globally in segments where drone technology has been already adopted.

In more detail, the deliverable D1.3 is based on five sections.

Chapter 2 builds a theoretical foundation that supports the discussion of innovation and technological change in an industry or firm level, assuming that the Schumpeterian forces of "creative destruction" manifest pressure on companies to become more efficient and dynamic in traditional industries. The anticipated result, in the case of ICAERUS project's innovations, is a "skilled-biased technological change" within the agricultural and rural logistic sectors as the change in analytical occupational tasks' intensity on traditional and manual jobs has a positive impact on a broader basis. Furthermore, to increase productivity

in our five use cases, drones as a new technology was adopted with specific technical requirements to effectively perform the tasks. In this context, Schumpeter also assumes temporary monopoly rights for firms to be able to have both the resources and incentives to innovate while K. Arrow argues that innovation would be greater in competitive markets. Considering these opposing views, in our opinion firms may be allowed to exercise their market power if acquired legitimately in order to maintain their research and development activities. The ICAERUS Consortium acknowledges the innovative efforts and motivation for inventiveness exhibited by small, medium and large companies located within the European Union, which sustains long-term growth and an increased productivity in the region.

In addition, the theoretical overview in chapter 2 presents a brief historical outline of the newly emerging drone industry by discussing the innovations introduced by “two Ventures” which pioneered the industry back in 2007. The discussion offers a background to the development of the civilian drone industry together with a representation of the potential stages to progress further. The stages of industry development are important as they show the key events and milestones for an industry to evolve from the initial nascent stage to the stage of maturity. In this chapter three main stages of nascent industry evolution: ‘incubation’, ‘pre-firm take off’, ‘pre-sales take off’ and all processes taking place (such as knowledge accumulation) are illustrated and explained.

Chapter 3 then elaborates on the market needs of users and new global trends that can be matched with the existing technology. The generic market for civilian drones is at the emerging stage of development substantiated by the literature sources cited in chapter 2, with a future growth path in the shape of “s-curve”. Therefore, drone technology is expected to have a fast rate of uptake until it has reached a stage of maturity. In this early to middle stage, market needs expand quickly, and investors’ interests increase fast.

Moreover, to discuss the potential of drone technology in various sectors of the European and global economy as well as the creation of novel market needs in times of digitalisation, the analysis paid attention to many popular use cases, R&D projects and commercial start-ups that focus their resources on the adoption of new technology and the expansion of markets. Thus, the analysis began with more technical details of the relevant market segments and the drone specifications in:

- E-commerce and deliveries
- Urban air mobility
- Government and community services
- Sustainable and smart ports / airports
- Recreational
- Infrastructure and constructions
- Mining and resources
- Defence
- Agriculture

The main conclusions and recommendations made in chapter 3, and what the technology companies need to upgrade and increase their investments in to match users’ needs are:

- To increase autonomy of drones
- To increase endurance
- To increase payload capacity
- To increase the sound perception of environment (not limited to visual)
- To increase human-drone interaction (remote and proximity)
- To enable drones with robotic arms to interact with the environment
- To enable social inclusion and co-creation
- To modify and upgrade the regulatory frameworks – interaction with the authorities

- To increase dissemination and technology education programmes

The usefulness of this approach is proved by the comparative analysis in **Chapter 4** where use cases' needs are matched with the drone technology in the context of the local and global trends. While chapter 3 shows what the positioning of other sectors is with a brief discussion of agriculture, chapter 4 solely focuses on the agricultural and logistic industries, and more specifically, how the two sectors based on a comparative analysis of use cases can develop UAV applications and adjust them to the needs of the European stakeholders. The undertaken approach provides opportunities for comparison and positioning.

To perform the comparative analysis of all use cases, a certain architecture was designed in the last chapter of D1.3. In constructing this architecture, a number of different dimensions, categories and objects were taken into consideration derived from:

- 1) the provided taxonomy of technology in T1.2 *Stock-taking of Drone Technologies*;
- 2) the requirements of the ICAERUS work packages, mainly WP1 *Drone Landscape Analysis* and WP3 *ICAERUS Use Cases and Demonstration Activities*;
- 3) overall tasks and structure of WP1 as defined in the *Description of Work and Methodology*;
- 4) results of stakeholders' surveys in T1.1 *Understanding the Drone Market*.

Based on the method of refining objects and characteristics, a four-level architecture for the comparative analysis was established with the relevant dimensions in the last chapter. It is considered sufficient to enable a match of stakeholders' needs with the technological solutions in each use-case on a wider foundation. The structure and results are illustrated in Table 15 and 17 of this document respectively.

The results of all work presented in an introduction, three major chapters and a conclusion will be utilised by:

- WP4 "Online Training Courses" – ICAERUS Academy
- WP5 "Inclusive Business and Governance Models" and
- WP5 "Dissemination, Exploitation and Communication Plan"

to complete the basis for future developments of European drone innovations in agriculture and logistics.

Table of Contents

1. Introduction	12
1.1 Objectives and structure of the document	13
2. Literature overview: a theoretical foundation	16
2.1 Industry Perspective	16
2.1.1 Drone industry: initial innovations and milestones in the nascent civilian industry	17
2.2 New market entry and higher productivity	20
2.2.1 Adopting drone technology for higher productivity: examples from the US	21
2.3 Competitiveness, sustainability and acceptability	22
2.3.1 The growing civilian drone industry: Patterns of growth based on knowledge evolution	23
2.3.2 Factors affecting the transfer and diffusion of UAVs	26
2.3.3 Needs of global drone stakeholders extracted from ICAERUS surveys	27
3. Market needs and technological global trends	30
3.1 Drone market needs	32
3.2 Use cases by segment: to demonstrate potentially emerging needs	36
3.2.1 Urban air mobility	36
3.2.2 E-commerce and deliveries	39
3.2.3 Government and community services	41
3.2.3.1 Firefighting	42
3.2.3.2 Policing	43
3.2.3.3 Border control	46
3.2.3.4 Customs	49
3.2.4 Sustainable and smart ports and airports	52
3.2.5 Recreational usage	54
3.2.6 Infrastructure and construction	54
3.2.7 Mining and resources	55
3.2.8 Defence	56
3.2.9 Agriculture	56
4. Comparative analysis of stakeholders' needs by case and technological solutions	59
4.1 Taxonomy of the comparative analysis	59
4.1.1 Use Case 1: Crop monitoring	63
4.1.2 Use Case 2: Crop spraying	66
4.1.3 Use Case 3: Livestock monitoring	68
4.1.4 Use Case 4: Forestry and biodiversity	71
4.1.5 Use Case 5: Rural logistics	74
4.1.6 Summary of all UCs' characteristics	77
4.1.7 An integrating lens for the technological needs across Use Cases	82
4.1.7.1 Concluding remarks	83
5. Conclusions	85
References	88

Table of Figures

Figure 1 Diagram for key interrelations with T1.3 and WP1 in the first phase of ICAERUS	13
Figure 2 ICAERUS Platform architecture	14
Figure 3 Nascent Industry milestones and stages (Moeen et al., 2020)	17
Figure 4 Civilian Drone Market Size (sales) and VC Financing (Bremner & Eisenhardt, 2022)	18
Figure 5 Total Number of Civilian Drone Firms (Bremner & Eisenhardt, 2022)	20
Figure 6 Cumulative building of industry knowledge base (Moeen et al., 2020)	24
Figure 7 Processes of industry emergence based on industry knowledge base development (Moeen et al., 2020)	25

Figure 9 Drone spraying applications	66
Figure 10 Drone providing visual feedback to livestock farmers	69
Figure 11 Forestry and biodiversity drone monitoring	71
Figure 12 Rural transportation and deliveries.....	74
Figure 13 Industry Emergence and Technology Emergence (Giones and Brem, 2017).....	83
Figure 14 Outputs of WP1 and T1.3 during the project's timeframe	86

Table of Tables

Table 1 Market Segments	21
Table 2: Responses for each identified stakeholders' need (percentage from total).....	27
Table 3: Responses for each identified end-users' need (percentage from total)	28
Table 4 Commercial drone applications' categories and maturity	31
Table 5 Market segments and needs by 2040	32
Table 6 UKRI's innovative projects in air mobility.....	37
Table 7 UKRI's innovative projects in e-commerce.....	40
Table 8 EU-funded projects that integrate drone solutions into firefighting services.....	42
Table 9 EU-funded projects that integrate drone solutions into policing operations.....	46
Table 10 EU-funded projects that integrate drone solutions into border control	48
Table 11 European projects that use drones to support all first responders	49
Table 12 UKRI's innovative projects in industrial drone operations	53
Table 13 UKRI's innovative projects in industrial infrastructure	54
Table 14 Dimensions with characteristics	61
Table 15 Taxonomy of the comparative analysis	62
Table 16 Top ten needs of UC1 stakeholders.....	64
Table 17 Technology for Use-Case 1: Crop monitoring	65
Table 18 Top ten needs of UC2 stakeholders	67
Table 19 Technology for Use-Case 2: Crop Spraying.....	67
Table 20 Top ten needs of UC3 stakeholders	69
Table 21 Technology for Use-Case 3: Livestock monitoring	70
Table 22 Top ten needs of Use-Case 4 stakeholders	72
Table 23 Technology for Use-Case 4: Forestry & biodiversity	72
Table 24 Top ten needs of Use-Case 5 stakeholders	74
Table 25 Technology for Use-Case 5: Rural transportation	75
Table 26 Characteristics of all UCs in a comparative mode.....	77
Table 27 Updated characteristics of all UCs	80

1. Introduction

Historically, the topic of innovation has been of interest to economists and engineers for over a century. In his 1911 book “The theory of economic development”, J. Schumpeter focused on the typical entrepreneur as a driving force of innovation. According to him, “...his characteristic task ...consists precisely in breaking up old, and creating new, tradition”². In the next book “Capitalism, socialism and democracy” from 1942, Schumpeter said: “Technological progress is increasingly becoming the business of teams of trained specialists who turn out what is required and make it work in predictable ways”³.

In his theoretical arguments, Joseph Schumpeter allows temporary monopoly rights to firms to be able to have both the resources and incentives to innovate. This approach was challenged by Kenneth Arrow in the 1960s and 1970s when he argued that innovation would be greater in competitive markets⁴. According to his theory, the competitive environments can generate better incentives for firms to innovate and earn profits⁵. On the contrary, Schumpeter thought that markets with increased competition would tend to discourage innovative thinking by the slow adopters as the catching-up with the leader reduces their extra short-term profits. These long-standing opposing views have brought some useful insights to social science as a recent OECD report “Competition and Innovation” argues regardless of where a theoretical model is positioned in the debate of Schumpeter and Arrow (OECD, 2023). One insight is the inverted-U relationship between competition and innovation, which suggests that there is an optimal level of competition that produces the highest levels of innovation (Griffith & Reenen, 2021), and the second one is that different states of technology across firms also relate to the inverted-U curve. This means that the slow adopters are not motivated and do not have incentives to catch-up with the leader when there is a huge gap between the leader as a technology advanced firm and the laggard firms.

The challenges of the last century are still present today in the case of innovation of digital goods and competitive markets. The topic becomes even more complex when we consider <drone providers> as digital algorithmic service providers, since physical goods have different characteristics from digital ones. Digital goods or services have five characteristics that illuminate the difficulties in valuing such goods and the networks that innovate and produce them, and then the resulting constraints on drawing conclusions.

In times of digitalisation, modern economics defines digital goods as non-rival, infinitely extensible, discrete, aspatial and recombinant. Non-rivalry is a property of the public good; it means that the use of one agent does not diminish its utility to another agent in the network. Excludability is a property of private goods. As far as digital goods (drone algorithms, artificial intelligence, robotics) are concerned, excludability can be enforced by laws or technological encryption, but it is not inherent in them. All mentioned characteristics of digital goods raise some problems with traditional understandings of K. Arrow or J. Schumpeter. Market equilibrium is not always socially efficient in the digital economy’s conditions.

On these theoretical grounds, our ICAERUS project aims to introduce drone innovations as digital technology in five different use cases to demonstrate the environmentally and technologically sustainable alternatives to the conventional agricultural methods and improve quality of life in rural areas.

Innovation discussed as a concept has a wider meaning and has been evolving for years. There are numerous definitions of innovation in policy reports, academic literature or industry briefings. Therefore, to establish a better understanding of innovation in its broader meaning, we take into consideration the well-developed OECD definition in this D1.3:

² Quotation: Schumpeter J., (1934 [1911]) The theory of Economic Development, Cambridge, MA: Harvard University Press

³ Quotation from: Schumpeter J., (1942). Capitalism, socialism and democracy, London

⁴ Arrow K., (1971). Economic Welfare and the Allocation of Resources for Inventions”, in Essays in the Theory of Risk-bearing, ed. Kenneth J. Arrow (Amsterdam: North Holland, 1971), 144 – 160.

⁵ Nelson R., (ed.), (1962). “Economic welfare and the allocation of resources for inventions” by K. Arrow

For the purposes of the presented document, this prelude to the described work under *T1.3 Comparative Analysis and Needs* aims to brief the reader with the background information of our understanding of innovation and competitive markets as an overall framework of the incorporated comparative analysis. Each chapter of the deliverable dives deeper into the challenges of this topic.

The aim of Work Package 1 (WP1) as per DoW is to conduct a thorough analysis of the *European Drone Landscape* by achieving four specified objectives:

- The relation of WP1, and more specifically T1.3, which is the focus of this deliverable, with other WPs of ICAERUS can be seen in the following diagram 1:



13

T1.3 *Comparative Analysis & Needs* takes the output of WP3, mainly the outputs of T3.1, where the planning of all UCs has been described and focuses on the results of T1.1 *Understanding the Drone Market* and T1.2 *Stock-taking of Drone Technologies*, which provide the background information for the comparison – specifically the stakeholders needs extracted from the surveys in T1.1 and the available technological solutions and components accumulated as organised knowledge in a library structure in T1.2 (and WP2). The overall output of WP1 *Drone Landscape Analysis* will be a direct input to WP4 ICAERUS Academy and WP6 ICAERUS Platform.

The methodological approach of WP1 is based on eight steps covered by all four tasks:

Step 1: Drone market research analysis (T1.1)

Step 2: Use Case market and stakeholders' analysis (T1.1)

Step 3: Mapping stakeholders and value flows (T1.1)

Step 4: Description of drone technology and categories (T1.2)

Step 5: Develop a taxonomy to define and validate Use Cases (T1.2)

Step 6: Compare drone market needs and technology trends (T1.3)

Step 7: Compare stakeholders' needs by case to technological solutions (T1.3)

Step 8: Explore external factors - standards, regulations, and risks (T1.4)

In T1.3 the emphasis is on Step 6 and Step 7 of the overall methodology, which offers an extensive contemporary foundation for performing a wider comparative analysis of UCs' needs of stakeholders and existing drone technology. For this purpose, a taxonomy of the analysis has been derived from the already collected informative basis for T1.1, T1.2 and T3.1 (WP3).

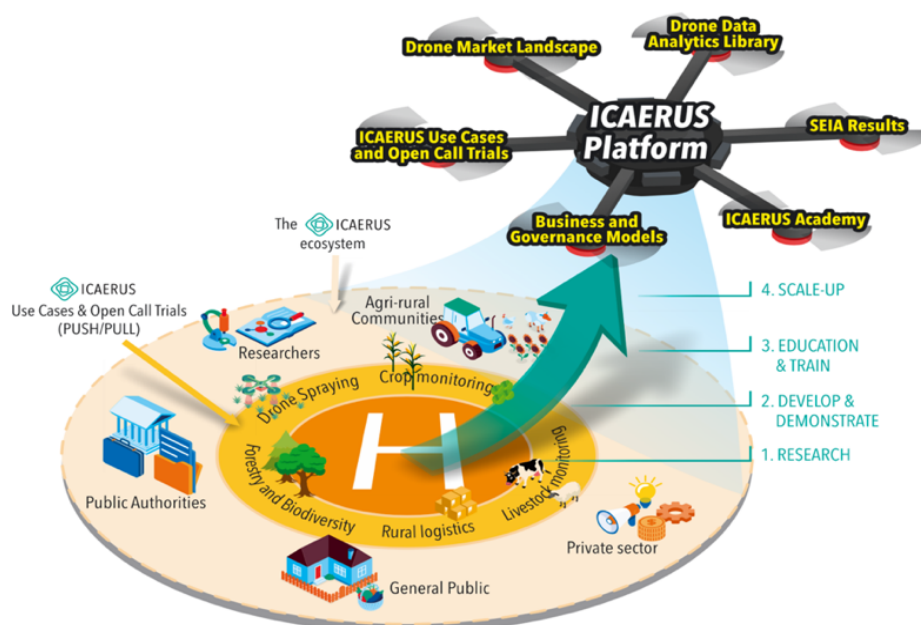


Figure 2 ICAERUS Platform architecture

The D1.3 is structured in three major chapters:

- the **first** large chapter offers an overview of theoretical sources from the field of economics of innovation and strategic management. It presents a brief historical overview of any development observed in this emerging civilian drone industry. It describes the milestones and stages of a nascent industry with the need to accumulate certain types of knowledge to grow and mature.

- The **second** large chapter conducts research on market needs and expectations in segments with a high adoption rate of drone technology. It compiles information about nine well-established segments where traditionally drones have been utilised or drone technology is expected to penetrate more intensively from now on. Table 5 *Market segments and needs by 2040* reveals some disparities between the needs and drone specifications, and some recommendations in terms of the applications have been mentioned in the chapter.
- The **last** major chapter performs the comparative analysis by use case. It compares the local stakeholders needs and expectations with the available technology by trying to match them up. It elaborates on the difficulties and unresolved questions by scientists. All structured knowledge gathered in this document will be utilised by later WPs such as “Business and Governance Models”, “ICAERUS Academy and Platform” as exhibited in Fig. 2 above.

2. Literature overview: a theoretical foundation

The theoretical foundation of our analysis in *D1.3 Comparative Analysis and Needs Report* is grounded on the endogenous growth principles exhibiting the natural tendency towards creative destruction, where resources are dedicated to research and innovation to generate improvements in productivity and efficiency. Firms compete to develop new technology, and thus boost growth in the economy. Start-ups and incumbents seek to maximise profit within the industry they operate, by pursuing different kinds of innovation.

The emergence of new technology gradually drives the emergence of novel industries going through several stages of development before reaching maturity. This chapter 2 sheds more light on the development process of the nascent civilian drone industry.

2.1 Industry Perspective

The intention is here to explain the microeconomic impact of the new drone technology once it is introduced. These future effects are naturally expected to be on an industry level as well as a firm reorganisation level. From an economics perspective, technological change leads to structural changes in the firm and the industry.

Hypothetically, the Schumpeterian forces of “creative destruction”⁷ will put pressure on firms from the industry to become more efficient and dynamic via structural and organisational changes to adapt to the offered innovation. As Schumpeter had suggested in his theory of economic innovation (Schumpeter, 1942), the old ways are destroyed endogenously by the new ways. In terms of modern economic theories, the forces of creative destruction have been associated with technological change and innovation is encouraged when the market is contestable. A contestable market allows firms to compete easily when they offer a product that is attractive to consumers (Shapiro, 2012). Innovators are successful if they could capture, at least temporarily, the benefit from innovation.

The specific technological advancement that the ICAERUS project offers to the agricultural sector and the rural logistics in countries of the European Union will induce the “skill-biased technological change” (SBTC) within the sector. This means an increase in relative demand for skilled workers within the industry in Europe, but also due to the international operations of drone service providers the skill upgrading will occur in other countries too as in one of the use cases, the drone coverage is above Greece and North Macedonia, the latter is a non-EU-state and a part of the Western Balkans. Due to the complementarity between trade and technology, international trade alters the returns of different technologies and induce skill upgrading⁸ widely⁹. As a result of these complex economic relations the ICAERUS multi-purpose drone applications may have broader effects that stretch beyond the borders of the EU.

In addition, economists have extended the traditional Heckscher-Ohlin (HO) model and shifted the focus away from trade in goods to trade in tasks and offshoring (Freenstra et al., 1999). This shift makes the skill upgrading within industry possible. Naturally, firm skill upgrading follows from the above-mentioned mechanism. Due to the technological change within the industry, the firm will have to provide the technology upgrade, to the extent that the latter is skill-biased - will increase firm’s relative employment of skilled workers. Technology and trade lead to employment structure changes within industries and firms. If firms are heterogeneous in dimensions that affect their likelihood to grow, survive and update their production process, then a substantial part of skill upgrading within an industry may occur across a wide

⁷ Quotation: Schumpeter J., “Capitalism, socialism and democracy”, London 1942

⁸ See more in: Acemoglu, D., “Patterns of skill premia”, Review of Economic Studies 70(2), 2003

⁹ See more in: Bloom, N., Draca M., van Reenen, J., “Trade induced technical change? The impact of Chinese imports on technology and employment”, Mimeo, 2008

range of firms. These are the complementary reallocation mechanisms observable within an industry with heterogeneous firms.

From a labour perspective, drone technology will change workers' tasks on the job, and this process has been observed in many other industries because of the increased IT use. The striking feature of the academic results is that the change in analytical (interactive and routine cognitive) occupational tasks intensity has a positive impact across the board meaning that in an industry with large changes, firms have experienced both higher (lower) likelihood of entry and exit (Ariu & Mion, 2011). Many small-sized firms that lack necessary resources (financial, human, or software) to comply with analytics tasks and standards could be easily pressed to exit or merge.

2.1.1 Drone industry: initial innovations and milestones in the nascent civilian industry

Further to the theoretical explanation of expected changes in the drone industry, this part of the literature overview offers a background to the development of the civilian drone activities, together with a representation of the potential stages of development of nascent industries. It presents a brief historical overview of this newly emerging industry. This is based on Moeen et al., (2020) and Bremmer and Eisenhardt (2022). This is a new industry and an in-depth revision of these seminal pieces of research is considered appropriate because it offers a fruitful background to examine all ICAERUS use cases which are at different stages of industry development.

The stages of industry development are important as they show the key events and milestones for an industry to evolve from the initial nascent stage to the stage of maturity. In Figure 3 one sees the three main stages of nascent industry evolution: 'incubation', 'pre-firm take off', 'pre-sales take off' and the milestones to be achieved for a nascent industry to evolve from one stage to the next (see Moeen et al., 2020).

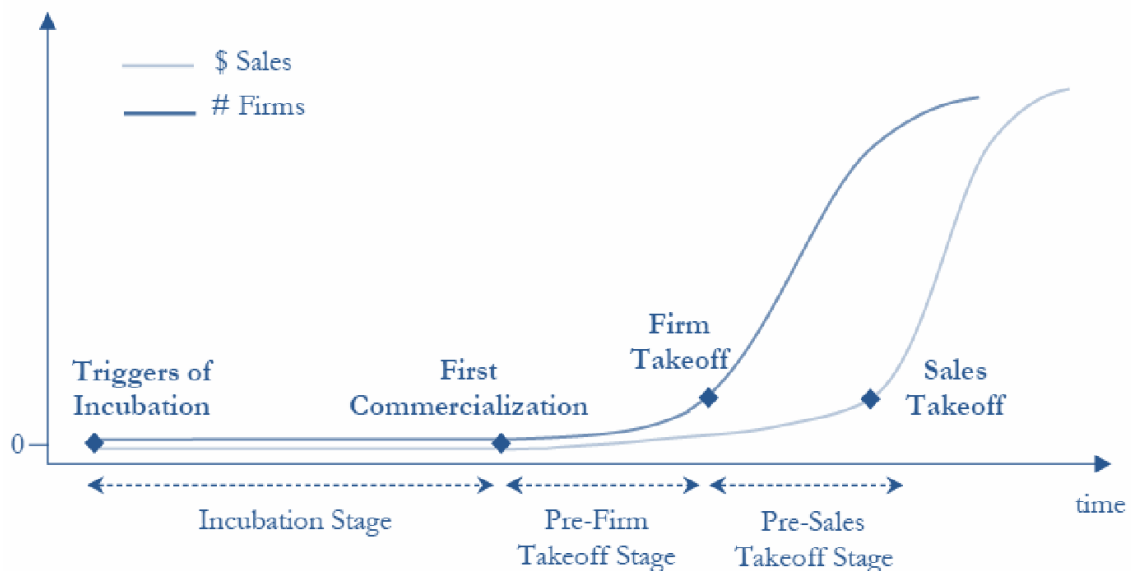


Figure 3 Nascent Industry milestones and stages (Moeen et al., 2020)

For the civilian drone (or alternatively UAV¹⁰) industry, it is interesting to examine in some detail the 'triggers of incubation' which precedes the first stage and show what happens before industries start to exist. The civilian drone industry emerged in 2007 with innovations introduced by two Ventures which pioneered the industry. Drones were widely used before that in the army, this is an important fact that will be picked up later. Both ventures were founded by hobbyists. Venture 1 was a community venture and

¹⁰ UAV – unmanned aerial vehicles

focused initially on developing a drone that can be more easily and widely used by a community of hobbyist (Venture 1 was located in Northern California) (the research is based on Bremner and Eisenhardt, 2022).

The drones manufactured were sold back to the community at the beginning and then in 2008 Venture 1 also became for profit but retained its close links to the community of users. Venture 2 had a commercial for-profit status from the start and was based in Shenzhen China (Bremner & Eisenhardt, 2022). The two ventures introduced three innovations: 1) the quadrotor product architecture, 2) the drone gimbal, 3) the 'ready-to-fly (RTF) drone, that all played a fundamental role in growing the civilian drone industry and extending its market from a number of hobbyists to a product aimed primarily at professionals (gimbal) and then to a mass market product for commercial and consumer use (the RTF).

All three innovations were developed by the two Ventures while identifying and solving problems related to how the drones will perform better to meet the specific needs of the primary users. For example, the quadrotor (2007-2010) was a new product architecture (architecture refers to how everything that makes a drone is arranged together and the types of interconnections among drone components) that was developed as the two Ventures were trying to solve problems related to flying range and carrying capacity, problems experienced at the time with the two existing drone architectures of airplane and helicopter. The quadrotor was comparatively superior as it was manoeuvrable and safe.

It is interesting to note here that Venture 1, relied on ideas and solutions offered by the growing 'DIY drones' community (5,000 members in 2008, growing to 12,000 members in 2009) which were openly sharing their experiences with using the drones, problems with use, and were experimenting with alternative prototypes; a small number of community members were getting involved in writing code and designing hardware. The community sourcing of ideas, experimentation with different prototypes and openness of design solutions gave Venture 1 an advantage and they were the first to bring the quadrotor to the market with the two alternatives at the time, the helicopter, and the airplane, performing far more poorly compared to the quadrotor. By 2010 Venture 1 switched completely to the quadrotor architecture while Venture 2 still used the helicopter architecture for both commercial and hobbyist markets. Venture 2 released its first quadrotor in 2011 and its DIY kit of parts in 2012 as multirotor were outselling helicopters 20 to 1 in 2011.

The innovation of the quadrotor and the decision of both pioneering Ventures to switch to it, was a turning point for the industry. The market expanded to a broader group of hobbyists, such as robot enthusiasts and the industry revenue increased about 10 times between 2010 and 2011 (see Figure 4 taken from Bremner & Eisenhardt, 2022).

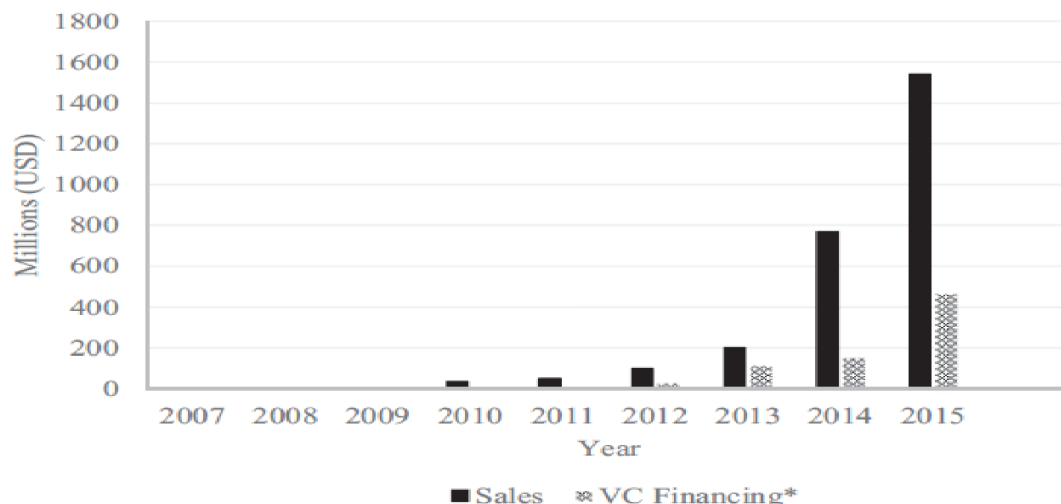


Figure 4 Civilian Drone Market Size (sales) and VC Financing (Bremner & Eisenhardt, 2022)

One could argue that the innovation of the quadrotor reflects the first milestone of nascent industry development: ‘first commercialisation’ (as depicted in Figure 3). At that time both Ventures 1 & 2 realised the potential of a bigger market for drones and started setting ambitious strategic goals to open-up those markets. The major bottleneck in industry growth was that both Ventures could not identify a ‘killer application’ or a compelling product for a group of buyers that would be sizeable enough to propel the industry beyond hobbyists. Identifying the ‘killer application’ was a matter of matching technical characteristics of drones (architecture and combination of components) with the needs of the market or potential consumers (technology and demand fit). At that stage applications in several vertical markets such as construction, real estate, agriculture, as well as applications in movies were explored in parallel.

Aerial photography seemed like a ‘killer application’ at the time, but the underlying problem of low-quality video of existing drone architectures blocked industry growth. Venture 2 created the gimbal innovation solution in 2012 that integrated more powerful cameras and offered higher stability for image quality. The gimbal might have had fewer components but required tightly integrated computer science, electrical engineering, and mechanical engineering, making the gimbal difficult to manufacture. The importance of the gimbal is that it did push the growth of the drone industry: by creating high quality video, drones became appealing to the lucrative high-end professional market of aerial photography. Indeed, industry revenue doubled in 2012 and again in 2013. Venture’s 2 growth soared from \$4M in 2011 to £131M in 2013 and they changed the product meaning to a ‘flying camera’ beginning a new identity for this lucrative new market of aerial photography. Venture 1 was a laggard in this innovation, because the openness of the designs for the gimbal didn’t suit the complexity of the architecture; traditional proprietary designs of Venture 2 allowed it to be quicker and to be the first to innovate the gimbal.

In 2012 the commercial drone industry comprised of hobbyists and some professionals buying components and DIY kits. However, another bottleneck of further growth was that most commercial and consumer users were not interesting in assembling hundreds of parts and installing software to use drones. Both Ventures 1 & 2 attracted VC (venture capital) investment and worked to solving this problem which resulted to the major third innovation, the RTF drone, a fully integrated product right ‘out of the box’.

As in the previous cases, matching technical and demand related knowledge (what drones can do and what the new market applications desire/need) was essential in offering a new solution that will lead to further industry growth. The RTF was very complex, combining more components than the gimbal. There were many interrelationships across the components, complicating the size and weight constraints and trade-offs. The importance of the RTF was that it qualitatively changed the industry as it offered a mass-market product for both commercial and consumer users. Indeed, industry revenue exploded doubling in 2013 and quadrupling in 2014 (see Figure 3). The growing market size attracted more VC funding and a higher number of firms started entering the industry, some new start-ups and some established firms diversifying from other established industries (see Figure 5, next page). It could be argued that the industry was achieving another milestone that of ‘firm take off’ (see Figure 3) and progressing gradually to further growth in sales, which is expected to succeed the ‘firm take off’ stage (see Figure 3), when a greater number of consumers adopt the use of drones within specific application areas. Section 2.3.2 below discusses some of the barriers in user adoption.

As discussed below, these three innovations, although fundamental in shaping the nascent drone industry from a market of hobbyist to a mass-market covering a range of user needs, there are still a potential high number of applications of drone technologies that have not been commercially exploited yet (see Nex et al., 2022; Duffy, 2018). This is because drones are a generic technology which is likely to have a range of different applications. These applications can lead to revolutionary changes to a range of sectors.

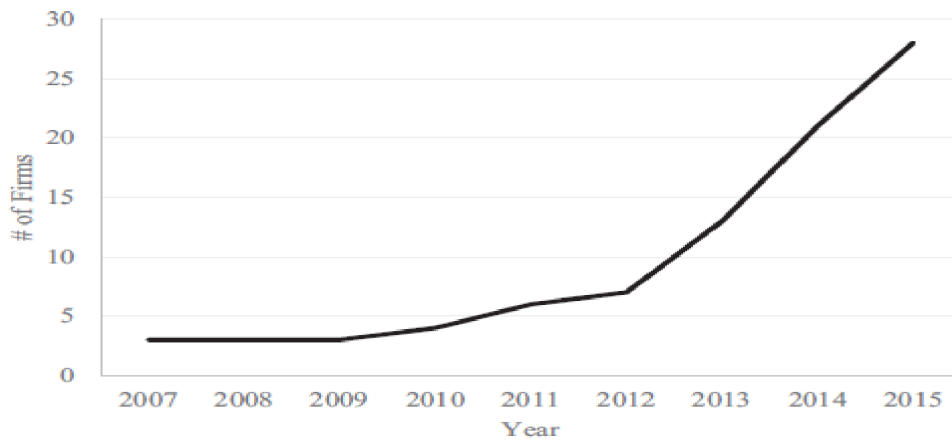


Figure 5 Total Number of Civilian Drone Firms (Bremner & Eisenhardt, 2022)

The above imply that there can be successive waves of ‘firm take off’ for each one of the different application areas of drones. For instance, this project explores two applications within agriculture and drone applications in logistics, forestry, and livestock management. However, other potentially lucrative applications, such as those in the medical sector, rescue operations and security surveillance (policing) are not examined in this project (Pulsiri et al., 2021). These applications form markets of their own, with their own demand peculiarities and user preferences. These preferences should be met by entrepreneurs for the specific industry applications to be commercialised and for the markets to grow.

As discussed in the case of the three initial innovations, entrepreneurship is about solving a specific problem, arising from technology and demand fit. At least this is the case at the initial stages of a nascent industry development. Moreover, technology can be taken to include a broader set of knowledge which is more encompassing than just the drone technical characteristics. It is important to look back at the Taxonomy presented in T1.2 and included in D1.1 at this point and to consider the range of architectures, components and software integrations that comprise the current drone alternative options. ‘Technical characteristics’ could be taken to include the software component of drones and entrepreneurial opportunities can arise from modifying and customising such software to meet bespoke user needs. Indeed, firms offer such customisable solutions to farmers with GPS and map modifications for drones to exclusively scan specified farming plots. The industry of drones in the UK in 2018 comprised of 700 firms with the majority (70%) being service providers (Duffy, 2018). Other service providing examples are firms that offer stations for drone battery charging /switching options.

The section 2.3.1 below discusses the range of other types of knowledge that need to be developed and aggregated for further industry growth. It also shows the important role that can be played by other actors forming the industry ecosystem, such as institutions (including universities and research centres), regulators, and complementors and go beyond the entrepreneur (firm) and user (demand side).

2.2 New market entry and higher productivity

In the last two-decade-models of firms, firms self-select an entry into export markets depending on their productivity as only the most productive firms can absorb all costs of exporting (Melitz, 2003). Prior models, for instance Krugman’s representative-firm model, assumed either all or no firms participated in trade, and that their level of trade responded to trade costs solely through the margin (Krugman, 1990). Thus, the relative costs of becoming an exporter to new markets influences the decisions of any firm in an industry. This gives relative importance to each margin.

Empirical evidence on the statistical relation between time and trade has defined two distinctive effects: first, it determines whether a manufacturer will enter a foreign market or not (for instance, either the

American manufacturer Boeing entering the European market for drones' production or the European well-established manufacturer Airbus deciding to enter the North American market for UAVs). Second, time affects the volume of trade once a market entry is made. A detailed study of the US imports found that an increase in logistics time of just one day reduces the probability that a country will export manufactures to the USA by 1.5% (Hummels, 2001).

In general, transport costs that are independent of trade volume such as time for administrative procedures, waiting times, etc. mainly affect market entry of new foreign companies, while costs that are proportional to trade volume or value such as insurance, storage fees mainly affect trade volume¹¹. In this respect, any technological improvement that will reduce the overall delivery times to the EU market and ease the process of innovation in Europe will have a profound effect on local innovators. New technology reduces costs for manufacturers.

2.2.1 Adopting drone technology for higher productivity: examples from the US

In the United States, the industries that have been adopting drones are classified into five usage segments by Shermon and Moeen¹²:

- 1) photography and videography;
- 2) short-distance inspection;
- 3) long-distance surveying;
- 4) precision agriculture and
- 5) aerial supply chain management.

The usage of drone technology in these five segments is for the drones to perform common tasks for multiple industries, and some technical differences are required in the specifications to effectively perform those tasks and improve productivity. For instance, for supply-chain and remote delivery tasks, drones typically hover in place and fly long distances, therefore hybrid types with multiple rotors mounted on the fixed-wing airframes are favoured in such cases. Furthermore, for agriculture and long-distance surveying, the suitable drones usually can scout large areas speedily and provide information in large quantities. Drones with a fixed-wing airframe architecture are faster, while longer battery life and autonomous navigation helps with flying BVLOS.

In precision agriculture thermal sensors are acceptable as payloads, but multi- or hyper-spectral sensors used for different purposes could provide more accurate vegetation data, which helps agronomists to take better decisions. Naturally, payloads vary in weight, position, and signal interference with the navigation system. For this reason, it is important to appropriately match technical specifications of a drone with the nature of the task to efficiently meet customer requirements and market needs. All these specifications of the technology support the selection process of proper equipment and instruments that are to increase productivity in the relevant sectors and facilitate any creation of novel markets or alternatively penetrate new markets. The table below provides more details about the above-mentioned drone usages in the US:

Table 1 Market Segments

Usage segment	Common applications / industries	Common drone features / specifications
Professional photography and videography	Movie production Events and sport News and media Nature and landscapes Movie special effects	<i>Architecture:</i> - multi-rotor airframe <i>Performance metrics:</i> - shorter endurance, range;

¹¹ "Logistics and time as a trade barrier", OECD Trade Policy Working Paper No 35, 2006

¹² See more in: Shermon A., M. Moeen, (2022), "Zooming-in or zooming out: entrants' product portfolios in the nascent drone industry", Strategic Management, John Wiley & Sons Ltd

	Real estate promotion	- ability to hover in place; <i>Valuable payloads:</i> - high revolution cameras - gimbals
Long-distance surveying	Pipeline inspection Railroad inspection Search and rescue Security surveillance Mining, Mapping, Oil & Gas exploration, Wildlife, and ecological monitoring	<i>Architecture:</i> - fixed-wing airframe; <i>Performance metrics:</i> - longer endurance range; - beyond visual line of sight (BVLOS) <i>Valuable payloads:</i> - LiDAR, laser-based systems; Thermal and infrared sensors;
Short-distance inspection	Utilities inspection Insurance assessment Bridge inspection Turbines Gas and electricity, Wind turbine, Flare stack, Petrochemical plants	<i>Architecture:</i> - Rotary-wing airframe; <i>Performance metrics:</i> - Shorter range; - Ability to hover in place; <i>Valuable payloads:</i> - Thermal and infrared sensors; Gas sensing and leakage sensors;
Precision agriculture	Field monitoring Crop health assessment Crop dusting and spraying	<i>Architecture:</i> - fixed-wing airframe; <i>Performance metrics:</i> - longer endurance range; - faster max speed; <i>Valuable payloads:</i> - Hyper- and multi-spectral sensors; - Liquid sprayers;
Aerial supply chain management	Retail parcel delivery Inventory management	<i>Architecture:</i> - hybrid airframes; <i>Performance metrics:</i> - longer endurance range; - beyond visual line of sight (BVLOS); - faster max speed; <i>Valuable payloads:</i> ability to lift and drop;

Source: Shermon & Moeen (2022), p.12

2.3 Competitiveness, sustainability and acceptability

The impact of technological advancement or entirely new technology upon the competitiveness of a country is enormous, but the channels may vary depending on the specialisations of firms. For instance,

the single market has made EU economies more open and more specialised. The demand for EU exports is a powerful driver of sustaining regional competitiveness. The emerging economies are increasingly competing with Europe not only in traditional exports but also in knowledge-intensive industries. Fast-growing new industrial powers outside Europe, for instance China, India, Brazil present EU firms with both challenges and opportunities. Competitive factors provide the incentives to adopt new technologies in both very traditional (agricultural sector) and knowledge-intensive (such as robotics, space industry) sectors of the EU economy, and help the market select the most productive firms.

The competitiveness is fostered by the institutional and regulatory environment as it creates the right framework for adopting and developing new ideas and innovation. Due to a change of globalisation in recent years, the value chain positioning and performance of EU industries is an essential factor for optimisation. The internalisation of industrial value chains resulted in a sharp increase in trade in intermediate and semi-finished products in the past. Partially this changed the way firms compete and made the value-chain performance become a more important measure of competitiveness than the traditional emphasis on export performance measured through market shares and advantages¹³. However, due to the COVID-19 pandemic in the last three years, a recent upward pressure on prices above all for food and energy, military actions in Ukraine and the global GDP stagnated in 2022¹⁴, which all of these led to fragmentation of the global supply chain in general terms, thus the network and the concept of value delivery via the **network** became a key focus of many measures taken by businesses.

A recent paper by Baldwin and Freeman proposes a way to measure the foreign input dependence based on gross, or cumulative trade as an index that gauges the exposure to shocks emanating from abroad (Baldwin et al, 2021). They argue that exposure to foreign input reliance is higher than the direct indicators imply. Disruption to production or shipping from one country, due to a Covid lockdown was likely to affect the total value of goods produced or shipped, irrespective of the source of the inputs. To capture the indirect links in the network, Caselli et al. (2020), built a quantitative model of trade with global supply chain networks to trace how shocks in one or more sectors transmit across other sectors in the network¹⁵.

2.3.1 The growing civilian drone industry: Patterns of growth based on knowledge evolution

In this subsection, for the industry to grow and become competitive, one can see the areas of knowledge that are important to be developed at every stage of industry development together with the interactions between these areas on Figure 6. The figure broadly reflects the expectation that industries develop as actors in such industries reduce uncertainty about a new product and its use. This uncertainty is reduced as actors generate, share and aggregate knowledge in four main areas: technology, demand, ecosystem and institutions (Moeen, Agarwal & Shah, 2020). For instance, it is clear to see how the innovations discussed in the previous section reflect the Incubation Stage and the important role of interactions between technology and demand knowledge for that stage (e.g., the three innovations were technical solutions to the demand needs). During pre-firm take off stage, actors' motives shift towards economic considerations and the visible commercialisation history of early pioneers can stimulate entry of a critical mass of firms. Furthermore, during pre-sales take off stage, there is a diversity of commercialising actors that focus on scalability and the interactions across knowledge of all four knowledge dimensions.

¹³ OECD, De Backer, K., N. Yamano, "International comparative Evidence on Global Value Chains, OECD Directorate for Science, Technology and Industry, in Sydor, 2011, pp103-126

¹⁴ OECD Economic Outlook, Interim report, "Paying the price of war", September 2022

¹⁵ See more details about the model in: Caselli F., Koren M., Lisicky M., S. Tenreyro, (2020), "Diversification through trade", *The Quarterly Journal of Economics*, Volume 135, Issue 1; 02/2020

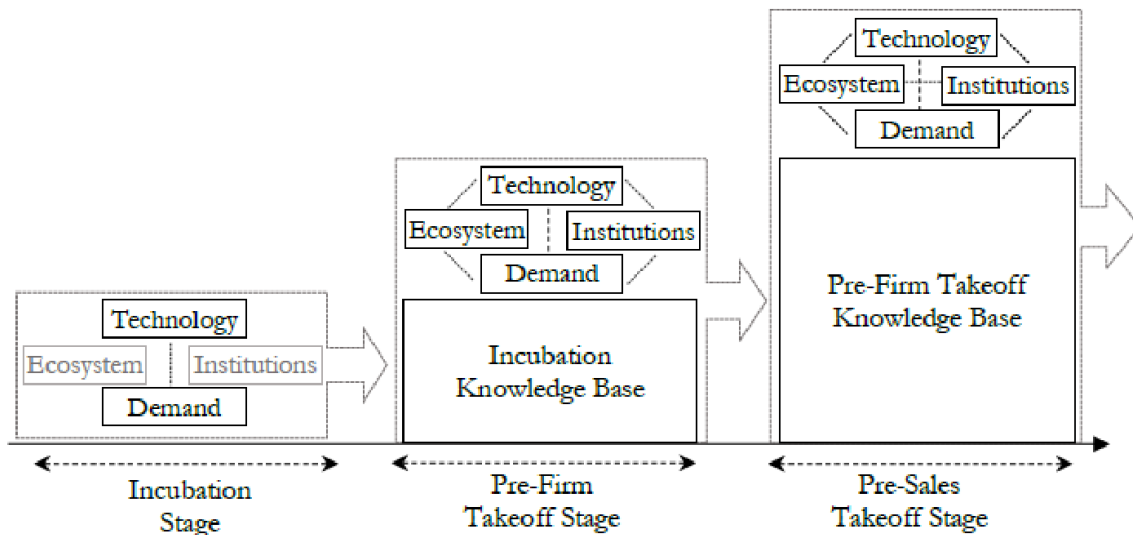


Figure 6 Cumulative building of industry knowledge base (Moeen et al., 2020)

Moreover, Figure 7 below elaborates on the framework of Figure 6 showing the types of actors that are important for the development of each stage, the types of new knowledge that are important to be created and finally the types of knowledge that need to be aggregated in the overall industry system. At any point in time, insufficient knowledge can lead to delays or abandoning industries.

It is clear to see how the framework helps to understand the important ingredients for the development of the civilian drone market, but also of each one of its wide range of applications (current and potentially future). For instance the role of regulatory institutions in terms of aviation rights and flying path licenses played a critical role in offering a clear legitimate backdrop that stimulated firm take off (see second stage in Figure 7). Venture 2, unlike Venture 1's community focus and open-source approach, pursued active patenting for its innovations since 2008, using both the US and the European patent systems due to the comparative strength of the appropriability and protection regimes of these jurisdictions for this industry at least at that time. The eligibility for IP rights gave Venture 2 the opportunity not only to protect its intellectual property and to gain monopoly rights to commercially exploit its innovations, but also kudos that boosts its image beyond the stereotypical 'Chinese copycats', a stigma that Venture 2 carried at the early stages of its initiation due to its location which was seen as a comparative disadvantage to Venture 1 which was based in North California, proximate to Silicon Valley (Bremner and Eisenhardt, 2022). Defining the industry identity as 'flying cameras' was another important development in the knowledge base of the industry during its pre-firm take off stage (stage 2 in Figure 7). This was the first most lucrative use of drones.

As it will be discussed later on, corporate image and reputation are important in the success of companies to attract new users to this new and potentially controversial for some industry. Controversies are mainly stemming from the military background of the drone technology and the still unshaped legal framework around privacy violations (see aerial photography in urban areas) (Mendoza et al., 2021).

It is noteworthy that collective coordination amongst the four types of knowledge and actors representing these areas is important to attract more investment in the industry for the industry to proceed to 'firm take off stage'. The 'pre-sales take off stage' shifts emphasis from ecosystem suppliers (stage 2) to ecosystem complement providers (stage 3). Complement providers include a range of actors in the ecosystem, from those working /offering complementing services to those operating in complementing areas where developments in knowledge and technologies have important implications for the development of drones as a product. Advancements in complementing areas can offer a resolution for several problems with

existing drones, which if successfully resolved can attract more users in the market by convincing them about the benefits and ease of drone use.

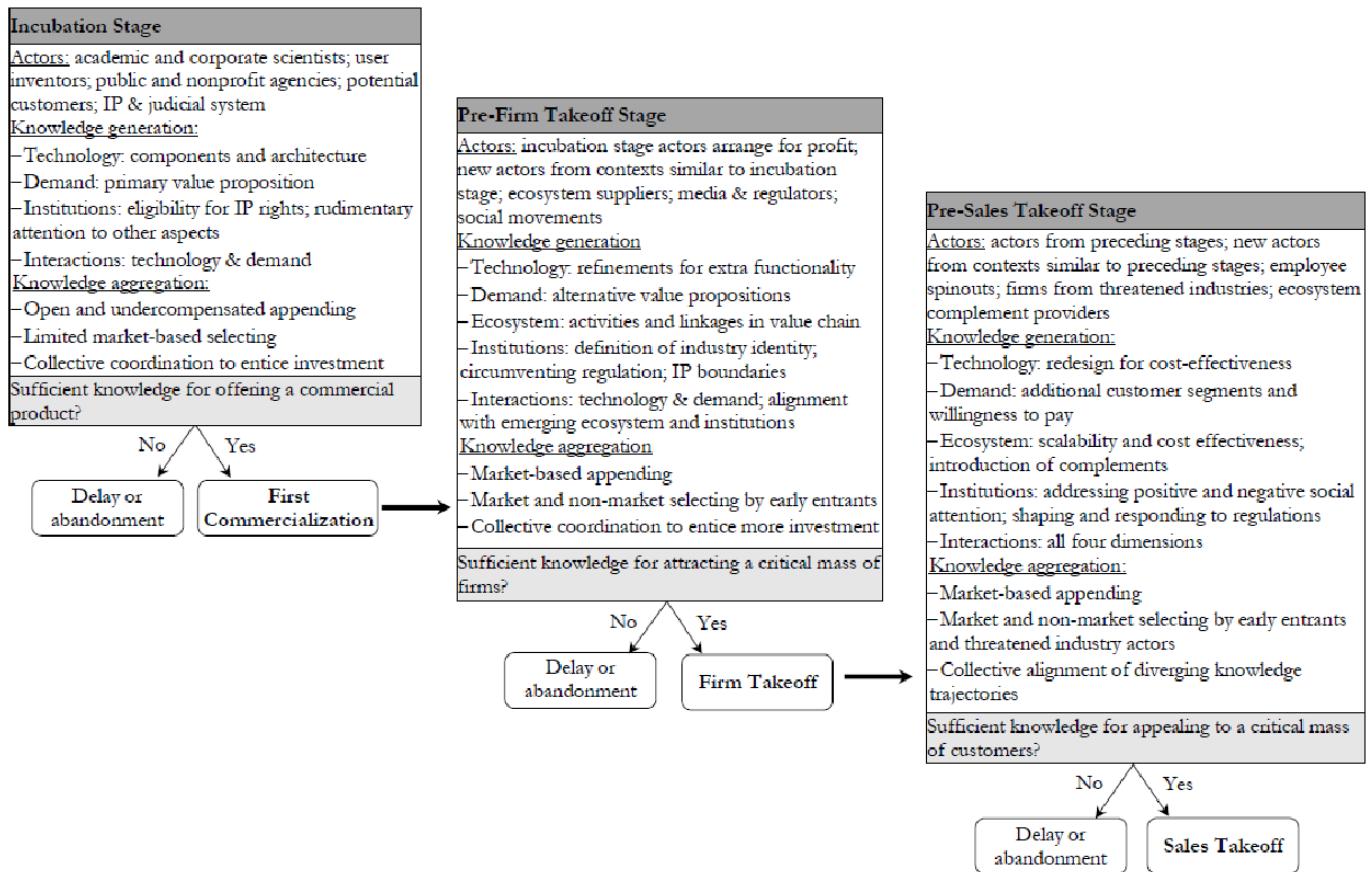


Figure 7 Processes of industry emergence based on industry knowledge base development (Moeen et al., 2020)

Advancements in complementing areas and enabling technologies can open up opportunities for further drone applications. Indeed, a recent article on the future of UAVs (with a focus on photogrammetry) notes how technological developments in miniaturisation of onboard sensors, the development of algorithms and software has pushed the conception of new applications that will further boost the use of UAVs in the future (Nex et al., 2022). In furthering the development of drones, some of the most important considerations are size, weight, camera accuracy (sensor type and number of sensors, image resolution), flight time (battery type: e.g. Lithium Polymer, Lithium-Ion), calibration, but also options such as desirability of live streaming of images, lights and other accessories, which complicate the architecture arrangements of new drone solutions. These solutions can include substantially new drones, and/or improvements and enhancements of existing drones. Some of the current experimentations in the industry, which focus on the flying time and drone independence work around themes such as: a) using multiple drones that alternate their flight over the interest area, b) automated battery swapping where robotic actuators can change autonomously the UAV batteries, c) wireless transfer power approaches that can be divided in electromagnetic field charges and non-EMF charges¹⁶ (Nex et al., 2002). Moreover, one can clearly see how further advancements in algorithms that enabled autonomous UAVs, and technologies such as deep learning can offer safer options through collision avoidance and expand the opportunities of drones in the future. The last examples are offered as an illustration of the business opportunities available in this industry for existing firms but also for others operating in adjacent and complementing segments of the vertical structures, such as batteries production, energy, charging stations and car manufacturing¹⁷.

¹⁶ For example, photovoltaic cells used to keep the battery level high.

¹⁷ See drones and flying cars.

2.3.2 Factors affecting the transfer and diffusion of UAVs

The use of UAVs has been accepted in some applications and by some users, but because of their military origins there is a certain controversy and aversion towards acceptance by new or growing number of users, which can affect the rate and extent of UAV technology adoption. Controversies can be linked to concerns around engendering privacy, safety, ethical and transparent use. These concerns can be characteristic of dual use technologies (those with military-use that move to other settings) but can also be a wider phenomenon, for instance the use of GM crops was (is) surrounded by ethical considerations around food and environmental safety.

Literature on technology adoption and transfer focuses on how technology is adopted from originator to recipient organisations; here it is important to discuss the barriers that can be raised in the adoption of the technology by end users, their perceptions of the technology and how these can be altered in order to facilitate technology transfer, diffusion and adoption by new users (Mendoza et al., 2021).

These barriers can include psychological barriers, which include conflicts users may experience when innovations require them to change existing beliefs, or to break away with accepted societal norms and traditions. These barriers may include image barriers associated with stigma attached to the technology. For instance, the use of drones for surveillance and for carrying out active combat attacks in the military, carries a stigma that many users may not overlook because of their ethical and moral values, or the social and cultural implications by the end user implementation (also broadly known as sociocultural barriers) (see Mendoza et al., 2021).

There are technology-related barriers to the transfer and diffusion of technology which involve user uncertainty about the functionality of the technology, its performance, relative value, and costs compared to alternatives and risks associated with its use. Within this category are barriers regarding the ease of use of the technology, the utility derived and user's existing level of knowledge of the technology. Furthermore technology related barriers may include concerns of the lack of safety in the use of UAVs and any impact on people's privacy and welfare, impact on buildings and vehicles from use in urban locations (Mendoza et al., 2021).

There are political barriers which are linked to the overall unpreparedness of the political system and the regulators to balance social and economic benefits stemming from the broader diffusion of dual-use technologies and to enact new regulations for privacy, safety, security, and liabilities.

There is a range of economic barriers that stem from cost of the technology, the risks and costs of maintenance, economic profitability in terms of financial and time savings from the adoption of the technology against the aforementioned risks and costs. Users need to be convinced that the technology is a worthwhile investment and they need to be convinced that there is an appealing performance-to-price ration at the time of purchase / adoption (Mendoza et al., 2021).

Furthermore, there can be considerable market barriers in the diffusion of a dual-use technology which are erected to constrain the natural tendency that consumers may have towards adopting the technology and its products. These barriers are quite broad and may include restrictions in the availability of the technology and its products (e.g., tariffs, market and industry protectionism, access to UAV products and desirable product range and variants of UAVs), the availability of promotions (the prevalence of UAV promotions to end users) and recommendations by specialists (UAV and application-specific experts endorsing the use of UAVs). Finally, availability of rich information, in terms of knowledge of the benefits from adoption and of options of complementary products and services (e.g., maintenance agreements, contracts for use) can also influence the decision to adopt / purchase the technology and its products.

Market related barriers can exist when the end user is not involved in the purchasing decision, as when for instance, associations and cooperatives may decide on purchase (Mendoza et al., 2021).

There are a range of interventions that can be implemented to support in lifting those barriers. Some concerns around the use of drones for deliveries shifted because of external shocks such the pandemic caused by Covid-19 (Yaprak, Kilic & Okumus, 2021). Broadly speaking, institutions and ecosystems can play fundamental roles in generating knowledge (see Figure 6) about the benefits of the use of the technology that can alleviate some of the above concerns. Moreover, start-ups or established firms entering this industry can adopt a range of communication strategies to build a corporate image for their products and for the broader industry applications that assist to overcome the above barriers, particularly those associated with psychological, social stigma, ethical and moral use of the technology¹⁸.

2.3.3 Needs of global drone stakeholders extracted from ICAERUS surveys

If one takes into consideration all theoretical achievements in the field of *economics of innovation* and *strategic management*, and to understand better how the local stakeholders in European countries may be able to absorb the technological change in the organisational structure of their firms due to new drone applications, we asked drone industry actors and end-users to assess a list of identified needs, which was performed in T1.1 *Understanding the Drone Market* and discussed in D1.1 *European Landscape of Drone Innovations and Technologies*. For the purposes of this comparative analysis report, it will be presented only an extraction of results obtained via two global surveys¹⁹ in Table 2 and 3.

The results are arranged by importance as the first eight specific needs of drone stakeholders in Table 2 received the highest score of **E**, which means that they are “absolutely essential” and must be fulfilled so that stakeholders can operate and stay in business. In Table 3, the first six specific needs of drone end-users received the highest score of **E**, and they are absolutely needed for the firms to be operative. The others scored **D**, which means “its presence is needed”, and the last three scored **C**, meaning “satisfied by its presence and do regret its absence”.

Table 2: Responses for each identified stakeholders' need (percentage from total)

Needs of drone stakeholders	A	B	C	D	E
1. EU R&D projects or collaborating with universities	3%	9%	18%	21,2%	48,4%
2. Assessment of operational risks and treatment actions	9%	0%	24,2%	21%	45%
3. Certification and legalisation of drone services	6%	3,2%	15%	30,3%	42,5%
4. Training of personnel	6%	6%	10%	33,3%	42,4%
5. Working in a network and transferring know-how	3%	6%	9%	42%	42%
6. EU policy directives, regulations, and compliance	3%	9%	24,2%	24,2%	39,4%
7. Understanding regulatory processes and rules	9%	3%	21%	30%	39%
8. Knowledge on optimal, environmental, and safe UAVs operational usage	9,2%	3,2%	18%	33,3%	36,3%

¹⁸ These will be discussed in WP4 and WP5.

¹⁹ See more in D1.1 Section 5.2: Surveys and Interviews

9. Commercial clients	6%	9%	15%	45%	24,2%
10. Access to new markets in Europe for drone applications	9%	9%	15%	45%	21,2%
11. Private investments	10%	3%	21%	42%	24%
12. Communication with customers	9%	9%	21%	40%	21%
13. Access to new markets worldwide	3%	3%	30,3%	42,5%	21,2%
14. Collaborative activities and cost-sharing	3%	3%	24,2%	42,5%	21%
15. Processing drone business activities	10%	9%	33%	42%	6%
16. Research-based evidence of efficiency of drone usage in rural and isolated areas of Europe	6%	3%	15%	39,3%	33,3%
17. Skilled workforce	6%	3%	15%	39%	36,3%
18. Science knowledge (drone-related)	6%	6%	21%	38%	29%
19. Public-private partnerships	9%	9%	24%	36%	18,2%
20. Software development and algorithms	9%	9%	21,2%	30%	30%
21. Scientific publications	9%	12%	18%	30%	30%
22. Inspections and auditing	3%	3%	42,4%	30,3%	21,2%
23. Components to manufacture drones	10%	18%	42%	9%	21%
24. Shared values and risks	6%	9%	36,4%	24%	21%

Source: Deliverable 1.1, p. 131

Overall, all specific 24 value flows identified in this survey's list of assessed needs are deemed to be either "essential" or "its presence is needed" (answer D and E).

Table 3: Responses for each identified end-users' need (percentage from total)

Needs of end-users	A	B	C	D	E
1. Training of personnel	0%	2,2%	9%	40%	48,8%
2. EU R&D projects or collaborating with universities	0%	6,7%	13,3%	37,7%	42,2%
3. Skilled workforce	2,2%	4,4%	9%	42%	42%
4. EU policy directives, regulations, and compliance	2,2%	2,2%	17,8%	35,5%	40%
5. Knowledge on optimal, environmental, and safe UAVs operational usage	5%	9%	13,5%	33,3%	37,7%
6. Software development and algorithms	2,2%	13,3%	13,3%	31%	37,7%
7. Shared values and risks	0%	5%	17,7%	66,7%	9%
8. Access to new markets in Europe to increase the food production	0%	5%	24,5%	57,7%	11%

9. Collaborative activities and cost-sharing	2,2%	9%	17,7%	55,5%	13,3%
10. Research-based evidence of efficiency of drone usage in rural and isolated areas of Europe	0%	2,2%	13,3%	53,3%	26,7%
11. Inspections and auditing	0%	6,7%	15,5%	48,8%	26,7%
12. Commercial clients	2,2%	9%	15,4%	48,8%	20%
13. Working in a network and transferring know-how	0%	2,2%	15,5%	46,7%	33,3%
14. Access to new markets worldwide to increase agricultural production, biodiversity, and rural logistics	0%	6,7%	17,7%	44,4%	31,1%
15. Private investments	2,2%	9%	27%	44,4%	15,5%
16. Scientific publications	0%	2,2%	24,5%	42,2%	28,8%
17. Communication with customers & awareness campaigns	2,2%	13,3%	9%	42%	33%
18. Public-private partnerships	0%	9%	33,3%	35,5%	22%
19. Public opinions from the community	6,7%	4,4%	22,2%	37,7%	26,7%
20. Science knowledge (drone-related)	5%	13,3%	20%	31%	31%

Source: Deliverable 1.1, p. 134

Overall, all specific 20 value flows identified in this end-user survey's list of assessed needs are deemed to be either "its presence is needed" or "essential" (answer D and E). Both tables give us a better understanding of the current drone stakeholders' expectations and challenges. In summary, from the two global surveys' results, the top 10 specific needs are as follows:

Drone Stakeholders

1. EU R & D projects or collaborating with universities
2. Assessment of operational risks and treatment
3. Certification and legalisation of drone services
4. Training of personnel
5. Working in a network and transferring know-how
6. EU policy directives, regulations, and compliance
7. Understanding regulatory processes and rules
8. Knowledge on optimal, environmental, and safe UAVs operational usage
9. Commercial clients
10. Access to new markets in Europe for drone applications

End-users

1. Training of personnel
2. EU R&D projects or collaborating with universities
3. Skilled workforce
4. EU policy directives, regulations, and compliance
5. Knowledge on optimal, environmental, and safe UAVs operational usage
6. Software development and algorithms
7. Shared values and risks

8. Access to new markets in Europe to increase food production
9. Collaborative activities and cost-sharing
10. Research-based evidence of efficiency of drone usage in rural and isolated areas of Europe

All interviewees in T1.1 and analysed in D1.1 make similar conclusions in recognising the essentiality of several specific needs such as:

- a. Scientific and technical knowledge
- b. Drone awareness campaigns with explanation of regulations
- c. Social campaigns in communities with proper explanation of technology
- d. Collaboration of stakeholders
- e. Sufficient informative content
- f. Scientific data and publications
- g. Personnel training
- h. Attracting younger personnel in agriculture
- i. Synergy between private businesses, academia, and the public sector
- j. Solid communication among stakeholders and institutions

However, it is noticeable the variations in specific needs from one use case to another, and the purposefully targeted interviews in the countries of our use cases (Spain, Greece, France, Lithuania) that present the current understanding and experienced challenges of involved stakeholders. While most of them focused on the necessity of drone technology applications and methods that can be utilised in the agricultural, forestry and logistic sectors, some of them distinguished between the opportunities provided by the private or public sector.

The deliverable D1.3 *Comparative Analysis and Needs* will further elaborate on the comparison of needs in the drone ecosystems of Europe, present technological solutions which were deeply explored in T1.2 *Stock-taking of Drone Technologies* and global market trends that are expected to shape the future drone markets. For instance, the Covid pandemic has shown that different cargos can now be carried by a drone at a small fraction of the price of a conventional aircraft. Also, medical supplies were transported by drone during the heavy lockdowns everywhere in the world. Therefore, more industries will be looking at the success of drone delivery to expand the type of goods that can be transported, and these novel types of drone applications will shape the new markets and future global trends.

3. Market needs and technological global trends

Navigating more into detail, this *chapter 3* aims to provide some insight about the more prominent needs driving the drone market, the developing global trends, what is the near future and the next-generation solutions²⁰. It also delineates the broader context of development of UAV applications within which the comparative analysis in *chapter 4* is set out. It provides the necessary background information for being able to position the agricultural developments of the European Union in a comparative perspective.

In many sectors of the global economy, commercial drone applications and more precisely the **hardware** are in the early to middle and late stages of development, which means that in some market segments there is huge potential for market growth along with the benefits of improving efficiency of production. To illustrate this tendency, Table 4 presents the categories of drone applications as identified by the team of Deloitte Touché Tohmatsu (2020) – there are five categories for which there is growth potential and other five categories where the components (communication systems, GPS, motors, microprocessors, and sensors) are at a late stage of development. Their growth potential has been exhausted. On the contrary, engines, advanced manufacturing, and batteries or other power of drone machines still have huge potential for further development and modernisation, and hence, these applications can be explored. Further

²⁰ Source: RPAS The Global Perspective Volume 1 – Systems – 17th Edition, 2022

developments in these categories are important for the applications such as air transportation and parcel delivery. The deployment phase of these two market segments is expected to be undertaken through application developers and software upgrades across smartphones, smartphone-connected devices (drones), cloud-based services, and smartphone-enabled services.

Table 4 Commercial drone applications' categories and maturity

Category	Early stage	Middle stage	Late stage
Advanced manufacturing		✓	
Batteries and other power	✓		
Communication systems			✓
Detect, sense, avoid capabilities		✓	
GPS			✓
Lightweight structure		✓	
Microprocessors			✓
Motors			✓
Engines		✓	
Sensors			✓

Source: 2020 Deloitte Access Economics, Deloitte Touché Tohmatsu

In terms of the **software** market segments, a series of large investments have been made into the broader unmanned aircraft systems traffic management (UTM). For instance, Thales invested in developing an “ECOsystem” together with Unifly²¹. Their funding came mainly from the German ANSP Deutsche Flugsicherung GmbH DFS²² (controlling the air traffic in Germany) and Belgium’s Federal Holding and Investment Company (FPIM). As a Belgium-based company Unifly partners with other research groups and firms from Europe and beyond to collaborate and integrate their competences.

Their open platform aligns stakeholders’ interests and ensures an air-traffic management system for drones to increase visibility and prevent collisions²³. In addition, Thales²⁴ leveraged their expertise in air traffic, system integration and cyber security to provide the leading UTM application.

Another large investment in the software segment was AirMap for Drones that now offers an app that helps operators plan missions, flights, and request airspace authorisation for operations in controlled areas. It helps companies understand the regulations that govern their flights, receive automated approvals and pdf proof of compliance, and get airspace notifications to stay on course²⁵. AirMap’s UTM and U-space products are deployed in Europe – the Czech Republic and Switzerland; Asia – Japan and Singapore; and the United States. The major investors of AirMap were Microsoft, Airbus and Sony.

²¹ www.unifly.aero

²² www.dfs.de

²³ See: <https://www.unifly.aero/company/about-us>

²⁴ See: <https://www.thalesgroup.com/en/worldwide/activities>

²⁵ <https://www.airmap.com/manage/operators/airmap-app-for-drones>

Overall, drone technology has the potential to provide more time and cost-effective solutions through reduced labour and risk, mainly in infrastructure, agriculture, transport, and security. The next section elaborates on the market needs and new global trends that can be matched with the existing technology.

3.1 Drone market needs

The generic market for civilian drones is at the emerging stage of development as discussed by the theoretical overview in chapter 2, with a future growth path in the shape of “s-curve”. This means that the drone technology is expected to have a fast rate of uptake until it has reached a stage of maturity. In this early to middle stage, market needs expand quickly, and investors’ interest increases fast. To discuss the potential of drone technology in various sectors of the European and global economy as well as the creation of novel market needs in times of digitalisation, the analysis will pay attention to many popular use cases and commercial start-ups that focus their resources on the adoption of new technology and the expansion of markets. First, the analysis will begin with more technical details of the relevant market segments and the drone specifications collected in Table 5:

- E-commerce and deliveries
- Urban air mobility
- Government and community services
- Sustainable and smart ports / airports
- Recreational
- Infrastructure and constructions
- Mining and resources
- Defence
- Agriculture

Then a description of all use cases as well as R & D projects will follow. From the uptake of all cases in the respective market segments, the main conclusion and recommendation made, and what the technology companies need to upgrade and increase the investments in to match the needs are:

- To increase autonomy of drones
- To increase endurance
- To increase payload capacity
- To increase the sound perception of environment (not limited to visual)
- To increase human-drone interaction (remote and proximity)
- To enable drones with robotic arms to interact with the environment
- To enable social inclusion and co-creation
- To modify and upgrade the regulatory frameworks - interaction with the authorities
- To increase dissemination and technology education programmes

Market needs well understood and future potential in the relevant market segments by 2040 are presented in the table below. It is noticeable that several sectors can further grow from the future uptake of UAV applications – mobility, e-commerce, government services, agriculture, infrastructure, and sustainable ports.

Table 5 Market segments and needs by 2040

Market segments	Drone applications	Market Needs	Growth area	Drone specifications
1. Urban air mobility	1. Airport taxi 2. City point-to-point 3. Nordic air mobility	- taxi passengers -city taxis - short-trip domestic aviation	Future potential in Europe from 2025 onwards	Larger carrying capacity for a person. Big batteries: Electric Car sized. Safety of vehicle, redundant systems

				Autonomy/Unmanned: similar requirements and technology to Autonomous Cars Regulatory framework to be unlocked.
2. E-commerce and deliveries	1. Parcel delivery 2. Food delivery 3. Pathology deliveries in remote areas	- express parcel transportation - transportation of small amounts of dangerous goods - express food deliveries - pathology testing and medical support in remote areas	Future potential with early developments globally from 2020 onwards (the first use case in Switzerland 2015)	Social acceptance and regulatory frameworks limit UAV that allows longer flight times, either fixed wing or VTOL. High accuracy positioning (either RTK GPS or vision-based) to fully automate processes like landing. Technical developments: mainly in last-metre delivery: landing, attaching, removing a parcel from the UAV. More complicated fleet systems (e.g., Zipline P2 Zip) Cargo chamber should account for the transport of delicate packages (e.g., medical supplies). Needed increased payload capacity to facilitate the transportation.
3. Government and community services	1. Firefighting 2. Border control 3. Customs 4. Police support	- control of fire hot spots - control of migration - custom monitoring - supporting police services	Future potential until 2040	Wildfire detection through high endurance UAVs (fixed wing / VTOL). Currently UAVs cannot carry enough liquid volume to actually put out a fire. Need to increase payload capacity. <u>Border patrol:</u> Thermal cameras for monitoring human movement are possible and available. Such as tracking footsteps, or other heat signatures. <u>Police:</u> Ground-based crowd observations from real-time video streams, integration of speakers to transmit messages to crowds. Need to strengthen human-drone interaction. Therefore, sound sensors / microphones should be added to obtain a

				better capture (not only visuals) of the surroundings. <u>Note:</u> Performing any of these tasks <i>autonomous</i>, requires more developments in datasets, analysis models (Deep Learning, Computer Vision), path planning and flight control
4. Sustainable and smart ports / airports	1. Inspection of assets 2. Security 3. Trips of engineers 4. Detection of drugs collectors and intruders (drone detection system) 5. Ship visits 6. CO2 measurements	- inspection and maintenance of critical infrastructure - outdoor inspection of aircrafts - security and safety of assets - passengers transportation - protection of port territory and airports - drone deliveries (on and off board) - emissions control	Future potential	Inspections of aircrafts and ships using UAV imagery. Detection of potential damages and hazards. Performed with highly stable rotor systems that fly close to the targets. Point measurements of GHG emissions using gas sensors, which is then interpolated to reconstruct emissions. Similarly, rotor systems that enable high manoeuvrability are used.
5. Agriculture	1. Agriculture 2. Forestry 3. Fishery	- crop monitoring - aerial crop analysis - yield estimation - insects control - drone spraying - plant disease detection - biodiversity monitoring - wild animal detection - livestock monitoring	Well established with future growth potential	Field inspections using various cameras (visible, infrared) for crop status monitoring. Lighter drones with high autonomy (path planning) are more efficient. Enable drones with manipulators/robotic arms to interact with the environment. Pest control through chemical or mechanical solutions (https://www.pats-drones.com/pats-x). Spraying drones are rotary systems to enable stability and low altitude/speed flight. Animal monitoring (wildlife or livestock) is generally

				performed by both fixed wing and rotary systems. Monitoring of nocturnal species normally requires thermal imagery. Herd control is also performed through integrated devices (speakers), or the aircraft itself. <u>Fishery:</u> drones to drop bait or send video streams to fishmongers. Illegal to pull in a fish hooked with a line attached to the drone. <u>Note:</u> Performing any of these tasks <i>autonomous</i>, requires more developments in datasets, analysis models (Deep Learning, Computer Vision), path planning and flight control
6. Infrastructure, construction	1. Surveying 2. Inspection 3. Mapping 4. Inventory management	- inspection of assets - maintenance of assets - inventory management - repair infrastructure - visual images - computer mapping	Well established with growth potential	Rotor systems are mainly used to reconstruct buildings, civil structures (e.g., bridges) or conduct topographical land surveying, through photogrammetry. Inspection on infrastructure or utilities (drainage, leakages, electrical or other faults/hazards) Solar panel inspection through highly autonomous UAVs, often equipped with thermal cameras. Geometric accuracy of surveys is confirmed with Ground-control points, RTK-GPS and state-of-the-art photogrammetry. Warehouse managing through indoor fleets (https://verity.net/automated-inventory-management-warehouse-drones-solution/) <u>Note:</u> Performing any of these tasks <i>autonomous</i>, requires more developments in datasets, analysis models

				(Deep Learning, Computer Vision), path planning and flight control
7. Mining and resources	1. Surveying 2. Inspection on sites 3. Mapping 4. Underground applications	- stockpile management - automated surveying and mapping - support of emergency operations	Well established with growth potential until 2030	Mapping of underground formations and layers through magnetic sensing systems, usually rotary systems. Similar to above survey tasks: Photogrammetry, RTK GPS, etc. <u>Review article:</u> Park & Choi, 2020
8. Defence	1. Surveillance 2. Warfare	- enhance defence capabilities	Future potential	This category is probably not relevant to the project. More budgets, more potential, more dangerous, and sophisticated classified R&D, surveillance, direct warfare, etc.
9. Recreational	1. Recreational activities	- filming, videography - photography - hobby-based activities	Already established and affordable	User-friendly systems that prioritise safety. Rotary systems are both easier to control and safer. Using FPV racing UAVs for cyclocross through the forest

Looking at Table 5 and the popular use cases provided, it becomes apparent that UAVs are a key component of the digital economy - they can establish the basis for new competitive markets. To respond to this rapid technological advancement, regulators in several countries have decided to relax the regulations for commercial operations while also providing guidelines and training. These moves have opened up new use cases by introducing less restrictive rules on factors such as drones' maximum altitude and minimum distance from dense areas. Still there are regulations that constrain commercial autonomous flights and BVLOS operations, and in *T1.4 Standards, regulations and risks* these issues are thoroughly explored and reviewed. In the future, if regulations would be eased, drones operating beyond visual line of sight would be able to undertake remote monitoring of the extensive infrastructure networks (fibre networks or power-line communication) of telecom operators and other industrial entities.

3.2 Use cases by segment: to demonstrate potentially emerging needs

3.2.1 Urban air mobility

The case of urban air mobility has been pushing the frontiers of innovative thinking in all parts of the world. In Europe, testing has begun in Germany, France and Finland, similar project pilots have been funded in the United Kingdom too.

The **Finnish UAV Ecosystem** (FUAVE) has developed operating models around the two urban test areas: Helsinki – Jätkäsaari and Oulu – Hailuoto in Northern Finland. These test areas act as Living lab environments in urban or rural regions, providing a one-stop shop for research, business, and applications

of UAVs²⁶. For instance, the living lab of City of Oulu provides a single entry and a one-stop service point for any matters associated with making business in the city's U-space, as well as drone applications, particularly in the Nordic conditions, and enabling technologies for testing, research, and demonstration purposes to develop safe, secure, and all-weather resilient technologies.

The research consortium of the Finnish UAV ecosystem covers several fields that are needed when aiming to develop automated and autonomous drone applications to match the market needs of urban mobility such as geospatial research, remote sensing and analytics, robotics, 5G/6G connectivity, ecosystem co-creation, mobility and drone logistics, regulations, and challenges in the Nordic conditions²⁷.

It is expected the urban mobility drones to act as a transport mode between infrastructure nodes sometimes referred to as "vertiports". These infrastructure nodes will function as drop-off/ pick-up locations for passengers and will require passengers to complete the rest of the journey, for instance between origin points to a "vertiport". Globally, some reports give an early estimation of introduction and adoption paths for this technology between 2023-2025 in controlled areas, and more widespread adoption in 2030. The European legislation sets a high demand for safety and provides explicit accepted means of compliance, as well as guidance regarding policies and procedures to achieve safety.

The United Kingdom Air Mobility Consortium is led by Eve and joined by NATS, Heathrow Airport, London City Airport, Skyports, Atech, Volocopter and UK-based Vertical Aerospace. It is also associated with two of the most recognisable vertiport start-ups - Skyports and Urban-Air Port. The consortium has generated significant investment interest from the private sector.

In 2022, Urban-Air Port with Hyundai's Supernal (a smart mobility service provider) opened the first fully operational eVTOL hub, Air-One, in Coventry. Demonstrations conducted at the site intended to help gain public acceptance. Funding is partially provided by the municipality of Coventry and the design of vertiports are highly flexible and deployable at short notice for the air transport. It aims to serve four markets in a variety of situations: passenger air taxis, autonomous delivery drones, emergency management, and defence and logistics operations. An important component is the environmental impact - the services will be zero-emissions, off-grid power, supplied by AFC Energy's H2FC generator for Air-One.

On the research and commercialisation side, UKRI (UK Research and Innovations)'s Future Flight Challenge (FFC) initiated research studies in 2021. It provides £125 million in public funding matched by industry with £175 million, to develop greener ways to fly by advancing electric and autonomous flight technologies. More projects that were funded under the FFC at UKRI in 2022 demonstrate the expected technological and societal benefits in urban air mobility, and four projects are described in:

Table 6 UKRI's innovative projects in air mobility

Project	Definition	Consortium
AgiLe Integrated Airspace System (ALIAS)	The airspace system incorporates drones, air taxis and piloted aircraft working in unison to deliver economic and societal benefits	Volant Autonomy Ltd; TEKTowr Ltd; Drone Defence Services Ltd; Skyports Deliveries Ltd; Ports of Jersey Ltd; Adjsoft Limited (DroneCloud); Cambridge Sensoriis Ltd; Angoka Limited; Sky-Drones Technologies Ltd.

²⁶ The Finnish UAV Ecosystem (FUAVE): <https://www.fuave.fi>

²⁷ Publications and topics available at <https://www.fuave.fi/research/>

Skyway	It uses drones powered by renewable energy sources on a 165-mile superhighway connecting the airspace above cities including: Reading, Oxford, Milton Keynes, Cambridge, Coventry, Rugby	Altitude Angel; Connected Places Catapult; HeroTech8; ARPAS-UK Ltd; BT Group Plc; Reading Borough Council; Oxfordshire County Council; Coventry County Council; Angorka Limited; Vizgard Limited; Skyfarer Limited; Skyports Deliveries Ltd
Air Mobility Ecosystem Consortium	The project includes demonstration flights between a new Skyports vertiport and London Heathrow and Bristol airports using Vertical Aerospace's VX4 eVTOL aircraft, operated by Virgin Atlantic	Atkins Limited; Vertical Aerospace Group Ltd; Skyports Infrastructure Ltd; Virgin Atlantic Airways Ltd; Heathrow Airport; London City Airport; Bristol Airport; NATS; Cranfield University; The University of Warwick Manufacturing Group; Connected Places Catapult with support from EVE air mobility
PORTAL: the infrastructure launchpad for the future of flight	It will focus on developing a scalable, reconfigurable, and rapidly deployable automated vertiport capability. This technology will serve permanent vertiports, new bespoke vertiports and retro-fitted installations on car parks or rooftops as well as supporting temporary operations as a pop-up vertiport for events or disaster-relief.	SLINK-TECH Ltd; Angoka Limited; R4DARTECH Ltd; Cambridge Sensoriis Ltd; Snowdonia Aerospace LLP; Auriga Aerospace Ltd; University of Bristol

Source: www.ukri.org

The Air Mobility Initiative in Germany is a leading initiative for future urban air mobility initiated in 2022 by Airbus, Munich Airport and other research and commercial organisations, supported by the local state of Bavaria and the federal government, to conduct a series of research projects that aim to make the air mobility a travelling option between cities and within certain city routes. The consortium will offer a full range of solutions including:

- options for aircraft,
- navigation, vertiports and
- operations services in simplified packages.

The total budget of the initiative is EUR 86 million²⁸. Previously, in 2021 Munich Airport teamed up with Urban-Air Port as Munich Airport agreed to purchase at least one full-scale operational Urban-Air Port and develop vertiports that are expected to be ready by 2025.

Airbus concentrates its efforts on the development of CityAirbus NextGen, its electrical take-off and vertical landing (eVTOL) aircraft, along with key support and service offerings around it while Munich Airport offers ground infrastructure services and solutions. This initiative is now expanded to cover global cities and

²⁸ <https://www.munich-aerospace.de/en/all-news-en/air-mobility-initiative-en>

regions, so that advanced air mobility ecosystems spread worldwide. The objective is to create completely new ecosystems with the integration of eVTOL solutions and other means of mobility to bring added value to cities and communities.

In **France**, in 2020 a consortium of three organisations - airport operator Groupe ADP, transit operator RATP Group and Choose Paris Region - came together to develop an industry of Urban Air Mobility that was intact with Paris' objectives of environmental transition in air transport, economic recovery, and urban densification. The focus was on making experiments with eVTOL aircraft and demonstrating the technology at the 2024 Olympic and Paralympic Games in Paris. In the long-term, the aim is to create an ecosystem of larger groups, start-ups, SMEs, laboratories, universities to operate in the region of Paris.

The final use cases originate from non-EU countries. For instance, in **the United States**, Los Angeles (LA) is one of the most promising cities for advanced air mobility (AAM), because of its extensive network of helicopters, high willingness to pay for the service, a large customer base, severe road congestion and mild winter. The LA Department of Transportation plans to introduce electric air taxi services by 2028, when the Summer Olympics Games will be hosted in the city. One concern that was raised by this plan was the disadvantage of visualisation of all these electric taxis in the air. In this context, the Urban Movement Labs was initiated by the mayor's Office of Economic Development in 2020 to lead the integration of the AAM into the city's mobility network in a safe and sustainable way.

The other example from outside the EU is **Singapore's** development of Skyways UAS Proof-of-Concept (PoC) trials between Airbus and the local CAA, which led to an urban-focused UAS sharing and development agreement with the EASA. This development started relatively early in 2016. In 2021, OneSky and Nova Systems completed a Ministry of Transport and CAA UAS call for proposal with demonstration of UTM system scalable BVLOS operations that will be used to inform their UAS roadmap. Singapore also advanced its aerospace cluster to move forward with air mobility. It accelerated air traffic management digitalisation with the support of the French Thales that conducts UAS and UTM system R&D locally. The Singaporean public estate developer, JTC, provides space for drone developmental trials and plans for cluster-oriented industrial space supply²⁹.

3.2.2 E-commerce and deliveries

This is the next market segment where investors' interest has been increasing, and in Europe and worldwide, **Switzerland** became the first country to implement ongoing urban drone delivery via a collaboration between Swiss Post and Matternet, a drone company based in Palo Alto, California³⁰. The work began in 2015, and it was balanced between testing and scaling commercial operations together with modifying the regulatory framework. While the technical case has been established, the business case takes longer to be proven successful.

Nowadays, the case for drone deliveries becomes more compelling with the operative activities of Amazon, which plans have been developing since 2013. They intend to use drones for 30-minute deliveries directly to customers' residence, with the first drone-delivery customer planned to take place before Christmas 2022 in Lockeford, California. But this first flight was unsuccessful with issues that Amazon's headquarters in Seattle tried to diagnose and resolve. However, the deliveries began in January 2023 with a slow pace in accordance with a plan approved by the Federal Aviation Authority (FAA).

²⁹ See more in: [https://www.edb.gov.sg/content/dam/edb-en/about-edb/media-releases/news/seletar-aerospace-park-to-support-advanced-air-mobility-growth/Press Release - Seletar Aerospace Park to Support Advanced Air Mobility Growth.pdf](https://www.edb.gov.sg/content/dam/edb-en/about-edb/media-releases/news/seletar-aerospace-park-to-support-advanced-air-mobility-growth/Press%20Release%20-%20Seletar%20Aerospace%20Park%20to%20Support%20Advanced%20Air%20Mobility%20Growth.pdf)

³⁰ <https://mttr.net>

The US FAA doesn't issue licences to operate autonomous drones and drone delivery services. It creates *specific exemptions* to the strict US airspace regulations, with a long list of conditions that companies must follow. The FAA required Amazon's drone pilots to have a private pilot licence to fly a plane, not just a drone. In addition, both its California and Texas operations were limited to flights within 3-4 miles of drone launch sites. This of course restricted the number of potential customers for the drone deliveries.

This area of new market developments – e-commerce and deliverables – led to the modification of existing regulations and rules of the Aviation Authority in Switzerland. The first operation of Matternet used the GALLO³¹ approach, identifying operational mitigations for an uncertified aircraft system. In 2015, the first demonstrator began, Matternet from the US came to Switzerland, in a field, the first BVLOS flights took place in coordination with the GALLO approval process. With each additional successful test, the authority could move forward with longer and longer flights. Later the GALLO became the SORA (the specific operations risk assessment), which is now the means of compliance to meet the EASA's specific category of flights³². With the SORA intact, any country can develop a framework to enable advanced drone operations. Such innovative business activities take time to build trust with the community. Thus, Switzerland is recognised as the "home of drones", driving forward not only innovations and technological advancements, but also creating novel forward looking market expectations, and improving regulations.

In **Bulgaria**, Dronamics tested their first cargo drone flight on the north side of the Black Sea coast near Balchik. It is the first of its kind cargo drone with the capacity to carry up to 350 kg in a distance of 2,500 km (*Dronamics Cargo Drone First Flight*). The test was successfully completed on 25th May 2023, and the company plans to start with the commercial cargo flights by the end of the year to various Greek islands. Dronamics is the only UAVs company with a European licence to fly cargo across the whole continent.

In the **United Kingdom**, projects funded under the UKRI in 2022 demonstrate the potential technological and societal benefits for the communities in drone deliveries, and few of them are described in:

Table 7 UKRI's innovative projects in e-commerce

Project	Definition	Consortium
CAELUS 2	It aims to show the operation of a network of multiple electric drones for the distribution of medical products and medicines across Scotland.	AGS Airports Ltd.; NHS Scotland; NATS; University of Strathclyde; Connected Places Catapult; ANRA Technology; Atkins; Arup; Cellnex Telecom; Commonplace Digital; DGP Intelsius; Dronamics; Planefinder; Skyports Deliveries Ltd.; The Drone Office; Trax International.
Morecambe Bay Medical Shuttle 2	It uses drones to shuttle pathology samples between three hospitals in north-west England. The solar powered drones will deliver better healthcare to the Morecambe Bay community by speeding up the processing times of samples and reducing carbon dioxide emissions.	Digital and Future Technologies Ltd.; University Hospitals Morecambe Bay NHS Trust; Miralis Data Ltd.; Lancashire Teaching Hospitals.

³¹ Guidance for Authorisation for Low-level Operation

³² More details see in: D1.5 "Drone Standards, regulations and risks"

Open Skies Cornwall	It will test the next generation of drones, their infrastructure requirements and enabling technology to serve: NHS, Royal Mail, users of Falmouth harbour; Cornwall Council, International humanitarian medical logistics providers.	DronePrep Ltd.; Cornwall Development; Skyports Deliveries Ltd.; Trust Port: Falmouth Harbour Commissioners; Royal Mail Group Ltd.; NHS Kernow Integrated Care Services; jHub-Med; University of Southampton; Neuron Innovations Ltd.; TFC Inc.
BLUEPRINT	It aims to provide regulators, technology providers and operators with a blueprint for a UK-wide rollout of beyond visual line of sight drone operations.	Neuron Innovations Ltd.; Cranfield University; University of Southampton; Distributed Avionics Ltd.; Future Aerial Innovations Ltd.; AdjSoft Ltd.; Anra Technologies UK Ltd.; Sky-Drones Technologies Ltd.; Ebeni Ltd.

Source: www.ukri.org

An integral component of this market segment is the carriage of dangerous goods that became popular to investors, operators, and competent authorities during the lockdowns due to the COVID-19 restrictions (2020/21). Various goods such as medical supplies and patient specimens were transported by drone and due to their low hazard, crash protection was not required from operators.

The carriage of dangerous goods by drone provides new opportunities and operators see the potential in this new method of transport. The dangerous goods are classified into 9 classes. Shippers of dangerous goods comply with a set of requirements for packing, marking, labelling and documentation. Operators must know how to load them and what to do in emergencies too. As for the transportation by drone, there are additional requirements - the need for a crash protected container. These require a package to survive, without leakage, a fall from a height typically flown at by a drone i.e., in the region of 400 feet. Operators need an additional approval to carry dangerous goods granted by their competent authority.

Commercial tests of this service have been run in Japan by Zipline Instant Delivery & Logistics (www.flyzipline.com) and in the United Kingdom by Viking Drone Packaging (www.vikingpack.co.uk). The Viking pack now offers drone packaging solutions using smart packages and robotic systems to remove the labour-intensive processes.

Overall, this market segment - e-commerce and deliveries - has huge market potential with early developments from 2020 onwards as the market needs are already well investigated. The e-commerce is expected to have as high as 2.2 million units of drone deliveries by 2025, which estimation is based on work done by Frost and Sullivan³³.

3.2.3 Government and community services

Drones offer effective and safety improvements in civil services such as firefighting, using thermal imaging cameras to see through smoke and assist in rescue efforts. Additionally, drones can be used post-fire in disaster management to survey or map scenes to assess damages or to search for missing people. The data accumulated by the drone technology during the flight can result in better informed decision-making.

³³ <https://www.eft.com/technology>

3.2.3.1 Firefighting

Since 2015 drones have become an increasingly popular toolkit in the arsenal of firefighters and first responders both in the EU and across the world. This can be seen by the value of the global firefighting drone market which was valued at \$0.97 billion in 2021 but is expected to grow at a CAGR of 10.2% from 2022-2031 to reach a projected value of \$2.4 billion. A large share of this growth is expected to result from increased usage of drones to extinguish wildfires³⁴.

The extent of drone potential has been demonstrated across all stages of emergency response, even assisting firefighters before fire trucks and individuals are on the scene. The main phases include:

- Preparation:
 - o Data collected from drones equipped with thermal cameras sensors (wind detection, smoke, wind direction, vegetation, topography) help predict fires and provide early detection
 - o Drone recorded responses to previous emergencies can provide useful feedback for improving future responses and best practices and for creating effective training and simulations.
- Firefighting operations:
 - o Drones can release water and fire-retarding agents.
 - o Drones enhance situational awareness, improve decision management, and reduce risks.
 - o In search and rescue operations drones equipped with thermal sensors, speakers, spotlights, cameras etc. can help locate and communicate with victims with a lower risk to rescue crews. In some cases, supplies can also be delivered with drones.
 - o In forest fires drones can assess situations in hard to reach and dangerous areas
 - o Tethered and untethered drones in urban settings can quickly provide aerial views of the scene.
- Post-fire management:
 - o Drones can be used to survey damage caused by a fire and help assess if and where danger might remain.
 - o Drones equipped with Lidar can assess fire impact in substantial detail (to the tree level), including the likelihood of future risk such as flooding or erosion.
 - o These data are valuable for informing effective rebuilding.
 - o Drones can support tree planting and can help reforest 6x faster than hand planting³⁵.

The International Emergency Drone Organization (IEDO) is a global non-profit organisation founded in 2018 to promote the use of drones for emergency services and to develop exchange between first responders locally, regionally, nationally, and internationally. In 2022, IEDO was made up of 718 drone remote pilots, specialists and 27 public safety agencies and associations from 55 countries. In 2020 the IEDO Tactical program was launched to collect, assess, synthesise, and disseminate best practices for drone use in disaster and crisis management, utilising 13 national working groups and 7 subsequent thematic working groups. In 2022, IEDO planned to establish the IEDO Fire and Rescue drone commission and create a series of working groups for sharing knowledge on safety and legislation.

Companies and research institutes across Europe have been advancing the capabilities of drones for firefighting with support of EU funding as well as the interest and uptake by local and regional authorities. The European Emergency Response Association (EENA) has been at the forefront of integrating drones into public safety since 2014. They initiated pilot project test sites with members to test technologies and produced a significant well referenced white paper. They have supported training school establishment (Ireland), start-up program (crisis-tech), to bring technology and drones further (see projects in Table 8):

Table 8 EU-funded projects that integrate drone solutions into firefighting services

Project	Definition	Coordinator
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³⁴ <https://www.alliedmarketresearch.com/firefighting-drone-market-A06280>

³⁵ <https://www.verizon.com/business/resources/articles/s/the-case-for-using-drones-for-firefighting/>

Firedragon ³⁶ Eurostars 2023-2025	Firedragon will develop a long-range drone solution that can monitor flames on a large scale as well as small pockets of fire day and night with the aim of giving emergency services a better overview of the ground with the help of real-time fire maps.	Teknologisk Institut (DK)
TREADS ³⁷ H2020 2021-2025	The project will integrate drones into their toolkit for forest fire risk assessment, prevention, and preparedness technologies.	Rise Fire Research AS (NO)
HOPPERSUP ³⁸ H2020 2020-2022	The project aimed to improve the Drone Hopper UAV by increasing the payload capacity (water tank) from 150L to 600L and improve the stabilisation system to support firefighting missions.	Drone Hopper SL (ES)
Fotokite ³⁹ H2020 2019-2021	The project utilised tethered UAV systems that could be autonomously launched from fire vehicles to provide real time thermal and visual information.	Perspective robotics AG (CH)
DUF ⁴⁰ H2020 2017-2019	DUF used deep learning techniques for estimating the spread directions of fires based on infrared camera streams provided by UAVs.	Istanbul Teknik Universitesi (TR)
FIRESPEC ⁴¹ Excellent Science 2016-2017	FIRESPEC integrated small, low-weight low power, real time gas sensors with high specificity into drones used for detecting and monitoring fires.	Universiteit Gent (BE)
AF3 ⁴² FP7- Security 2014-2017	The project aimed to integrate drones into early detection and monitoring of forest fires.	Leonardo-Societa per Azioni (IT)

3.2.3.2 Policing

Drones have been integrated into police agencies since the early 2000s and have been increasing in popularity since as they increase efficiency and save time, improve quality of operations, and keep officers safer as they provide valuable information while increasing the safety of officers on the ground⁴³.

The current Emergency drone market size is US \$4,245.1 million and is expected to grow at a CAGR of 13.1% to reach US\$ 16,729.8 million by 2033. While this encompasses all end uses from police, homeland security, fire departments and disaster management, the police and homeland security currently hold the second largest market share⁴⁴.

International Criminal Police Organisation (INTERPOL)

In 2019 INTERPOL's Drone Response and Forensic Guidelines were drafted to offer police and other first responders' procedures for handling cases where drones are part of the criminal investigation, from tracing the use of the devices to extracting digital evidence⁴⁵. In 2022, INTERPOL held their 4th annual expert conference on the use of drones to bring law enforcement agencies together to discuss best practices and potential assistance offered by drones for security and emergency preparedness and were intending to

³⁶ <https://www.dti.dk/services/drone-technology-to-fight-europe-s-growing-forest-fires/44842>

³⁷ <https://cordis.europa.eu/project/id/101036926>

³⁸ <https://cordis.europa.eu/project/id/101000154>

³⁹ <https://cordis.europa.eu/project/id/880480>

⁴⁰ <https://cordis.europa.eu/project/id/752669>

⁴¹ <https://cordis.europa.eu/project/id/693447>

⁴² <http://www.cordis.europa.eu/project/rcn/185483/factsheet>

⁴³ <https://www.dartdrones.com/drones-for-police/>

⁴⁴ <https://www.factmr.com/report/emergency-drones-market>

⁴⁵ <https://www.interpol.int/en/News-and-Events/News/2018/INTERPOL-to-issue-drone-guidelines-for-first-responders>

prepare a strategic framework to support member counties with implementation of drones for law enforcement. Specially, INTERPOL's innovation centre based in Singapore, brings together academics, analysis and law enforcement and technology experts to research, develop and implement the latest technologies, including drones to fight international crime⁴⁶.

*United Nations Office on Drugs and Crimes (UNODC)*⁴⁷

The United Nations Office on Drugs and Crime law enforcement agencies use drones for mapping and monitoring in anti-drug trafficking missions. A specific case study in the Kyrgyz Republic is deploying drones equipped with cameras to map potential illegal drug harvesting areas together with an unattended ground sensor system. The UNODC has also provided aerial surveillance via drone-based camera technology to the Royal Thai Marine Police (RTMP) to address drug trafficking on the Mekong River⁴⁸.

International Emergency Drone Organisation (IEDO)

IEDO promotes drone use for all first responders including police. In 2022 they hosted the first IEDO emergency drone conference, engaging 54 fire departments, 25 police agencies, 19 search and rescue agencies, a coast guard and medical service from 31 counties. In 2020, the International Police Association (IPA) signed a Memorandum of Understanding (MoU) with IEDO to receive training for their members. As of 2022 IEDO also planned to form the IEDO Police Drone commission to implement extensive training courses in support of the IPA run by working groups that will also be used to share knowledge.

Singapore⁴⁹

The Singapore Police Force (SPF) has been at the forefront of cutting-edge technology enforcement. The Special Tactics and Rescue Unit (STAR) established in 1993 uses drones for identifying threats beyond the sight lines, situational analysis, surveying, and monitoring to take high quality images and videos, particularly in dangerous, hard to reach areas. In 2020, The SPF began testing drone boxes, together with the "Home Team" science and Technology Agency (HTX). This system enables the automation of the pre-flight process of the 10kg, 1.8m drones stored inside. Within the boxes, payloads are attached, and batteries are changed, with control happening by an operator and the Command-and-Control Centre. Once in flight, valuable data can be sent to officer on the ground to provide between situational awareness, and the drones can flight beyond sight lines⁵⁰.

Europe

Denmark

The police district for Funen Denmark (Fyns Politi) began using drones for public safety in 2017 and now have drones operating regularly. The "Drones for public safety and emergency response operations report"⁵¹ outlines specific cases where drones have been indispensable:

- During traffic accidents drone images replace manual measurements of implicated cars, so the accident site may be clear faster.
- Real time image assessment reduces disruption in the site area of pollution spills.
- Drones hovering at a single corner of sports stadiums are used for crowd monitoring and detecting disturbances.
- Arsonists have been detected through drones equipped with thermal imaging that detected the culprits near the fire site.

⁴⁶ <https://www.interpol.int/en/News-and-Events/News/2022/INTERPOL-convenes-global-summit-on-the-use-of-drones>

⁴⁷ <https://www.unodc.org/centralasia/en/news/unodc-explains-the-combined-use-of-unmanned-aerial-vehicles-and-ground-surveillance-systems.html>

⁴⁸ <https://www.unodc.org/roseap/2021/09/drug-trafficking-mekong-river/story.html>

⁴⁹ <https://opengovasia.com/robotics-and-uavs-advance-singapore-police-force-capabilities/>

⁵⁰ <https://www.mha.gov.sg/home-team-news/story/detail/airborne-drones-for-a-crime-free-zone/>

⁵¹ <https://industriensfond.dk/wp-content/uploads/uniflip/1109899.pdf>

- Drone images are used to reconstruct crime scenes, particularly when victims must be transferred immediately to the hospital. During special operations, drones are used for scenario assessment.

France

In 2023, a new decree that implements in practice security law that was voted on last year will enable French police (customs and military) to use drones to⁵²:

- Prevent attacks on people and property, including the prevention of terrorist attacks.
- Keep gatherings in public spaces safe.
- Maintain or restore public order.
- Regulate traffic flow; Conduct border surveillance and Rescue people.

The new legislation does not allow their use by municipal police officers or national police without authorization by superiors even in urgent situations⁵³.

Sweden⁵⁴

The Swedish Police Authority established the police drone program in 2018 after an extensive piloting study. Currently there are approximately 350 drones in operation, with >200 officers (1% of the police force) with licences and certifications for law enforcement drone operation, enabling each police authority to be equipped with a drone. Benefits have been observed in numerous cases:

- Deploying drones to capture crime and accident scene photos and video footage has reduced the risk of evidence contamination.
- In hazmat, fire and disaster response, drones provide aerial reconnaissance and support search and rescue operations.
- Drones are used for surveillance during large events to ensure safety and crowd control.
- Drones are flown regularly in Malmo public spaces and suburbs with high crime, gang, and drug trafficking rates to both detect and prevent crime, while supporting officers on foot patrol.
- Images acquired by drones are used as evidence for criminal prosecution and provide invaluable information when witnesses are not available.

By integrated drones, the cost of airborne monitoring decreased by 200%, despite the costs of equipping each police vehicle with UAS program with DJI Mavic 2 enterprise and using the DJI Matric 2010 V2 for large scale operations, the Mavic 2 pro for forensic work and the Mavic mini for indoor use.

Belgium

In spring 2023, Belgium announced the purchase of 70 Nokia drones deployed in 35 emergency zones across the country to gather information for police officers within 15 minutes of an emergency call. Citymesh, the telecom operator also announced SENSE, the world's first nationwide network of public safety drones, a 5G automated grid connected to the drone units that will inform and increase the speed of resource mobilisation⁵⁵.

Ireland

Through the implementation of the Guard Project, the Irish government has been using a specially produced UAV to detect and interpret drug runner activity along the coast. These drones can fly beyond sight lines up to 800 km, withstand harsh, windy, and wet conditions and are able to take off and land both

⁵² <https://www.reuters.com/world/europe/french-police-cleared-use-drones-crowd-monitoring-2023-04-21/>

⁵³ <https://dronedj.com/2022/01/21/french-law-allowing-police-drone-use-ruled-mostly-constitutional/>

⁵⁴ <https://geo-matching.com/content/how-the-swedish-police-uses-drones-to-increase-safety-and-security-of-citizens#:~:text=There%20are%20roughly%20350%20police,fifth%20largest%20country%20in%20Europe.>

⁵⁵ <https://www.eurasiareview.com/17052023-nokias-5g-connected-drone-platform-selected-by-belgiums-citymesh-for-worlds-first-nationwide-drone-network/>

on solid ground and ships⁵⁶. Irish police also outfitted the Garada Air Support Unit (GASU) with 21 drones for major surveillance and undercover operations, largely focused on drug shipments⁵⁷.

United Kingdom

The use of drones by police forces across the UK has been rising, with more than 5500 observable flights in the first half of 2020 and it has been estimated that at least 288 are in operations across at least 40 police forces⁵⁸. For example, in Devon and Cornwall police use drones to help detect driving offences on high harm routes in the region⁵⁹. The Lincolnshire Police also deployed their own drones more than 80 times in January 2023 marking 36 operational hours to search for missing persons and suspects⁶⁰.

EU-funded projects

Table 9 EU-funded projects that integrate drone solutions into policing operations

Project	Definition	Coordinator
SILENT FLYER ⁶¹ H2020 2019-2023	The project developed a drone for civil surveillance that looks and flies like a bird.	Flygilidi EHF (IS)
CPSwarm ⁶² H2020 2017-2019	The project aimed to develop and test Cyber-physical systems (CPS) applications. One of the scenarios for swarm drones was to provide surveillance and detect intrusions at a power plant and observe their actions. The project also envisioned their utility in search and rescue missions for detecting casualties, people and for assessing disaster scenes.	ACT Operations Research IT SRL (IT)
KNOX ⁶³ H2020 2017-2019	KNOX aimed to optimise and demonstrate a drone alarm and protection system for security service providers to detect, identify and locate civilian drones around secure areas. Case studies were conducted in 2 prisons and sports stadiums in Denmark and the UK	MYDEFENCE AS (DK)
ROCSAFE ⁶⁴ H2020 2016-2019	The project aimed to increase safety when assessing chemical, biological, radiological, nuclear, and high yield explosive (CBRNE), threats and crime scenes. Together with ground robotics, drones were equipped with chemical sensors, autonomous navigation, obstacle detection and real time video.	National University of Ireland Galway (IE)

3.2.3.3 Border control

Border areas are typically vast, with varied terrain making it difficult to monitor. The use of drones by border agencies has increasingly significantly been expected to continue. UAVs can provide around the clock surveillance, cover massive distances and rugged terrain⁶⁵.

⁵⁶ <https://dronedj.com/2022/06/17/ireland-to-deploy-drones-to-battle-sea-based-drug-smuggling/>

⁵⁷ <https://www.irishmirror.ie/news/irish-news/crime/garda-deploy-fleet-drones-bid-29437150>

⁵⁸ <https://skykam.co.uk/police-drones-at-night-in-the-uk/#:~:text=As%20the%20use%20of%20drones,6%20months%20of%202020%20alone%E2%80%9D>

⁵⁹ <https://www.airmedandrescue.com/latest/news/devon-and-cornwall-police-introduce-drones>

⁶⁰ <https://www.airmedandrescue.com/latest/news/lincolnshire-police-drone-unit-reports-busy-january>

⁶¹ <https://cordis.europa.eu/project/id/867637>

⁶² <https://cordis.europa.eu/project/id/731946>

⁶³ <https://cordis.europa.eu/project/id/768242>

⁶⁴ <https://cordis.europa.eu/project/id/700264>

⁶⁵ Ahmadian, N., Lim, G.J., Torabbeigi, M., Kim, S.J. 2022. Smart border patrol using drones and wireless charging system under budget limitation. Computers & Industrial Engineering, V. 164. <https://doi.org/10.1016/j.cie.2021.107891>

Frontex and EU Member States have been increasing cooperation significantly to enhance situational awareness along borders. Since 2016, drones use has been increasing as well as investment to evaluate needs, and the development and implementation of innovative border control technologies⁶⁶.

Frontex

It has been investing in drone technologies since 2016, with the number of public tenders to obtain Remotely Piloted Aircraft Systems (RPAS) increasing consistently since then. In 2020 Frontex also implement a technology pilot project for land and coastal surveillance incuse a small MALE RPAS and VTOL and in 2021 the agency conducted 468 aerial surveillance flights⁶⁷.

European Maritime Safety Agency (EMSA)⁶⁸

EMSA has been a leader in drone trials and has a fleet of drones that can be leased to member states. Drone services are offered freely to member states, candidates, and EFTA member states as long as the operating site is a sea surrounding the EU and the starting point is an EU or EFTA member.

Finland and France

Drones are one of the technologies deployed by the Finnish Ministry of the Interiors Border Guard Department for tracking illegal crossings⁶⁹. In France, May 2023, the government approved the use of four drones to patrol the French-Italian border around the Menton region to monitor for illegal crossings⁷⁰.

Shared border between Bulgaria (EU) and Türkiye

Türkiye's borders are currently monitored for illegal activities including terrorism, illegal crossings and drug smuggling using integrated security solutions including drones⁷¹. In February 2023, the European Commission President indicated the desire of the EU to strengthen the shared border between Bulgaria and Türkiye by offering infrastructure and equipment including drones⁷². The incorporation of drone technology in processes of controlling the external border of the EU is speeded-up by the increasing inflow of migrants and the necessity to have cost-effective techniques for monitoring the local situation.

United States⁷³

The US military has been using drones to patrol the Mexican border since the 1990s and have been increasing sophistication since. In the late 90s and early 2000s drones were used by the inter-agency drug interdiction campaign- Joint Task Force Six which also assisted with identification of illegal crossings. Day to day border patrol is the responsible of The Department of Homeland Security's Bureau of Customs and Border Protection (CBP) which began using drones in 2004, and now has a fleet of ten Predator drones which:

- Patrol the border for illegal crossing of goods and/or people.
- Provide aerial support for law enforcement and investigations.
- Support emergency and disaster response

⁶⁶ https://centredelas.org/wp-content/uploads/2022/06/WP_DronesFrontex_ENG.pdf

⁶⁷ Ibid.

⁶⁸ <https://dronewars.net/wp-content/uploads/2020/12/DW-Crossing-a-Line-WEB.pdf>

⁶⁹ <https://thebarentsobserver.com/en/borders/2023/01/finnish-border-guard-deploys-surveillance-drones-norway-not#:~:text=The%20Puma%20dance%20now%20operated,mission%20is%20surveillance%20and%20intelligence.>

⁷⁰ <https://www.infomigrants.net/en/post/48890/french-police-deploy-drones-at-italian-border-to-track-migrants>

⁷¹ <https://www.defensenews.com/unmanned/2021/10/28/unmanned-tech-dominates-turkeys-border-security-summit/>

⁷² <https://www.schengenvisainfo.com/news/bulgarian-president-wants-eu-to-fund-new-fence-on-common-border-with-turkey/>

⁷³ <https://dronewars.net/wp-content/uploads/2020/12/DW-Crossing-a-Line-WEB.pdf>

Current drones are equipped with electro-optical and infrared cameras so recording can happen even at night and can stay in the air for 30hr. One drone also features wide area persistent surveillance (WAPS) enabling monitoring of an area 3.7miles wide.

EU-funded projects

Table 10 EU-funded projects that integrate drone solutions into border control

Project	Definition	Coordinator
I-SEAMORE HorizonEU 2023-2025	The project aims to develop an advanced platform solution to host and manage services and system that improve situational awareness of maritime surveillance including drones	ATOS IT Solutions and Services Iberia SL (ES)
EMERITUS⁷⁴ HorizonEU 2022-2025	Drones will be one of the technological tools for the monitoring and collecting of evidence for waste-related environmental crimes. The project's aim is to create a platform for law enforcement and border guards to improve investigative proof collection capabilities for these crimes.	GMV Aerospace and defence SA (ES)
BorderUAS⁷⁵ HorizonEU 2020-2023	The project is developing a multi-role lighter-than-air unmanned aerial vehicle with an ultra-high resolution multi-sensor surveillance payload. The remote sensing payload will include a synthetic aperture radar (SAR), laser detection and ranging (LADAR), shortwave/longwave infrared (SWIR/LWIR) and acoustic cameras for direct target detection as well as optical and hyperspectral cameras for indirect detection. The technology will be tested by police based along illegal border crossings in Greece, Bulgaria, Romania, Moldova, Ukraine and Belarus.	Software Imagination and Vision SRI (RO)
NESTOR⁷⁶ H2020 2021-2023	NESTOR is demonstrating an entirely functional, next-generation, comprehensive border surveillance system offering pre-frontier situational awareness beyond sea and land borders. Both manned and unmanned UAVs equipped with optical and thermal imaging will be part of a sensor network that can operate standalone, tethered and in swarms.	Hellenic Police (EL)
ROBORDER⁷⁷ H2020 2017-2021	The project integrated large UAVS for maritime and land operations (and small UAVS) connected to a common radar network and for autonomous resource and task coordination for border patrols and operational personnel to strengthen detection and identification of border related threats (e.g., pollution, illegal activity)	The Center for Research and Technology Hellas (EL)
ARcopter⁷⁸ H2020 2018-2018	ARcopter aimed to develop a fully autonomous UAV with accurate vertical take-off and landing able to fly for 2.5 hours and 150km flight range with accurate landings at 55 km/wind speeds. One of the target applications was	Colugo Systems (IL)

⁷⁴ <https://www.zabala.eu/projects/emeritus/>

⁷⁵ <https://cordis.europa.eu/project/id/883272>

⁷⁶ <https://cordis.europa.eu/project/id/101021851>

⁷⁷ <https://cordis.europa.eu/project/id/740593>

⁷⁸ <https://cordis.europa.eu/project/id/816552>

	governmental agencies firefighters' police, border patrol, coastguard for Homeland Security (HLS) and Public Safety	
COMPASS2020 ⁷⁹ H2020 2019-2021	The project included UASs as part of a toolkit of manned and unmanned vehicles meant to integrate seamlessly to support border security, search and rescue and monitoring irregular migration.	Direcção Geral da Autoridade Marítima (PT)
ARESIBO ⁸⁰ H2020 2019-2022	The project used all types of unmanned vehicles including UAVs as part of a system to improve situational awareness along borders.	Airbus Defence and Space SAS (FR)

3.2.3.4 Customs

In 2016, the World Customs Organization stated that “the use of drones in the Customs environment does no longer belong to the next generation”⁸¹. At that time, it was acknowledged that further investigation was required from both user and regulator perspectives but there was a large potential for drones. While their use hasn’t increased to the same extent as firefighting, border control or policing, the use of drones has been increasing since then and has seen several unique innovations.

EU maritime agencies

Investments in drones have been made by the European Maritime Safety Agency (EMSA), the European Fisheries Control Agency and Frontex not only for environmental protection, border and fisheries control and surveillance but also for customs control. Together these agencies coordinate 300 civil and military authorities across the EU member states⁸².

Netherlands

The Customs Administration of the Netherlands uses drones with day and night vision and LED floodlights at the port of Rotterdam to monitor the area for smugglers. As of 2022, additional officers are being trained to operate drones and drone teams are being formed in other maritime regions (Amsterdam, Groningen, Breda) with the prospect of extending them across the country⁸³.

Dubai

Innovation is a critical part of Dubai’s custom’s strategy. They have integrated drones into their customs inspection systems including deterrence drones that can enter dangerous or hazardous areas such as narrow hulls of ships. These are dangerous areas that they were previously hesitant to send employees or even the K9 unit. Each custom officer is also equipped with such a drone and can direct its inspection⁸⁴.

First responders/Emergency Response EU projects

Table 11 European projects that use drones to support all first responders

Project	Definition	Coordinator
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⁷⁹ <https://cordis.europa.eu/project/id/833650>

⁸⁰ <https://cordis.europa.eu/project/id/833805>

⁸¹ <https://www.wcoomd.org/-/media/wco/public/global/pdf/topics/facilitation/ressources/permanent-technical-committee/211-212/pc0445e1.doc?la=en>

⁸² <https://www.statewatch.org/analyses/2020/drones-for-frontex-unmanned-migration-control-at-europe-s-borders/#:~:text=Three%20EU%20maritime%20surveillance%20agencies,authorities%20in%20EU%20member%20states.>

⁸³ <https://www.dronewatch.eu/dutch-customs-are-increasingly-using-drones-to-combat-drug-smuggling/>

⁸⁴ <https://english.alarabiya.net/News/world/2023/03/17/Dubai-Customs-innovates-with-drones-AI-and-the-Metaverse-to-secure-UAE-s-borders>

OVERWATCH⁸⁵ HorizonEU 2022-2025	The project is using drones for data acquisition (cameras), data processing (on-device), and a tethered drone communications relay system (as a backup communication network) to help develop an integrated holographic system to support emergency and crisis management.	Ithaca SRL (IT)
NIGHTINGALE⁸⁶ Horizon 2020 2021-2024	A UAV rapid triaging system is one of the novel tools in the Nightingale toolkit designed to support emergency medical response.	Institute of Communication & Computer Systems (EL)
IRIS⁸⁷ H2020 2020-2023	The project is designing an IT web tool for Incident commanders in the field to synthesise all the relevant data being related to the incident, including information collected by drones.	UNBLUR SL (ES)
Search and Rescue⁸⁸ H2020 2020-2023	The project is creating an efficient synchronisation framework managing the data, developed services and information flow between the different authorities involved in emergency management operations and the crisis managers from different sources. Drones are providing one of the sources of real-time data	Ethniko Metosovion Polytechnion (EL)
RESPOND-A⁸⁹ H2020 2020-2023	The project developed holistic and easy to use solutions for first responders including the coordination of unmanned aerial vehicles.	European University (CY)
CURSOR⁹⁰ H2020 2019-2023	The project is developing a system including UAVs, 3D modelling, mini sensor-equipped robots to detect volatile chemical signatures emanating from human beings. Real-time information and data collection and transfer to handheld devices support first responders at disaster sites.	Bundesministerium des innern (DE)
INGENIOUS⁹¹ H2020 2019-2023	The project developed the first responder toolkit for the future to increase protection and increase operational capacity. The MAX drone was a tool for performing indoor and outdoor inspections, monitoring and autonomously entering then sensing buildings. 3D models could also be derived from data collected.	Institute of Communication & Computer Systems (EL)
TANDO⁹² H2020 2020-2022	The project aimed to develop indoor drones equipped with advanced sensors that will allow them to detect and monitor any potential anomaly (e.g., fires, water leakages) with the aim of significantly reducing property destruction and fatalities.	Indoor Robotics (IL)

⁸⁵ <https://cordis.europa.eu/project/id/101082320>

⁸⁶ <https://www.nightingale-triage.eu/>

⁸⁷ <https://cordis.europa.eu/project/id/101010486>

⁸⁸ <https://cordis.europa.eu/project/id/882897>

⁸⁹ <https://cordis.europa.eu/project/id/883371>

⁹⁰ <https://cordis.europa.eu/project/id/832790>

⁹¹ <https://cordis.europa.eu/project/id/833435>

⁹² <https://cordis.europa.eu/project/id/953760>

ASSISTANCE ⁹³ H2020 2019-2022	The project used UAVs and drone swarms among other technologies to develop situational awareness modules for enhancing the safety of first responders and providing advanced training.	Universitat Politècnica de Valencia (ES)
RESPONDRONE ⁹⁴ H2020 2019-2022	The project aimed to develop and validate an integrated solution for first responders to easily operate a fleet of drones with multiple synchronised missions to enhance their situation assessment capacity and own protection.	Deutsches Zentrum Für Luft- UND Raumfahrt EV (DE)
TERRIFFIC ⁹⁵ H2020 2018-2021	The project aimed to utilise a set of modular technology components in a comprehensive system, which included drones to increase the effectiveness of first responders in Radiological, Nuclear, explosive incidents.	Arktis Radiation Detectors AG (CH)
HEIMDALL ⁹⁶ H2020 2017-2021	The project focused on achieving interoperability, inter-organizational coordination, and information sharing, including information collected by swarms of aerial drones equipped with sensors to improve emergency planning and management.	Deutsches Zentrum Für Luft- UND Raumfahrt EV (DE)
AirSens ⁹⁷ H2020 2018-2020	AirSens aimed to investigate the potential of swarms of UAVs for high-accuracy tracking and sensing in indoor context, in particular their mapping capabilities and localization performance.	Alma Mater Studiorum- Università di Bologna (IT)
AirBorne ⁹⁸ H2020 2018-2020	The project aimed to develop systems for quick localization of avalanche victims by equipping drones with 2 types of specialised sensors.	Alma Mater Studiorum- Università di Bologna (IT)
SURVEIRON ⁹⁹ H2020 2016-2018	The project embedded a set of AEORUMs intelligent robots inside a fleet of UAC deployed in fixed and mobile locations and supervised from an emergency command centre. Once notified via alarm, the system was designed to send one or more UAVs to the emergency area avoiding any obstacle in their way. Once there, SURVEIRON automatically scans and analyses the environment with different AEORUM detection technologies	Aerorum Espana SL (ES)
EXTREMDRON ¹⁰⁰ H2020 2016	The project developed a NexGen UAV for aerial monitoring apps in extreme operating environments (fires, radiation/nuclear, hazardous chemicals).	Aerdrone SL (ES)

Potentially, the estimations show an approximate number of half a million drones in operation to support the government and community services worldwide by 2040, what would be the exact number of UAVs in Europe is more difficult to calculate as it depends very much on the level of market penetration of this technology by country¹⁰¹.

⁹³ <https://cordis.europa.eu/project/id/832576>

⁹⁴ <https://cordis.europa.eu/project/id/833717>

⁹⁵ <https://cordis.europa.eu/project/id/786729>

⁹⁶ <https://cordis.europa.eu/project/id/740689/reporting>

⁹⁷ <https://cordis.europa.eu/project/id/793581>

⁹⁸ <https://cordis.europa.eu/project/id/780960/reporting>

⁹⁹ <https://cordis.europa.eu/project/id/711264>

¹⁰⁰ <https://cordis.europa.eu/project/id/717915>

¹⁰¹ Deloitte Access Economics, Economic benefit analysis of drones in Australia, 2020, Sydney

3.2.4 Sustainable and smart ports and airports

Drones offer greater precision in all commercial cases, timeliness and cost savings associated with more efficient decisions. The most drone activities in the port areas take place in the North Sea countries of North Europe. The ability to fly BVLOS as an important capability has been explored in the port of Antwerp (**Belgium**) via the Horizon2020 SAFIR project since drones can manage, control and inspect a large area of the port estate. Ports in Denmark, the Netherlands and Norway have already tested BVLOS flights that travel up to 16 km. out to sea for security measures like spotting any criminal activities. Due to these forward-looking drone operations, the port authorities began to develop drone ecosystems by themselves.

In **the Netherlands**, the Port Authority of Rotterdam¹⁰² began a prototype for regulations and traffic control in the low altitude airspace in 2022. This is happening for the first time in the Netherlands at such a scale. The drone applications in the port include:

- incident control,
- supervision, inspections,
- combating crime and drug smuggling.

Furthermore, the port management set up the innovation programme “Drone port of Rotterdam” to fully exploit the technological innovation in terms of technical developments, regulations, knowledge of added-value, specific business cases, and the degree to which the new technology is accepted and embraced.

In the long-term, passenger transportation per drone will be an opportunity and drones can then be used for taking service engineers or pilots to installations that are hard to reach, or to vessels outside the port, in a relatively short time. The Port Authority looks at passenger drone designs to understand how these drones can contribute to improved mobility in the port. Many companies, governments and emergency services in the port see drones as a way of efficiently inspecting and maintaining assets, providing better security, combating narcotics-related crime such as detecting intruders and drug collectors, measuring emissions, and improving ship visits by getting items on and off board earlier using delivery drones.

In 2019, the port of Amsterdam tested the Marine Anti-Drone System (MADS). It gives the port authority the possibility to control and protect the airspace to avoid violations of private security, terrorist attacks, fly-hacking and others. It is vital, not only to take advantage of the UAVs, but also to take security and other negative repercussions under consideration.

In **Germany**, the port of Hamburg or the harbour, where automated industrial drones can improve safety inspections and workflow efficiency at critical infrastructures, is another example of forward-looking expectations of new drone applications or initiatives. HHLA Sky drones (Hamburger Hafen und Logistik AG)¹⁰³ are used to inspect container gantry cranes in industrial estates. The German HHLA Sky designed and built a scalable Drone Control Centre that can simultaneously and safely manage and control 100+ drones in parallel operations.

Mainblades, a robotic company from **the Hague**, and a partner of KLM Engineering & Maintenance, is already exploring outdoor drone inspections in the Schiphol-East area¹⁰⁴. Given the scarcity of hangar positions with aircraft often having to “wait for a spot”, outdoor inspections (at the gate in the future) hold great opportunities for reduced ground time and delays. As a forward-looking project, the company now offers automated aircraft drone inspections and technical solutions to KLM - Dutch Airlines, Corendon and JetSupport for business aviation aircraft at the Amsterdam airport. Mainblades works with the authorities to establish operational procedures and those can be transferred to all other EASA compliant aviation

¹⁰² <https://www.portofrotterdam.com/en>

¹⁰³ <https://hhl-sky.de>

¹⁰⁴ <https://mainblades.com>

authorities. They have already begun working to achieve similar goals in the United States where drone fleets operate under the FAA regulations.

In **Italy**, the airport of Rome (Aeroporti di Roma) has developed a start-up incubator, Fiumicino's Innovation Hub, the first in-airport hub, to encourage innovation towards new sustainable mobility models¹⁰⁵. Also, the Rome airport together with the airports in Venice, Bologna, and the French Riviera, founded "Urban Blue" to study, design, build and operate vertiports. One thing which is impressive about this endeavour is the option for Aeroporti di Roma of issuing sustainability-linked bonds to raise capital.

In the **United Kingdom**, a few projects that were funded under the FFC at UKRI in 2022 demonstrate the potential technological and industrial benefits in sustainable ports and airports (see Table 12):

Table 12 UKRI's innovative projects in industrial drone operations

Project	Definition	Consortium
InDePTH: Intelligent Drones for Ports and Highways Technology	It uses drones to regularly survey wide infrastructure estates, including ports and highways, to create digital models and obtain detailed insight of these dynamic environments.	British Telecommunications plc; Associated British Ports (ABP); RoboK; HEROTECH8; Connected Places Catapult; Kier Highways.
HADO	It evaluates a live 24-hour commercial autonomous beyond visual line of sight drone service in the high intensity airspace of Heathrow Airport.	Operational Solutions Ltd., Cranfield University; Carmenta Technologies Ltd; Dynamic Intelligent Solutions Ltd; Heathrow Airport Holdings Ltd; HEROTECH8; Operational Solutions Ltd; Rinicom Intelligent Solutions Ltd; Thales UK.
SeaWatch: flexible AI coastal monitoring	It will see the fusion of leading-edge unmanned aircraft "drones" and artificial intelligence technologies, paving the way for cheaper, more reliable, and accessible improvements in safety at sea. In addition, it allows exclusive economic zone coastal monitoring, especially in remote and difficult to access areas.	Uavaid Limited; Archangel Imaging Ltd.
SafeZone	It will investigate localised aerodynamic meteorological data to allow unmanned aerial vehicles to adapt their route as they fly through wind changes and close to buildings at Cardiff Airport	Zenotech; Flare Bright; Cardiff Airport plc; Cranfield University.

Source: www.ukri.org

In **Spain**, Port of Barcelona tested in 2021 an aquatic drone designed and manufactured by GPASEABOTS, a GPA-INNOVA company. This was a joint project between the Catalan Infrastructure and the company to create an aquatic drone for the purposes of the port. The drone model used was SB

¹⁰⁵ <https://airportindustry-news.com/rome-fiumicino-launches-europes-first-airport-innovation-hub/>

100 PRO, which is a multi-purpose platform that can be applied in areas such as hydrography, water analytics, inspection, cleaning, and surveillance. All these tasks can be carried out automatically by a single operator and all accumulated data can be monitored in real time.

One use case from a non-EU country is **Singapore** and the activity of Willensem company that obtained an “Agency by Air” authorisation with which they supply ships with small spare parts, documents, supplies and consumables for 3D printers. This system replaced shipments by boat to reduce costs, lower pollution and ensure faster and risk-free transshipment delivery.

Summing it up, all segments with growth potential discussed above will continue progressing and become increasingly important in Europe. Investment in research and development by venture capitalists, universities, governments, and large corporations, including aerospace firms accelerates the development of this technology.

3.2.5 Recreational usage

Recreational drone use encompasses recreational flights, competition flying, photography and videography, and other hobby-based uses. It is also expected to grow in the future. It is boosted by the relatively low unit cost of drones which makes them affordable for such activities and the regulatory environment, which is not very strict. Market needs are well established in this segment as there is already an accumulated history, and the technological solutions and services will be increasing. In the summer of 2022, the EU Drone port delivered a drone show with 100 drones at the Barcelona beach. It was prepared for the entertainment organisation Flock and was organised in cooperation with the Spanish Aviation Authority (AESA), since flying a swarm of drones is still a challenge.

3.2.6 Infrastructure and construction

The other market segment of great interest to use drone applications, which is well matured is infrastructure for monitoring, maintenance, and asset inventory. They improve the precision of work from the design phase to the construction. Drone technology provides investors and construction managers with real-time data, high-resolution videos, and images, reducing costs of current work practices based on in-person inspections, a slow and expensive process that often is delayed, yields incomplete results, and impacts on asset performance. This is also relevant for the maintenance of assets where the cost-saving factor plays a significant role in the decision-making process.

One potential area which is expected to progress with the development of 3D-printing technology, which can be combined with drone applications to maintain and repair infrastructure, while also producing parts for damaged elements of infrastructure at the site. Further tasks will be performed by drone at height in the construction of power lines and bridges, also nano drones will be applied for building internal infrastructure. Furthermore, the construction industry is the fastest growing commercial adopter of drones ahead of agriculture and mining. Currently, drones offer the ability to gather data and visual images easily. What can be additionally offered is detailed measurements for visualisation software and data analytics. All this can be integrated to supply further value for the construction sector.

In the **United Kingdom**, a few projects that were funded under the FFC at UKRI in 2022 demonstrate the potential technological and industrial benefits (i.e., ensuring safety and real-world demonstrations in difficult conditions) in infrastructure and industrial networks, and two projects are described below:

Table 13 UKRI's innovative projects in industrial infrastructure

Project	Definition	Consortium
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Atypical Airspace BVLOS Solution (AABS)	Sees.ai's advanced drone system unlocks autonomous flight in industrial environments (electricity grids, rail network, etc.) at a national scale. It will use one of the world's most advanced solutions for unmanned flight and data capture at scale.	Sees.ai Livelink Aerospace; BT; Imperial College London; National Grid; Network Rail; Keen.ai; Across Safety; Lancashire Fire and Rescue Service; TerraDrone;
Future Flight and Land Infrastructure Programme (FFLIP)	FFLIP is expected to deliver a full-scale multimodal demonstration at a site in Oxfordshire, incl. A 600-kilowatt eVTOL charger infrastructure with multiple power configurations to support 24-hour rapid charging of: electric ground vehicles; trucks; drones; eVTOL aircraft.	Petalite; Custom Interconnect Ltd; Oxfordshire County Council; Midlands Aerospace Alliance; Vanti (RTS Technology Solutions Ltd.); ARC Aero Systems;

Source: www.ukri.org

Overall, this market segment has been adopting drone technology for a long time already and market needs are well explored and understood in the advanced economies. According to the PwC's analysis, the infrastructure sector accounts for over a third of the total value of the drone solutions market. Its potential value is about \$45 billion. There are plenty of technological developments in this segment and a few restrictions in terms of the datasets and analysis models (see more details in Table 5) that need further technological advancements and scientific discoveries to allow a lift-up of the segment.

3.2.7 Mining and resources

UAVs are used at varying steps in the mining/resource process, mainly for acquiring spatial data. This includes surveying mining sites for geological and structural analysis via remote sensing, aerial geophysical survey, topographic surveying, rock slope analysis, working environment analysis, underground surveying, and monitoring of soil, water, ecological restoration, and ground subsidence. The utilisation of UAVs and related research is expanding across industries owing to the significant cost reduction in vehicles and sensors and significant advances in data processing software.

UAVs are already important tools in the mining industry. Because UAVs can be equipped with optical devices, cameras covering different ranges of the electromagnetic spectrum and geophysical instrumentation such as magnetic and natural gamma-ray sensors they can be used for various purposes such as geological and topographic mapping calculation of fragmentation and the stockpile volume and monitoring related to slope safety road haulage and tailings dams. Increasingly intelligent systems, with increased adoption and creation of technology will see advanced and autonomous usages in mining. Such as real-time processing, autonomous flight inside mineshafts, and with better sensors, specifically for this application more detailed analysis can be done.

UAVs have advantages over helicopters and could be more cost effective, faster, easier to navigate and less pollution emitting. Drones are being tested and used in open cut mining operations where they can replace more labour-intensive methods of inspection, mapping, and surveying. This segment has a potential market value of \$4.3 billion. As explained, UAVs can be employed during virtually every phase of the mine lifecycle. It is expected the adoption rate in this market to continue until 2030, and thus the growth potential is still huge.

3.2.8 Defence

UAVs (drones) have become a key operational capability for defence forces and are used for both reconnaissance and direct warfare. Drone uptake in the military is assumed to commensurate with historical proportions of drone budget spend and grow in line with forecast military expenditure. Drone capabilities and systems are anticipated to be a fundamental area for investment until 2040. Usually, the modules are composed of a day-light camera, a thermal imaging camera, a video camera, and a radio transmitter. The cameras provide real-time intelligence, 3D maps, surveillance, and aerial reconnaissance. The imagery, video and other sensor data collected by the payloads are transmitted to the ground control station in real-time. Via electronic warfare capability the transmission of data is differentiated between friendly and non-friendly means of transmitting.

In Europe, the new Drone Strategy 2.0 recommends collaborations between the civil industry and the military drone ecosystem, which is less mature than the competitive US military industry. Stimulus will be provided to such collaborations to test new innovations. The number of drones in military use globally is expected to increase as this technology will further enhance defence capabilities.

3.2.9 Agriculture

The agricultural sector faces numerous challenges in maximising productivity, optimising resource allocation, and ensuring sustainability. The global supply chain is at an all-time high, propelling the need for a modern farming solution across the agricultural industry at a global level. Drones have revolutionised the agricultural industry globally by offering enhanced efficiency, cost savings, and increased profitability across all production systems. As versatile tools for addressing various user and market needs, drones demonstrate a consistently upward adoption trend. Although the agricultural drones market is well established, further growth is expected during this decade. This is due to the increase in venture funding for the deployment of drones in the agriculture industry and the optimization of existing commercial technologies. This section presents the requirements fulfilled by drones across the agricultural sector, with a focus on crop monitoring and management, livestock management, and fisheries.

Crop monitoring is a critical component of modern agriculture, and there is a significant market need for efficient and accurate monitoring solutions. Drones equipped with multi- or hyper-spectral cameras provide a bird's-eye view of agricultural fields, enabling farmers to assess crop health, identify nutrient deficiencies, detect irrigation issues, and monitor overall growth. Timely and precise crop monitoring helps farmers make informed decisions regarding irrigation schedules, fertiliser application, and pest management, resulting in optimised resource allocation, improved crop yields, and reduced production costs. The market demand for crop monitoring drones stems from the need for data-driven decision-making and the desire to maximise productivity in a sustainable manner.

Accurate **yield estimation** is a crucial piece of information for farmers, enabling them to plan harvesting operations, manage resources effectively, and make informed business decisions. Drones imagery or photogrammetric data combined with advanced data analytics capabilities provide an efficient and non-destructive means of estimating crop yields through reflectance analysis or photogrammetric reconstruction. By generating data on crop density, biomass, and other relevant factors, drones contribute to accurate yield forecasting. The market demand for yield estimation drones arises from the need for improved operational efficiency, optimised supply chain management, and enhanced profitability through better crop yield predictions.

Effective **pest control** is a paramount concern for farmers to protect their crops and optimise productivity. Drones offer a valuable solution to address the market need for efficient and environmentally friendly pest control measures. In lower resolution cases, by capturing detailed spectral data, drones can identify subtle changes in plant reflectance, allowing for early disease identification and targeted intervention across large areas / fields. However, their major advantage lies in their ability to efficiently generate imagery of unparalleled resolution through low-altitude flight missions. As the only remote sensing data source with adequate resolution to effectively identify pest infestations or disease symptoms, drone imagery can be

used to directly identify disease or weed hotspots, detect early signs of plant stress, and precisely target affected areas for treatment. The ability to deliver targeted pest control interventions reduces chemical usage, minimises environmental impact, and promotes sustainable farming practices. The market demand for pest control drones arises from the need to combat pest-related challenges while minimising the reliance on traditional, labour-intensive methods.

Another application is insect control in greenhouses as nano drones are programmed to collide with the moth in air and eliminate the moths through the impact of the small propellers¹⁰⁶. This is done with stationary cameras that through vision can detect and track the insect. The company, PATS located in the campus of TU Delft, have developed the software which is capable of classifying insect species and when labelled as a moth it predicts its flightpath. Then a successful interception strategy is established in a matter of milliseconds, and the camera system communicates with and controls the drone and launches it from its pad into the direction of the moth. The drone eventually collides with the insect, shredding it with its propellers. This takes a maximum of 2 seconds between the first detection of the insect and the collision. After that the drone returns to its pad and recharges on the platform. The company has established a fully autonomous insect control platform with drones that are very small and lightweight. With this automated monitoring, growers are helped to reduce crop losses, insecticide use and labour intensity, and this area has a good growth potential.

Drone spraying is one of the most rapidly growing market needs in agriculture, driven by the demand for precise and efficient application of pesticides, fertilisers, and other agricultural inputs. Drones equipped with spraying systems offer the advantage of high manoeuvrability, enabling them to access challenging terrain and apply treatments with precision. By leveraging GPS technology and advanced mapping software, drones can cover large areas quickly and accurately, minimising product waste and ensuring uniform distribution of inputs while also safeguarding human health through decreased exposure of the operators to the agrochemicals. However, the market demand for drone spraying arises from the need to optimise chemical usage, reduce environmental impact, and enhance the overall effectiveness of crop protection strategies, the single major limitation of their widespread adoption are regulatory barriers or outright bans that render them illegal in several agricultural cases.

The use of drones in precision agriculture began in late 1990s in Japan and there is an increase in awareness of how drones can benefit the agricultural industry. Some evaluations pointed to an increase in the global agricultural drone market by more than 30% per annum. It becomes more common and with the application of spraying chemicals, the market will become even larger. The DJI Agras Spraying Drones have already about 20 models¹⁰⁷ for this purpose. Drones increase the efficiency of spraying by distributing the correct amount and reducing the excess chemicals that may penetrate groundwater. However, the European regulations are strict and do not seem to allow such an activity in the EU Member states yet.

Preserving biodiversity and understanding its impact on agricultural ecosystems is a growing concern. Drones address the market need for efficient biodiversity monitoring by providing aerial access to large and remote areas. Equipped with high-resolution cameras and sensors, drones can capture detailed imagery and collect data on flora and fauna. This information aids in assessing habitat quality, monitoring population dynamics, and identifying potential threats. By contributing to biodiversity conservation efforts, drones enable farmers and environmental organisations to make informed decisions regarding land management, ecological restoration, and sustainable agricultural practices.

Managing human-wildlife conflicts is crucial for the agricultural industry, particularly in areas where wildlife encroachment poses threats to crops and livestock. Drones fulfil the market need for **wild animal detection** by providing aerial surveillance capabilities. Equipped with thermal cameras and advanced imaging systems, drones can detect and track wildlife movements, identify potential dangers, and help farmers take appropriate preventive measures. The ability to remotely monitor wildlife activities allows for

¹⁰⁶ <https://www.pats-drones.com>

¹⁰⁷ www.copters.eu

timely interventions, mitigating crop damage and ensuring the safety of livestock. The market demand for wild animal detection drones arises from the need to minimise human-wildlife conflicts, protect agricultural investments, and promote coexistence between farming and wildlife conservation efforts.

Efficient **livestock monitoring** is crucial for animal welfare, farm productivity and operational management. Drones address the market need for livestock monitoring by providing aerial surveillance and data collection capabilities. Equipped with mainly vision-based sensors (mainly visible or thermal camera), drones can monitor herd behaviour, track animal movement, and identify potential issues such as injury or disease. Real-time insights provided by drones enable farmers to make informed decisions regarding feeding, health management, and pasture rotation. The market demand for livestock monitoring drones arises from the need to enhance animal welfare, optimise herd management practices, and improve overall farm productivity.

The **fisheries** industry faces various challenges in effectively managing marine resources and ensuring sustainable practices. Drones fulfil a crucial market need in the fisheries sector by offering innovative solutions for surveillance, stock assessment, and operational efficiency. With their aerial capabilities and advanced imaging systems, drones provide a means for efficient marine surveillance, aiding in the detection of illegal fishing activities, enforcement of fishing regulations, and protection of marine ecosystems. Moreover, drones equipped with specialised cameras and sensors (e.g. LiDAR) contribute to accurate stock assessment and monitoring, enabling fisheries managers to make informed decisions regarding fishing quotas, conservation measures, and the overall sustainability of fish populations. By streamlining data collection processes and enhancing operational practices, drones address the market demand for improved resource management and promote the long-term viability of the fisheries industry. Overall, this market segment is well matured, and the market penetration of UAV technology might be in direct competition with the satellite technology and the operations of the European Space Agency in certain activities, which provide visual observations of large territories and mapping of terrains.

In conclusion, as demonstrated by the analysis in this chapter 3, there is a widespread applicability of various drone applications across industries, sectors, and smaller segments globally. The market needs will be expanding even further and the technology as well as regulations have to evolve to match the needs. One concluding remark from the research is that the UAV developments in the agricultural sector (agriculture, forestry and fishery as presented in Table 5) appear to be significant and well established with good prospects for future growth. Despite the technical and regulatory challenges in the agricultural market segments, end-users have high expectations and technology innovators will need to match them. This tendency is expected to have significant implications for the project's use cases and the next chapter 4 reveals some of them.

It must be also admitted that while there are challenges ahead in all market segments that reflect the disruptive impacts of any new technology, the applications and services enabled by drones underline the key opportunity amid this creative disruption – the chance for start-ups to leverage new technology in ways that transform them from industry disruptors into growth enablers. New technology and convergence effects may create a new path for operators, service providers, software developers, and open novel sources of revenue to boost the growth opportunities. Moreover, there are also market and non-market benefits that originate from technology adoption. For instance, labour cost savings and enhanced production processes, safety and environmental benefits. All these characteristics of drone applications make them adoptable and relatively affordable. PwC estimated the total market value of drone-powered solutions at over \$127 billion¹⁰⁸, and if companies make the appropriate investments now, they can reap a good share of this potential market pool of value. The **next chapter** continues smoothly with the ICAERUS' use cases, focusing only on two industries – agriculture and rural logistics – the traits of drone technology that are relevant for the UCs and the specific stakeholders' needs in each case.

¹⁰⁸ PwC Communications Review / July 2017: Insights for telecom, cable, satellite, and Internet executives by Brad Silver, Michal Mazur, Adam Wisniewski, and Agnieszka Babicz, Prague (CZ)

4. Comparative analysis of stakeholders' needs by case and technological solutions

4.1 Taxonomy of the comparative analysis

For the purposes of the analysis in this chapter 4, a certain architecture was designed to identify the components of the comparative analysis of all project's use cases. To achieve it, all collected information in T1.1, T1.2 and T3.1 were deemed important and applied in this task. In constructing this architecture, a number of different dimensions and categories are taken into consideration which are derived from:

- 1) the provided taxonomy of technology in T1.2 *Stock-taking of Drone Technologies*;
- 2) the requirements of the ICAERUS work packages, mainly WP1 *Drone Landscape Analysis* and WP3 *ICAERUS Use Cases and Demonstration Activities*;
- 3) overall tasks and structure of WP1 as defined in the *Description of Work and Methodology*;
- 4) results of stakeholders' surveys in T1.1 *Understanding the Drone Market*.

In the ICAERUS project, five different UAV use-cases are under development. Each use-case has provided a use-case plan, where project requirements are presented in ICAERUS WP3 *Use Cases and Demonstration Activities*. These plans provide initial decisions on hardware and software to be used over the years of the project.

Under each dimension, several categories are identified which are considered to describe the various substantial aspects representative of the dimension. Each of them can be expected to have many categories. The data collected in T3.1 *Use Case Planning* provided a first guide to define the characteristics common to the empirical cases.

The proposed dimensions are:

- ✓ description of use case,
- ✓ scope,
- ✓ technology,
- ✓ market and stakeholder analysis.

Then, characteristics are organised so that the objects or sub-criteria to be examined for the relevant characteristics and dimensions. There was significant work done to identify the objects of each dimension cross checking with all subjective and objective conditions such as types and needs of stakeholders.

Later in due course of the ongoing work in T1.3, various new characteristics were added under:

- ✓ the "stakeholder grouping" and
- ✓ the "stakeholder interaction" criterion

such as defining the type of transactions that flow among the stakeholders of each use case's network or role, objectives and needs of stakeholders. The interactions are described as monetary, knowledge, technology, policy, human resources, and goods / services and depicted on value flow maps. A comprehensive analysis of each UC's stakeholders' network has been developed in chapter 5 *Use Cases' Stakeholders Network Analysis* of D1.1¹⁰⁹.

These considered objects allow us to include all this information (see Table 15) in the comparative analysis to be able to match the needs with technology. The clarifications needed in the definitions were provided by WP1 partners in interactive monthly discussions.

¹⁰⁹ <https://drive.google.com/drive/folders/1yFEqxqP43mtn4esLlCL5KRPCD1ABnGfI>

The theoretical background for this architecture comes from the theoretical sources, and for instance, Moore (1993) provides one of the most commonly used references on business ecosystems: ‘in a business ecosystem, companies co-evolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations’ (pp. 76). There is a plethora of definitions on business, entrepreneurial and innovation ecosystems (e.g. Grandstrand & Holgersson, 2020; Shi et al., 2023). All are based on the concept of ‘systems’, which is composed of a set of components (C) or constituent parts and a set of relations (R) among these components. Across all various definitions of ecosystems, there are three recurring entities, namely actors, artifacts, and institutions (the constituent parts above) which are interconnected through a range of activities and relations, including collaborative / complementary and competitive / substitute relations (Granstrand and Holgersson, 2020). A parsimonious definition is offered by Granstrand and Holgersson (2020, pp. 3) ‘an innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors. In this definition, artifacts may include products and services, tangible and intangible resources, technological and non-technological resources, and other types of system inputs and outputs, including innovations. Relations actors can be collaborative (complementary) and competitive (substitute), while ecosystems may not necessarily be developed around a focal firm.

In this report the business ecosystem involves multiple stakeholders and interaction among them, which goes beyond cost and revenue models or operation financing. It is a purposeful business arrangement between several entities or members of a network to create and share in collective value with shared risk-taking. It is important to stress the role of collective value creation, which requires from firms, and organisations more broadly, to open their innovation processes and to interact with ecosystem actors and stakeholders to jointly create value propositions and extend their business models from a firm-centric to a stakeholder-based perspective (Shi et al., 2023). In this aspect, the four components described here include:

- value proposition (service, tangible, intangible);
- value creation (network, resources and activities, costs);
- value delivery (distribution and customer relationship, revenues),
- and market strategy (entry, diversification, price).

In refining the architecture of the analysis, more attention was given to the “market strategy” characteristics, where four criteria are considered such as market viability, competitiveness, barriers, and enablers since WP1 has overlapping market and technology dimensions. The market strategy includes everything from market research to product /service positioning and pricing. It is a plan of how to reach a target market and convince customers to buy the offered service or product.

Moreover, the market viability of any technology expresses the primary objective of entrepreneurship, which is to create and deliver value of monetised products, services, or processes. To entrepreneurs, acceptability is understood as “willingness and ability to pay a certain price that enables a sustainable and scalable enterprise”¹¹⁰, and market forces provide validation of innovation success.

The final objective is to translate a new “discovery or knowledge” to a commercial product and to define value-generating milestones that serve as key decision steps. From this point of view, the consideration of the market viability of drone technology in our analysis is critical and various sets of information about software and hardware prices and price mechanisms were collected under T1.2 to complement the sets of accumulated technical knowledge.

¹¹⁰ Quotation from: Thorp H., Goldstein B., (2013). Engines of Innovation: the entrepreneurial university in 21st century, Chapel Hill: The University of North Carolina Press

Lastly, a key lesson to be taken from entrepreneurship is the importance of understanding and effectively leveraging market forces for implementation. Push-out is important but insufficient for implementation success and market penetration. Cultivating demand is essential as market forces can support adoption of new technology and sustainment, and demand can guarantee viability. Entrepreneurs and start-ups are able to provide a network of expertise outside the project or academic community to bring in diverse, expert, and critical feedback to evaluate the feasibility of market proposals and financial funding in the design of use cases or projects consistent with stakeholders' engagement and implementation science. It is also important to know how market analysis (strategy, viability, competition) can best inform and facilitate the implementation.

In addition, competitiveness and barriers / enablers were included to describe the business environment in which the market entry and penetration can be assessed. This background information will be utilised in the definition of business models too (T5.6/WP5 *Inclusive Business and Governance Models*). In principle, entrepreneurs use strategies such as conducting market viability assessments, prototyping, estimating costs and leveraging market forces¹¹¹.

Based on this method of refining the objects and characteristics, a four-level architecture for the comparative analysis was established with the relevant dimensions. It is considered sufficient to enable us to match the stakeholders' needs with the technological solutions in each use-case on a wider foundation. As specified the first three dimensions with the common characteristics are as it follows below in Table 14.

Table 14 Dimensions with characteristics

1. Definition of Use case	2. Scope	3. Technology
1. Objectives	1. Industry	1. Software
2. Innovation level	2. Drone type	2. Sensing
3. Innovation type	3. Geographic coverage	3. Hardware
4. Type of stakeholders	4. Purpose	4. Decision & Data
5. Project initiator		

The last dimension "market and stakeholder analysis" has four layers with a set of criteria, which were explained above in the reasoning of setting-out this architecture. This last dimension demonstrates the importance in recent years of any innovation to reach the market and be commercially sustainable. For instance, in the US according to the Angel Capital Association, 298,000 investors invested \$24.8 billion in about 71,000 early-stage start-ups mainly in pharma, biotech and healthcare industry, which represented 21% of angel investments in 2015¹¹². The role of private funding becomes increasingly significant in combination with other public schemes of funding.

Overall architecture of the taxonomy is presented in Table 15:

¹¹¹ See more in: Sarasvathy SD, Venkataraman S. (2011) Entrepreneurship as method: open questions for an entrepreneurial future. *Entrepp Theory Pract.* 35(1):113–35

¹¹² Angel Capital Association: Predictive Analytics Startups, <https://angel.co/predictive-analytics>

Table 15 Taxonomy of the comparative analysis

Dimension	Characteristic / Criterion		Object / Subcriterion								
Definition of Use Case	Objectives		Productivity & digital solutions		Cost-efficiency		Comfort for farmers		Environment & sustainability		
	Innovation Level		Experimental		Emerging		Close-to-market		Deployed		
	Innovation type		Incremental		Differential		Radical		Breakthrough		
	Type of stakeholders	Municipality	Government	Drone manufacturer	Supplier	University / Research	Drone service provider	Crop Assoc.	Forest & landowner Assoc.		
		Media partner	Drone operators	Civil Aviation Authority	EASA	European Commission	End users	Others			
	Project initiator		Public Institution		Academia / Research Labs		Private		Public-private partnerships		
Scope	Industry		Precision agriculture				Rural logistics				
	Drone type		Fixed-wing		Rotary				Hybrid		
	Geographic coverage		Agricultural land & vineyards		Rural residences				Forest & mountain terrains		
	Purpose		Crop health assessment	Drone spraying	Wild boar detection	Forest health assessment	Livestock monitoring & digitalisation		Offering bio solutions	Vulnerable rural user	
Technology	Software		Analysis		Pre-processing				Post-processing		
	Sensing		Radar		Camera				Laser scanner		
	Hardware		Platform		Payload		Sensing		Non-sensing		
	Decision & Data		Algorithms			Simulation					
Market and Stakeholder Analysis	Value Proposition	Service	Tangible			Intangible					
	Value Creation	Operation financing	Public Grant		Licences		Private investors		Public-private partnership		
		Management of network	University		Public body		A dominant private leadership		Rural development organisation		
		Stakeholder Grouping	Role		Objectives		Needs	Input	Output	Type	
		Stakeholder interaction	Monetary		Human resources		Policy	Goods / Services	Technology	Knowledge	
		Revenue model	Revenue stream			Price targets		Profit margins			
		Cost structure	Tangible costs and minimum resource needs			Intangible costs and minimum resource needs					
		Target market segment	Crop monitoring		Crop spraying		Livestock monitoring	Forestry monitoring	Aerial supply chain		
	Value Delivery	Type	B2B			B2C		C2C			
		Value Flows	Categories			Scores		Mapping			
		Value Channels	Monetary		Technology		Science-related		Policy		

		Impacts	Economic			Social		Environment	
		KPIs	Deployment				Benefit		
		Timing	Short term			Medium term		Long term	
	Market Strategy	Market Viability	Need			Demand		Acceptability	
		Competitiveness	Beneficiaries			Advantages	Major rivals	Non-EU competition	
		Barriers	Market	Technical	Institutional	Organisational	Impact	Social & attitudes	Other
		Enablers	Market	Technical	Institutional	Organisational	Impact	Social & attitudes	Other

4.1.1 Use Case 1: Crop monitoring

The aim of the first use case is to detect diseases in field crops to reduce the need for chemical pesticides and it is presented in Figure 8. To achieve this, lightweight commercial UAVs will be used to take field observations from digital and multispectral cameras (Table 17). The top ten needs of UC1 network's stakeholders, that intend to turn the case into a viable commercial operation of crop health assessment, are presented in Table 16 to demonstrate the importance of certain value flows for the key participants in the value creation process.

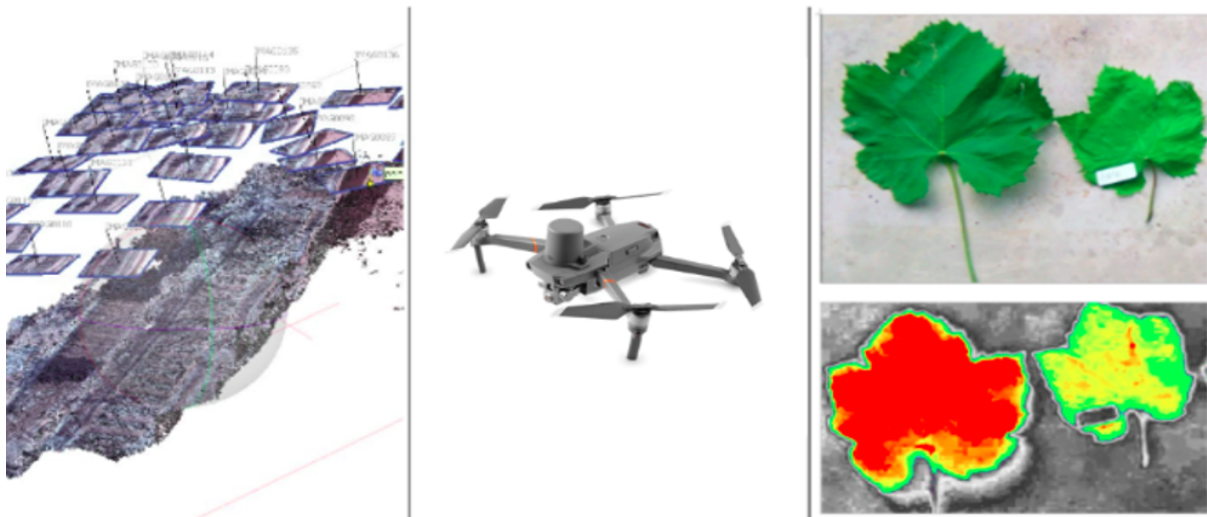


Figure 8 Crop monitoring technological components

The number of value flows is much larger in the UC1 since it is a relatively extended network of 25 stakeholders and more. It has the potential to expand to 40 stakeholders in a very dynamic way after the actual demonstrations that are planned under WP3 *Use Cases and Demonstration Activities* and will be executed later in 2024/25¹¹³. The end-users are family businesses in Catalonia, owning vineyards, land or practising modern farming, which is high tech and data driven. Some are oriented towards the production of organic wine. In general, organic farmers require more accurate crop monitoring and prediction methods and an access to reliable environmental and climate prediction data. Tied to data procurement organised by the Spanish authorities and crop monitoring markets defines the need for obtaining certification of quality and accreditation. This recent trend in the viticulture segment is accompanied with strict rules and control by the responsible public bodies but is also a contributing factor to the success of the regional organic wine production. The detailed market research analysis of UC1 under T1.1 provided statistical

¹¹³ ICAERUS, D3.1 Use Case Plan, Version A, 30th Dec. 2022

evidence of all these new developments in sustainable agriculture and biodiversity in the region of Catalonia.

However, the stakeholders stated that they search for commercial funding and an access to the wider European and global markets to increase the exported production. The precise and thorough analysis of the local network was presented in chapter 5 “Use Cases’ Stakeholders Network Analysis” of D1.1¹¹⁴. As demonstrated by the exchanged transactions among the stakeholders in Table 16 below, the UC1 is solely dependent on the scientific achievements in terms of the software and hardware engineering. The involved universities in the network from the region of Tarragona state that the scientific publications and opinions are of their primary priority to be able to advance their work. Also, the associations that represent the farmers and end-users as well as the research institutes find it absolutely necessary to collect the research-based evidence of the efficiency of the UAVs in sustainable and organic viticulture to support their decision-making. The essential need of farmers is the training and resources for modernisation.

This appears to be critical for the operational processes of the whole network, where farmers or end-users are simply one significant stakeholder group.

Overall, the UC1 network is knowledge and capital accumulation dependent. Similarly, the surveys’ results obtained from the global drone stakeholders presented in chapter 2 of this deliverable expose the same needs. Therefore, the local Spanish network of UC1 does not deviate away from the global trends dominated in the drone ecosystem.

Table 16 Top ten needs of UC1 stakeholders

NEED	Stakeholder
1. Commercial funding	AGRAWDATA
2. Access to wider European policy shifts	AEROCUB REUS
3. Access to wider markets	OpenVino, Mas Martinet Farm
4. Research-based evidence of the efficiency of UAVs in sustainable agriculture and biodiversity in Spain	Fundacio la PEDRERA
5. Science opinions and scientific publications	CRAG, UOC, UAB
6. Research-based evidence of efficient drone monitoring in the crop fields of Spain	IRTA
7. Public funding	DARP, Municipality Falset and Villafranca
8. Training and resources for modernisation	Farms (end-users)
9. Policy collaboration (engaging the end-users) and reports on EU best practices	AESA – Spain
10. Social media content, press releases, images, and videos	La Vanguardia

If we look now at the available technology, in terms of its characteristics, after the data acquisition, the imagery will be stitched together and will be the input for Deep Learning based detection models in this use case. A central requirement is that the quality of the data that the UAV provides must be detailed enough for disease detection over various timespans. Some images are presented in Fig 8.

¹¹⁴ ICAERUS, D1.1 European Landscape of Drone Innovations and Technologies, 30th Apr. 2023

In the hardware choice, the newest products from DJI are used, which are providing integrated solutions with UAVs, path-planning, and sensors in a single, user-friendly package.

Table 17 Technology for Use-Case 1: Crop monitoring

UAV Technology classification	UAV Technology details	Costs	Notes
UAV Platform: Quadcopter	DJI Mavic 3M	4,600 EUR	Has the sensors, stabilised and RTK geolocation
UAV Payload	Multispectral	Part of UAV	
	Digital camera	Part of UAV	
	Weather stations	Depending on weather station type	
UAV Software: Analysis	Deep Learning with Python	Software is free, high-end computing hardware is required (cloud computing as a service also available)	Training of DL models requires a high amount of data and compute resources
Photogrammetry	Agisoft Metashape	Starting at 180 EUR/Month	

A localisation feature, RTK GPS is included on the proposed commercial UAV. Usually, external ground control points are used to improve image alignment^{115 116}. Furthermore, adding more sensors to the UAV platform will increase the weight and reduce the flying time (Bourgoin et al., 2020). In addition, the impact of the additional weight to the balance and vibration of the UAV should not be overlooked, especially considering the quality requirements of the UAV.

Finally, the proposed complex sensors might be limited by the resolution they offer for disease detection in plants. Multispectral sensors have lower resolution than digital sensors.

On the software side, photogrammetry would be used for mapping, and various Deep Learning models will be used for disease identification. Accuracy in photogrammetry with RTK for tracking individual plants over time is technically feasible but should always be verified. Applying Deep Learning to UAV imagery has been successfully applied to many detection problems and has shown to be highly accurate. Furthermore, the combination of Deep Learning and UAVs is a promising field to many scientists. A Deep Learning method would require a large amount of labelled data for disease detection. Finally, the benefits of using multispectral imaging are missed. These sensors are able to directly calculate plant parameters from raw sensor data, such as soil water content, vegetation, and various spectra-analysis techniques available. Directly using thermal and multispectral images in a Deep Learning model is often less accurate than only using RGB imagery (Poley et al., 2020). In addition to increasing the complexity of adapting Deep Learning models to deal with these additional data sources for different resolutions.

¹¹⁵ See more in: Borrelli, L., Conforti, M. & Mercuri, M. (2019), LiDAR and UAV System Data to Analyse Recent Morphological Changes of a Small Drainage Basin. ISPRS International Journal of Geo-Information 2019, Vol. 8, Page 536 8, 536. issn: 2220-9964. <https://www.mdpi.com/2220-9964/8/12/536/htm%20https://www.mdpi.com/2220-9964/8/12/536>

¹¹⁶ See more details in: Donnellan, A. et al. (2020), Targeted High-Resolution Structure from Motion Observations over the Mw 6.4 and 7.1 Ruptures of the Ridgecrest Earthquake Sequence. Seismological Research Letters 91, 2087–2095. issn: 0895-0695

In terms of affordability, there are three elements to be considered. First, the price of UAV is in the range of EUR 5,000. Second, the UAV software is free of charge, and third, the photogrammetry is based on monthly payments starting from EUR 180 per month. In comparison to other business cases, the initial expenses are relatively low, and the monthly payments for the mapping are not too high.

4.1.2 Use Case 2: Crop spraying

The second use case is UAVs for crop spraying presented graphically on Figure 9 in generic terms. In this use-case, a UAV is fitted with a container and a spraying system. This additional weight and size of payload require a larger UAV, capable of carrying larger payloads, whilst also requiring precise movement, leading to the natural decision for a multirotor design. All testing is performed in open-field trials during the summer season when the weather conditions are not restrictive. Usually, different parameters are explored as the tests end up with the proper sample analysis, retrieval of data in laboratory conditions and image analysis.

New technology and precision methods in the use of drones for plant protection products and irrigation can further support the reduction of usage of chemical pesticides by 50% by 2030. One solution is the use of drones for the targeted application of pesticides, and agricultural spraying drones have been tested worldwide for years.

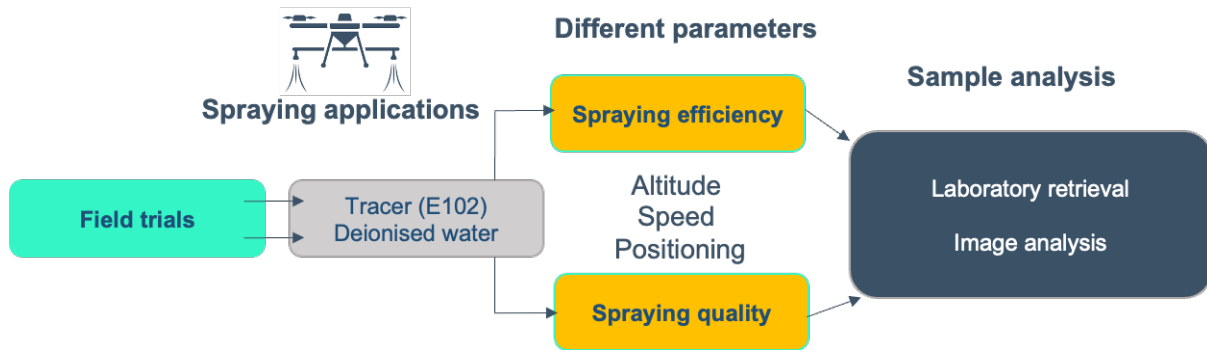


Figure 8 Drone spraying applications

Preliminary results suggest that drones could provide farmers with a precise tool for reducing pesticide use and increasing safety for biodiversity. In contrast to other continents (especially Asia and the US) where legislation has allowed for a longer study of UAV spraying (Bonds et al., 2024; Takekawa et al., 2023, He, 2018), these possibilities of drone applications have not been studied to the same extent in the context of the EU agricultural sector, due to the restrictive regulatory environment. The legislation is set out by the Sustainable Use of Pesticides Directive¹¹⁷ in Europe which defines the legal rules under which the testing of this technology can take place. EU countries must also promote Integrated Pest Management, which general principles are laid down in Annex III of the same Directive. A very detailed market research analysis performed under T1.1 *Understanding the Drone Market* and T1.4 *Drone Standards, Regulations and Risks* present all aspects of this market segment and the relevant legislation related to the testing of the drone spraying technology.

In addition, the needs of UC2 stakeholders that aim to make the case of crop spraying into a commercially viable operation by focusing on the top ten value flows are presented in Table 18. This network consists of 13 local core stakeholders, and it may expand with additional end-users or agents from supporting industries such as the crop protection fertilising producers or distributors. It can easily increase to 20 stakeholders in due course of the demonstration process, which was already implied by the stakeholders network analysis in D1.1. As shown in the table next page, the local network of UC2 is heavily dependent on agricultural scientific know-how, techniques and science achievements. The associations and

¹¹⁷ Directive 2009/128/EC https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides_en

manufacturers have urgent needs of obtaining knowledge on optimal use of UAVs or other specialised engineering machinery. The regional authorities and municipalities must understand better their communities and society needs to support the exchange of transactions among all local stakeholders. From the obtained and analysed global surveys' responses and the top priorities of UC2, it appears that the Greek stakeholders' needs are similar to the needs of stakeholders in the global drone ecosystem, which can be explained with the research intensity of the drone engineering science, plus the intense presence of international large companies in the food production chain of Greek local markets.

Table 18 Top ten needs of UC2 stakeholders

NEED	Stakeholder
1. Agri-science know how	HCPA
2. Skilled workforce	UCANDRONE, Agrotech
3. Research-based evidence of efficient drone spraying in crop fields of Greece	AUA
4. Guidelines on the optimal use of drones in crop protection in Greece	GiMas
5. Knowledge on optimal and safe UAV spraying in Greece	CAFFINI Sprayers Equipment
6. Specialised machinery knowledge	Agrotech
7. Knowledge about precision applications and environmental safety	CropLife Europe
8. Understanding better the community needs of how spraying UAVs have potential to improve the quality of life of local farmers and rural areas	Peloponnese Regional Authority
9. Understanding the importance of spraying UAVs as a novel / green tool	Civil Aviation Authority
10. Community acceptance for safety & environmental protection	EASA

If we look now at the technology aspects, in the hardware choice, the newest available products from DJI are used, which provide integrated solutions with UAVs, path-planning, and sensors in a single, user-friendly package (Table 19).

Table 19 Technology for Use-Case 2: Crop Spraying

UAV Technology classification	UAV Technology details	Costs	Notes
UAV Platform	DJI Agras T10	13,000 EUR Around 1,000 EUR per additional battery	Different costs, depending on number of batteries, etc. This is for a standard setup. T10 is also used as a backup.
	DJI Agras T16	13,000 EUR Around 1,000 EUR per additional battery	Different costs, depending on number of batteries, etc. This is for a standard-setup.
UAV Payload	Various spraying nozzles	SX11001VS: 30 EUR SX110015VS: 30 EUR TX-VK04: 5 EUR	Per nozzle, it is a small brass part with different hole-combinations for different spraying patterns.

Misc.	Meteorological stations		
	Spectroscopy in laboratory	Between 1,000 and 10,000 EUR	To verify findings from the field in the lab, already owned by AUA.

Using UAVs for spraying crops is a new use-case, and only recently have UAV-platforms been available for purchase for this exact usage. The technological limitations of UAVs themselves have only recently been overcome, such as being capable of carrying the heavy payload and maintaining high manoeuvrability¹¹⁸. Furthermore, complex interactions between prop-wash (the airflow under the propellers) and the spreading of herbicides and pesticides to a larger area are not well understood and difficult to simulate (Amarasingam et al., 2022). Different spraying nozzles impact the effectiveness of the system, and best practices have not been developed. Finally, the intelligence of the UAV system, to detect pests in real-time and to act on this information is an open research question and is partly limited by the computation and sensing technologies of today, see the crop monitoring section for more information. Additionally, the promise of this use-case is to reduce pesticide and herbicide use, by specifically targeting these pests, and not requiring the whole field to be sprayed (Amarasingam et al., 2022). Therefore, methods must be developed that can empirically measure the reduction in pesticides and herbicides in the field and food production. These methods should consider existing practices and other state-of-the-art developments, and further improvement on the algorithm writing part is expected.

In terms of affordability, the UAV is relatively expensive, up to EUR 20,000 depending on the number of batteries and the whole setup. The costs for the payload are very low, however the spectroscopy in the lab may cost between EUR 1,000 and 10,000. Therefore, the initial investment in this UC2 drone system is much higher than in the case of crop health assessment in UC1.

4.1.3 Use Case 3: Livestock monitoring

The third use case is livestock monitoring, in this field research is focused on the possibility of detecting animals, livestock or wildlife using UAVs and different sensors. It is visually presented in Figure 10. The market research analysis focused on the beef cattle and small ruminants in grassland-based farming systems. In EU-27 in livestock units: 1) beef cattle represent 51% of grazing animals; and 2) small ruminants represent 14%¹¹⁹. Therefore, both research-based farms involved in UC3 will test drone livestock monitoring for beef cattle and small ruminants (sheep, goats).

The network of stakeholders consists of 13 actors, well-described in D1.1, which aim to demonstrate and create the market needs for this drone service. The top ten stakeholders' needs in UC3 are presented in Table 20, which delineates the value creation in this drone monitoring operation and shows the complexity in matching all value flows. Therefore, the activity requires collaboration, leadership and sharing initiatives. This UC3 has a pivotal role in the French agricultural sector with the involvement of many research organisations to establish the foundations of this experimental case under the governmental initiative. The ICAERUS Consortium will be supporting the case's technological and business development.

The complexity of this network comes from the fact that the UC3 is at a very early experimental stage with less established market needs and many technological alternatives in the segment. It represents a small market niche where drone services can be tested to provide the farmers with visual feedback. Most of the local stakeholders involved expect to receive guidelines for safe uses of drone applications, plans and

¹¹⁸ See more details in: Zhang, P., Zhang, W., Sun, H., Fu, H. & Liu, J., (2021). EFFECT OF THE DOWNWASH FLOW FIELD OF A SINGLE-ROTOR UAV ON DROPLET VELOCITY IN SUGARCANE PLANT PROTECTION. *Engenharia Agrícola* 41, 235–244. issn: 0100-6916. <http://www.scielo.br/j/eagri/a/NZWRDXZHL8NKQYNzQcXdWtj/?lang=en>

¹¹⁹ ICAERUS, D1.1 European Landscape of Drone Innovations and Technologies, 30th Apr. 2023, Section 4.4, p.60.

reports. For both municipalities, it is important to avoid any conflicts among the villagers as drone flies can cause noise, clashes with birds, visual perception of spying and annoying tourists in the Alps region. To satisfy the expectations of each local stakeholder, the UC3 network should be working together and co-creating their initiatives and guidelines. Good communication among all actors in the network seems to be critical in this case.

Table 20 Top ten needs of UC3 stakeholders

NEED	Stakeholder
1. Communication with customers	Flying Eye
2. User opinion (feedback)	Livestock Farmers
3. Guidelines for a safe use of drones in livestock monitoring tasks	Livestock Farmers
4. Plans and reports of progress in projects' participation	IDELE
5. Guidelines on the optimal use of drones in livestock monitoring and its impact on farming in France	Jalogny farm, Carmejane farm
6. No conflict among the population	La Chaffaut-Saint-Jurson Municipality
7. Meetings with drone industry representatives	French Aviation Authority
8. Available time for educational initiatives	Schools
9. Community acceptance for safety & environmental protection	EASA
10. Taxes	Government

In comparison to the previous two cases – UC1 and UC2 – the French network expresses very localised needs particular to the region and the villages. It depends on good collaboration, clear communication between institutions and stakeholders, and feedback as well as research guidelines from the French government and scientific advancements. It doesn't reveal the same characteristics and needs as the global drone ecosystem's stakeholder international needs (see chapter 2 of this document). The centralisation of agricultural activities and funding mechanisms perhaps should explain the observed differences.

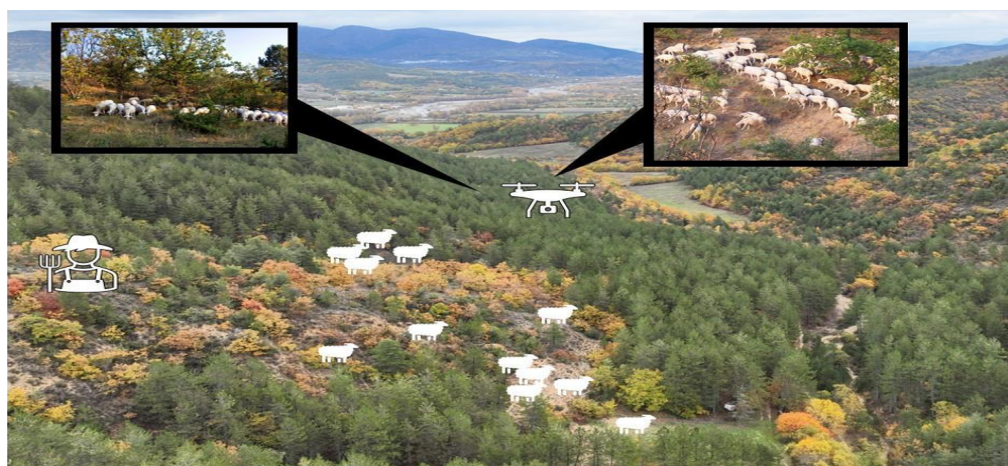


Figure 9 Drone providing visual feedback to livestock farmers

From the technological perspective, the things are less clear and rather uncertain. Thermal cameras have been used successfully for various detection algorithms. The heat from an animal can be instantly detected with a thermal camera, requiring minimal processing¹²⁰.

A digital camera requires more advanced computer vision algorithms (deep learning) to detect animals, but at a lower accuracy (Mamehgoi Yousefi et al., 2022). Little research has been done on detecting different animal species in the same image, in both thermal, multispectral, and digital imagery (Librán-Embid et al., 2020). In the hardware choice, the newest products from DJI are used, which are providing integrated solutions with UAVs, path-planning, and sensors in a single, user-friendly package.

Table 21 Technology for Use-Case 3: Livestock monitoring

UAV Technology classification	UAV Technology details	Costs	Notes
UAV Platform: Quadcopter	DJI Mavic 3 Enterprise	3,500 EUR	Built-in RGB, thermal and zoom camera, no RTK positioning
UAV Sensor	Thermal camera	Part of UAV	
	Digital camera	Part of UAV	
	DJI Mavic Speaker	170,00 EUR	
UAV Software: Analysis	Deep Learning with Python	Software is free, high-end computing hardware is required (cloud computing as a service also available)	Training of DL models requires a high amount of data and compute resources

The main difference between livestock and wildlife identification is that livestock is usually in a herd, whereas wildlife is often a single animal to be detected. In images from a herd, the visible overlapping of animals is more difficult to identify and can lead to miscounts of the livestock (Mamehgoi Yousefi et al., 2022). There are still many questions unanswered by scientists in this engineering field.

Depending on the complexity of the monitoring task, this use-case is either well-understood or highly underdeveloped. The question of 'where is the herd?' is well understood and thermal-equipped UAVs can be immediately deployed to support answering the question with a human in the loop. Whereas: 'which animal in the herd is feeling unwell?' is rather difficult, research only recently started to answer this question in the form of Deep Learning models. These require high-quality datasets to train on, with thousands of labelled images to train the model on. Furthermore, they face other problems such as the movement of a herd over time and space. So far, accurate results have not been acquired in this area (Mamehgoi Yousefi et al., 2022). Improved sensors, such as thermal cameras with higher resolution, or accurate deep learning algorithms for animal detection, will push this use-case forward to the complex monitoring tasks.

In terms of affordability, the drone equipment is not too expensive, EUR 3,500, and the payload is part of the UAV, only the speaker costs EUR 170. The software is free of charge. This drone system doesn't require a high initial investment in the UAV; however, training of deep learning models requires a high amount of data and computational resources.

¹²⁰ See more details in: Librán-Embid, F., Klaus, F., Tschamtk, T. & Grass, I. (2020). Unmanned aerial vehicles for biodiversity-friendly agricultural landscapes - A systematic review. *Science of the Total Environment* 732

In conclusion, comparing the stakeholders' needs to the available technological components for UC3, it appears that there are large disparities in expectations since the livestock monitoring may become a complex monitoring task that would require complex engineering and processing, and then farmers may not be able to handle all this know-how that would require proper training and management. Moreover, the centralised curriculum in France doesn't allow for external school initiatives that may be able to fulfil some gaps in the training of farmers as a local adult educational academy /programme.

4.1.4 Use Case 4: Forestry and biodiversity

In the fourth use-case, UAVs are used for forest management, and it is presented on Figure11 in terms of spatial resolution and costs. Three management scenarios are under development:

1. Tree health mapping,
2. Wildfire risk monitoring, and
3. Wild boar detection.

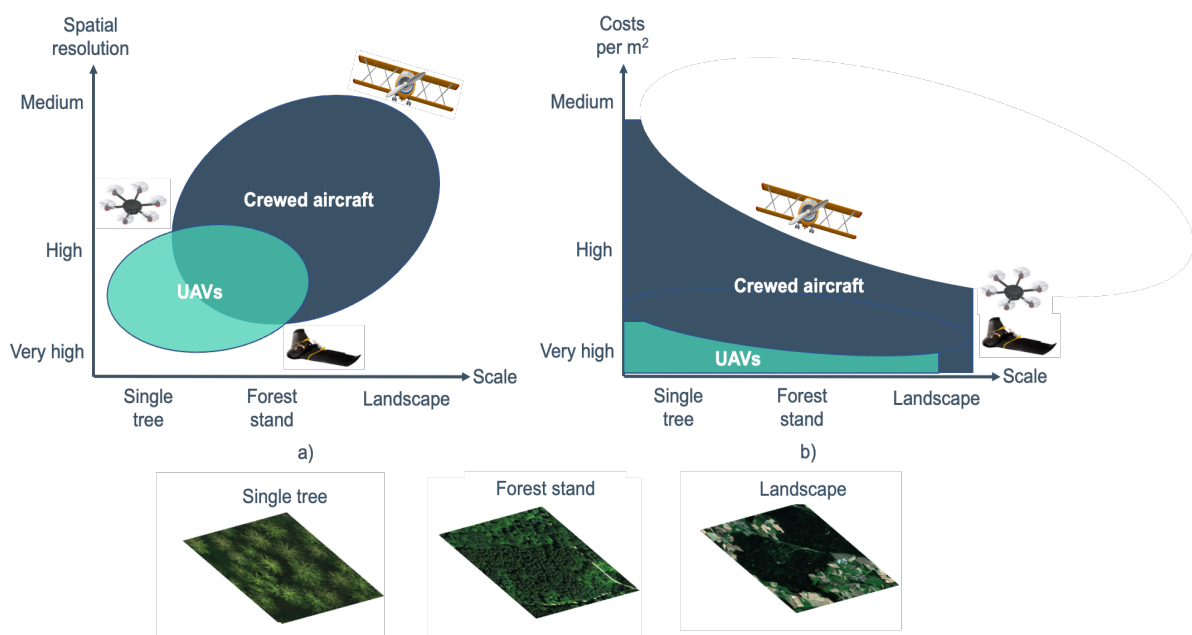


Figure 10 Forestry and biodiversity drone monitoring

The innovation of these proposed digital solutions is the provision of real-time data to state-owned agencies that can analyse, explore, and plan actions to protect forest, biodiversity, and wooded land, as well as to propose treatment and prevent damage from abiotic factors. The market research analysis in D1.1 paid attention to all aspects of this market segment and target customer groups to expose possibilities of expanding the network and the market in Lithuania and Scandinavia.

In addition, the top ten stakeholders' needs are presented in Table 22, containing 13 core stakeholders, demonstrating both a high level of knowledge-based value flows that are exchanged among the network and complexity of involved tasks. The UC4 drone applications are highly research intensive with a constant need of scientific advancements and mathematical modelling. Science opinions and publications as well as guidelines and periodic data are of primary concern to the universities and end-users. Skilled workforce and talent are irreplaceable. The knowledge-based transactions are extensively present in the Lithuanian network that relies on public-private collaborations to expand its market. The forest- and land-owners as end-users play a vital role in this case, which is also, similarly to UC3, at an early stage of development. It can be characterised as between an experiment and an emerging business case from the market and technological perspectives.

The needs of the local stakeholders reveal similarities with the needs of the global drone ecosystem's stakeholders in our global surveys.

Table 22 Top ten needs of Use-Case 4 stakeholders

NEED	Stakeholder
1. Improving and developing regulations	DroneA
2. Collaboration with other stakeholders to design incentives to foster dissemination practices that can attract new users	DroneA
3. Plan information exchange with landowners	FOAL
4. Science opinions and scientific publications	VMU
5. Guidelines on optimal use of drones for wildlife monitoring in Lithuania	SFVS
6. Periodic data and user-friendly tools	SFS, NPA (end-users)
7. Piloting and data sources to collect research-based evidence for science advances and publications	RCAF
8. Understanding the importance of monitoring UAVs as a novel / green tool	Transport Competence Agency
9. Compliance with policy directions about digitalisation	Government
10. Skilled workforce	EASA

If we look now at the available technology in UC4 to match with the needs of stakeholders, things are less clarified and certain. For tree health mapping, a hyperspectral sensor mounted to a multi-rotor UAV will be used to identify tree-tops and calculate spectral indices that indicate various tree-health parameters. The narrow spectral bands required for these indices are the main reason for choosing a hyperspectral sensor.

Table 23 Technology for Use-Case 4: Forestry & biodiversity

UAV Technology classification	UAV Technology details	Costs	Notes
UAV Platform: Hexacopter	Large multi-rotor	Between 1,000 EUR and 10,000 EUR	Depending on features of the system: RTK positioning, etc. Number of motors, level of autonomy
Fixed wing	Volantex RC ranger	250,00 EUR	Does not include base-station, remote controller, etc.
UAV Sensor: Hyperspectral	Specim AFX10	Between 30,000 EUR and 70,000 EUR	Depending on the model. Inquiring ART21 ATM
Thermal	WIRIS		
UAV Software: Analysis	Deep Learning with Python	Software is free, high-end computing hardware is required	Training of DL models requires a high amount of data and compute resources

		(cloud computing as a service also available)	
	ENVI	Requires a quote from Harris Geospatial	
	QGIS / ArcGIS	Free or a quote from ESRI	
	Snap by ESA	Free	Software tool made by the European Space Agency to download Satellite Imagery

Additionally, for the small areas to be covered by the UAV, a multi-rotor UAV is chosen for this application. Wildfire risk monitoring will use the same UAV setup: a multirotor with hyperspectral camera, the use of this system is deemed of higher accuracy in assessing forest flammability, compared to other sensors.

The chosen hyperspectral sensor has a push broom configuration, resulting in a single line of data being measured. In post-processing software, the path of the UAV is aligned to spectral information from the sensor, resulting in a map with hyperspectral observations on each pixel. The requirement for proprietary software for hyperspectral sensors makes the use case partially dependent on the quality of the provided software.

Similar to the crop-monitoring use case (UC1), there are high requirements for the quality of the data, as it must be able to detect individual trees accurately and repeatedly. Extra care must be taken with the mounting of the sensor, a stabilising camera gimbal could be essential. This might result in a heavier UAV, which in turn, impacts flight times. Furthermore, the complexities of acquiring high-quality hyperspectral imagery should not be understated. Calibration procedures, the sun and sensor angles, non-uniform canopy structure and accurate localisation are essential for high-quality observations. Finally, the use of hyperspectral sensors for forest monitoring is not standardised, and best practices have not been developed. There are a lot of uncertainties in the technological components of this case.

Interestingly, a multispectral sensor could fulfil many of the requirements of the use-case, as moisture content is one of the more important factors, which can be measured by a multispectral or thermal camera. With the added benefit of higher resolution, ease of interpretability and processing power requirement, and independence from analysis software. The same as in the livestock use case (UC3), identifying heat signatures with thermal sensors is well understood. But dependent on the specific identification task it might still be an open question. The task of identifying wild boars in a mixed forest, where other animals roam is one of the more complex problems in the animal detection field (Mamehgoi Yousefi et al., 2022).

Finally, the disturbance caused by UAVs in ecological areas should not be understated¹²¹. Noise emissions from UAVs can cause stress in various species of animals and should be carefully considered in the use-case. The end-goal is to improve forest management, and not introduce stressors to the natural system.

In terms of affordability, this drone system is relatively expensive as the UAV is between EUR 1,000 and 10,000, depending on the features, and the UAV sensor can be between EUR 30,000 and 70,000. The software is free of charge and open source. Overall, the initial investment is significant, and the training of deep learning models requires a high amount of data and compute resources. There are also high

¹²¹ See more in: Schaffer, B., Pieren, R., Heutschi, K., Wunderli, J. M. & Becker, S. (2021). Drone Noise Emission Characteristics and Noise Effects on Humans—A Systematic Review. International Journal of Environmental Research and Public Health 18. issn: 1660-4601. <https://www.mdpi.com/1660-4601/18/11/5940>

requirements for the quality of data. The UC4 drone system and technological solutions illustrate high-tech demanding services with quite complicated tasks to be resolved, which may result in high drone service fees. There is a need for a balance between the cost efficiency required from the technology side and the business model design that will fulfil stakeholders' needs and expectations.

4.1.5 Use Case 5: Rural logistics

In the fifth use case: rural logistics, UAVs will be used to transport goods in rural areas (see Figure12), which presents a drone carrying a small package. UAV platform technology and path planning methods are at the centre of this case. The use of drone-based logistics is of great interest for city suburbs, small villages, the countryside, and rural areas where the delivery of parcels is low and spatially dispersed. Also, for delivery of medical products in case of emergency, UC5 is very pertinent to the regions with absence of local pharmacies due to the small number of residents. A thorough market research analysis in D1.1 explored all opportunities for the market expansion of this use case beyond the initial testing zones - North Macedonia and North Greece.

Furthermore, the UC5 network contains 20 stakeholders from two countries, which is described in D1.1 and aims to show how the drone system can be customised to optimise the value creation process from goods delivery. The number of local stakeholders may increase after the demonstrations of this service. The top ten needs of the stakeholders presented in Table 24 demonstrate the necessity of collaboration at all levels, e.g., policy, stakeholders' activities, cost sharing, and research. Engaging the community and end-users seems to be of great importance for the delivery of medicines, blood in emergency cases and medical technology in order to improve the lifestyles of rural communities in small villages of the Balkans countries, some of which are still not members of the EU. In this respect, the inclusion of such countries in demos and testing supports their integration within the EU.



Figure 11 Rural transportation and deliveries

The needs of UC5 stakeholders as revealed in Table 24 appear to be very localised and typical of the rural settlements. Pharmacies in the testing area of North Macedonia have high demands for obtaining drone delivery services to be able to get the needed goods. The Civil Aviation Agency requires concrete evidence to justify the modification of local regulations that will allow the use of drones.

Table 24 Top ten needs of Use-Case 5 stakeholders

NEED	Stakeholder
1. Market analysis and data support	Makedonski Telecom AD
2. Access to medicines, blood, and medical technology to deliver emergency aid	MSF
3. Research-based insights of the economic aspects of rural logistics based on UAVs	UGD, UCM

4. Compliance with policy directions about digitalisation	Government
5. Drone delivery services	Pharmacies (end-users)
6. Guidelines on the optimal use of drones in rural logistics and in less accessible areas	Pharmacy, Ohrid
7. Collaborative activities and cost-sharing	Agri-pharmacy
8. Policy collaboration (engaging the community)	Municipality of Debarca, Kavadarci, Vevecani
9. Obtaining concrete evidence to justify the need for an update on regulatory obstacles that prevent the use of drones	Civil Aviation Agency
10. Skilled workforce	EASA

Looking at the technological side of UC5, as previously stated, UAV design is dependent on the weight of the system. This is also clear in the chosen platforms, where smaller multirotor UAVs are used for close-range and low-weight delivery.

Table 25 Technology for Use-Case 5: Rural transportation

UAV Technology classification	UAV Technology details	Costs	Notes
UAV Platform	Lightweight quadcopter	5,000 EUR	Small-to-medium distances, small cargo capacity
	Medium weight quadcopter	8,000 EUR	Small-to-medium distances, medium cargo capacity
	Medium weight Hybrid wing	25,000 EUR	Medium-to-large distances, medium cargo capacity
	Heavy weight Helicopter	65,000 EUR	Small to large distances, versatile
UAV Software: flight planning, path planning, fleet management	Drone Fleet Management & Customer Services infrastructure	Software is going to be made custom, as part of the main aims of the project.	Underlying software frameworks are free and open source: MAVLink protocol, PHP, NodeJS, Python.

Long distances are covered by a hybrid-wing UAV, with vertical take-off and landing, but efficient long-distance flight with a medium payload. Heavy payloads are covered by a large multirotor platform, which is limited to a close-range. The Helicopter design is chosen for the highest lift-capacity, for various ranges, requiring a single motor, and therefore more efficient at various ranges and payloads. Future technological developments will improve in battery-life and efficiency, therefore distance and/or payload weight will slowly increase over time. These different UAVs are proposed to be part of a UAV swarm, where a central fleet control system will divide the tasks and send the UAVs on their respective delivery missions. These UAV platforms are more expensive due to high redundancy requirements for autonomous flight. These requirements are additional 4G networking, improved GPS, and radio telemetry. These systems are not only of higher reliability than the commercial counterparts, but also operate at longer distances, to ensure safe operation.

The software developed for this central fleet control system must be made from the ground up, no existing UAV fleet management systems for delivery exist. An organised, human-free, autonomous warehouse might be able to run small, motorised ground vehicles as a fleet. But a heavy, flying UAV in the outdoors is multiple orders of magnitude more complex and hazardous. There are many regulations and safety features such a system should have (Zailani et al., 2020), and should be well understood before embarking on the programming side, to mitigate problems in the field. Many different safety and regulatory aspects exist. Next to the physical environment, path-planning algorithms should take no-fly zones into account. Safety features and protocols for different problematic situations should be in place whilst keeping communications at the highest security level¹²². All separate elements to this system are available in open-source format, from high-quality environmental data to safe communications protocols and path-planning algorithms. The main development will therefore be to integrate these different, existing software-technologies into a central, integrated fleet management system.

In terms of affordability, the UC5 drone system requires a significant investment similarly to the UC4. The software will be developed in-house as part of the ICAERUS project. Comparatively, the UC1 and UC3 drone systems are not too expensive or rather affordable while UC2 is more expensive, on the other side UC4, UC5 are highly demanding of the initial investments and software development.

¹²² See more in: Sch"affer, B., Pieren, R., Heutschi, K., Wunderli, J. M. & Becker, S. (2021)., Drone Noise Emission Characteristics and Noise Effects on Humans—A Systematic Review. International Journal of Environmental Research and Public Health 18. issn: 1660-4601. <https://www.mdpi.com/1660-4601/18/11/5940>.

4.1.6 Summary of all UCs' characteristics

In summary, all characteristics of our project's Use Cases are shown in the next table in addition to the details presented in the previous sections 4.1.1 – 4.1.5.

Table 26 Characteristics of all UCs in a comparative mode

Dimension	Characteristic / Criterion	UC1	UC2	UC3	UC4	UC5
Definition of Use Case	Objectives	Cost efficiency	Productivity & digital solutions	Comfort for farmers	Environment sustainability &	Productivity & digital solutions
	Innovation Level	Emerging	Emerging	Experimental	Experimental / Emerging	Emerging
	Innovation type	Radical	Radical in the method	Breakthrough	Radical	Breakthrough in the model
	Type of stakeholders	12 groups of stakeholders	12 groups of stakeholders	12 groups of stakeholders	12 groups of stakeholders	12 groups of stakeholders
	Project initiator	Public-private	Project / University	Project / Research Institute	Public-private	Public-private
Scope	Industry	Precision agriculture	Precision agriculture	Livestock	Forestry	Rural logistics
	Drone type	Quadcopter	DJI Agras	Quadcopter	Hexacopter	Quadcopter
	Geographic coverage	Agricultural land & vineyards		Grassland terrains	Forest & mountain terrains	Rural residences
	Purpose	Crop health assessment	Crop spraying	Livestock monitoring	Tree health assessment; Wildfire risk monitoring; Animal detection.	Goods delivery to vulnerable rural users
Technology	Software	Deep Learning with Python	UVA-platform	Deep Learning with Python	Deep Learning with Python	Open source software: MAVLink protocol; PHP, NodeJS, Python
	Sensing	Mapping	Mapping	UAV Sensor: Thermal camera	UAV Hyperspectral Sensor:	No
	Hardware	UAV Platform	UAV Platform	UAV Platform	UAV Platform	UAV Platform
	Decision & Data	High amount of data and computation	High amount of data and computation	High amount of data and computation	High amount of data and computation	High amount of data and computation

Market and Stakeholder Analysis	Value proposition	Service	Intangible	Intangible	Intangible	Intangible	Intangible
	Value creation	Operation financing	Project grant	Project grant	Project grant	Project grant	Project grant
		Management of network	Business & Governance model to be developed	Business & Governance model to be developed	Business & Governance model to be developed	Business & Governance model to be developed	Business & Governance model to be developed
		Stakeholder Grouping	Described in D1.1, Section 5.1.2	Described in D1.1, Section 5.1.3	Described in D1.1, Section 5.1.4	Described in D1.1, Section 5.1.5	Described in D1.1, Section 5.1.6
		Stakeholder Interaction	Value flow maps	Value flow maps	Value flow maps	Value flow maps	Value flow maps
		Revenue model	Various business models	Various business models	Various business models	Various business models	Various business models
		Cost structure	Tangible & Intangible costs	Tangible & Intangible costs	Tangible & Intangible costs	Tangible & Intangible costs	Tangible & Intangible costs
		Target market segment	Vineyard crop monitoring	Specifically targeted pests and pesticide spraying in crop fields	Livestock monitoring while the herd grazes or rests	Forest health checks; Wildfire risk monitoring; Wild animal detection	Aerial supply chain
	Value Delivery	Type	B2B	B2B	B2B	B2B	B2B, B2C
		Value Flows	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents
		Value Channels	Science-related and Technology	Science-related and Technology	Science-related and Technology	Science-related and Technology	Science-related and Technology
		Impacts	Economic	Environment	Economic	Environment	Social
		KPIs	WP3	WP3	WP3	WP3	WP3
		Timing	Long-term	Long-term	Long-term	Long-term	Long-term
	Market Strategy	Market viability	Affordable	Expensive	Affordable	Expensive	Expensive
		Competitiveness	Advantages	Advantages	Advantages	Satellite Alternative	Competition with transport modes
		Barriers	Data & algorithm related	Regulatory	Science-related	Technical	Technical
		Enablers	Market	Market	Government policy	Institutional	Impact/ Market

Moreover, during a roundtable session in Wageningen University, which was part of the project's management meeting on 28-29th June 2023, all UC leaders had a chance to clarify the details in Table 26.

The session's objectives were to:

- Clarify that all the details for the use cases are correct in the prepared and distributed table for comparison of all ICAERUS use cases. Characteristics provided are initially extracted from two deliverables – D1.1 and D3.1. Others are from the business and governance models in the DoW (from WP5);
- Debate particularly the innovation type of the drone services that the UC teams are aiming to provide and demonstrate to various stakeholders.

The market segments have been defined for each of the use cases in T1.1 and all UC leaders and teams will be testing and developing the UC as a business case in the relevant markets:

- UC1 Viticulture (organic production)
- UC2 Precision crop protection
- UC3 Precision livestock farming
- UC4 Forestry monitoring
- UC5 Rural logistics (small parcel delivery)

During the debate, questions and comments were raised and discussed accordingly:

- UC1: Added economic and environmental impact from their activities
- UC2: No sensing in this case and a low volume of data
- UC3: Who is the final end-user? Farming businesses
 - Also, the French team's members of UC3 are not really using models.
 - Classic software of the drone providers (not a special/unique software) will be utilised during the demonstrations.
- UC4: Thermal camera will be used
- UC5: The team will be modifying mostly the technology at the BVLOS, so it is an innovation in technology not the model – a radical innovation type.

The discussion was wrapped up, and Table 26 was updated. All changes made are in bold (see Table 27).

Table 27 Updated characteristics of all UCs

Dimension	Characteristic / Criterion		UC1	UC2	UC3	UC4	UC5
Definition of Use Case	Objectives		Cost efficiency	Productivity & digital solutions; comfort for farmers; environment	Comfort for farmers	Environment sustainability &	Productivity & digital solutions
	Innovation Level		Emerging	Emerging	Experimental	Experimental / Emerging	Emerging
	Innovation type		Radical	Radical in the method	Breakthrough	Breakthrough	Radical in the technology
	Type of stakeholders		12 groups of stakeholders	12 groups of stakeholders	12 groups of stakeholders	12 groups of stakeholders	12 groups of stakeholders
	Project initiator		Public-private	Project / University	Project-Research Institute	Public-private	Public-private
Scope	Industry		Precision agriculture	Precision agriculture	Livestock	Forestry	Rural logistics
	Drone type		Quadcopter	DJI Agras	Quadcopter	Multirotor and fixed-wing	Quadcopter
	Geographic coverage		Agricultural land & vineyards		Grassland terrains	Forest & mountain terrains	Rural residences
	Purpose		Crop health assessment	Crop spraying	Livestock monitoring	Tree health checks; Wildfire risk monitoring; Animal detection.	Goods delivery to vulnerable rural users
Technology	Software		Deep Learning with Python	UVA-platform	Classic software	Deep Learning with Python	Open source software: MAVLink protocol; PHP, NodeJS, Python
	Sensing		UAV sensor RGB and multispectral	No	UAV Sensor: Thermal camera + RGB	Thermal camera	No
	Hardware		UAV Platform	UAV Platform	UAV Platform	UAV Platform	UAV Platform
	Decision & Data		High amount of data and computation	High amount of samples, but low volume of data	High amount of data and computation	High amount of data and computation	High amount of data and computation
Market and Stakeholder Analysis	Value proposition	Service	Intangible	Intangible	Intangible	Intangible	Intangible
	Value creation	Operation financing	Project grant	Project grant	Project grant	Project grant	Project grant
		Management of network	Business & Governance model to be developed	Business & Governance model to be developed	Business & Governance model to be developed	Business & Governance model to be developed	Business & Governance model to be developed

		Stakeholder Grouping	Described in D1.1, Section 5.1.2	Described in D1.1, Section 5.1.3	Described in D1.1, Section 5.1.4	Described in D1.1, Section 5.1.5	Described in D1.1, Section 5.1.6
		Stakeholder Interaction	Value flow maps	Value flow maps	Value flow maps	Value flow maps	Value flow maps
		Revenue model	Various business models	Various business models	Various business models	Various business models	Various business models
		Cost structure	Tangible & Intangible costs	Tangible & Intangible costs	Tangible & Intangible costs	Tangible & Intangible costs	Tangible & Intangible costs
		Target market segment	Vineyard crop monitoring (Viticulture segment)	Specifically targeted pests and pesticide spraying in crop fields	Livestock monitoring while the herd grazes or rests	Forest health checks; Wildfire risk monitoring; Wild animal detection.	Small parcel delivery
	Value Delivery	Type	B2B	B2B	B2B	B2B	B2B, B2C
		Value Flows	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents	Monetary, knowledge, data, technology, plans, policy documents
		Value Channels	Science-related and Technology	Science-related and Technology	Science-related and Technology	Science-related and Technology	Science-related and Technology
		Impacts	Economic&Environment	Environment	Social	Environment	Social and Environment
		KPIs	WP3	WP3	WP3	WP3	WP3
		Timing	Long-term	Long-term	Long-term	Long-term	Long-term
	Market Strategy	Market viability	Affordable	Expensive	Affordable	Expensive	Expensive
		Competitiveness	Advantages	Advantages	Advantages	Satellite Alternative	Competition with transport modes
		Barriers	Data & algorithm related	Regulatory	Science-related	Technical	Regulatory
		Enablers	Market	Market	Government policy	Institutional	Impact/ Market

4.1.7 An integrating lens for the technological needs across Use Cases

The Use Cases use different types of UAVs which vary in terms of the product architecture and or the type of components integrated in the product architecture. Literature on innovation distinguishes, among others, between architectural and component innovations, an appealing distinction especially for products that can be considered as ‘systems’ of interdependent elements (components) that are connected together with specific arrangements (architecture) (Henderson and Clark, 1990). The component-architecture distinction is particularly appealing in the case of UAVs as it helps to understand how technical and technological developments can introduce innovations that could meet the technological needs of the specific UCs. Henderson and Clark (1990) define components as a ‘physically distinct portion of the product that embodies a core design concept and performs a well-defined function’ (pp 11). There are many types of components that can perform the same function, while the overall architecture of the product lays out how the components will work together.

It is clear to see how altering the number of components in a product can cascade changes in the architecture. In addition, changes in the type of a specific component, to achieve enhanced functionality, may also lead to changes in the product architecture. For instance, UC1 and UC3 currently employ a Quadcopter UAV architecture with different variations in the components, an RGB sensor with multispectral camera and a thermal camera with RGB respectively. As both UCs are at an emerging or at an experimental level, there are still business opportunities stemming from technological developments along both the Quadcopter architecture and the different components that can offer enhanced features that better serve the technological needs of the respective UCs. Indeed, as mentioned above for UC3, developments at the component level (e.g., thermal cameras) can generate more accurate images that could enable the detection of specific conditions of separate animals rather than generating images of animals in groups / herds. It is clear to see how technological developments in “Thermal cameras” need to be accompanied by developments in software to allow for the analysis and storing of more sophisticated data for each animal in a herd and not just for the group of animals collectively as it is currently.

As discussed in the literature section of this Deliverable D1.3, technological developments that resolve technical uncertainty and innovations that offer a sound justification for the benefits and advantages of the use of UAVs in specific areas of applications, can foster entrepreneurial activity and user (e.g., farmer) adoption of the technology. Figure 13 below offers an overview of the existing developments in industry applications of UAVs along respective technological advancements. By comparing Figure 13 below and Table 27 above, one can appreciate the areas where advancements in complementing (e.g., cameras) and enabling (e.g., batteries) technologies can play a crucial role in the future, for the further development and expansion of UAV applications defined by the UCs of the ICAERUS project.

The interrelationships among organisations providing components, enabling technologies, UAV manufacturers and software providers shape the innovation ecosystems that are important for generating high performance from the innovation (UAVs), for each actor separately and for constellations of actors (Granstrand & Holgersson, 2020; Jacobides et al., 2018). Such ecosystems are not stable constellations of actors and may evolve in terms of actor membership and nature of interactions among actors or networks of actors (Shi et al., 2023). Ecosystems extend to involve institutional actors (regulators, IP systems), universities and other loosely connected organisations, which interact in complex ways and align themselves to support new products, satisfy customer needs and eventually incorporate the next round of innovations. The capabilities and roles of both corporate and other type of organisations in such ecosystems co-evolve as there is co-dependence in value creation and capture. For instance, the role of regulators that shape the boundaries that restrict UAV use, is highly influential for pushing UAV applications in forestry and agriculture such as those in UC3 and UC4 from an experimental stage to an emerging and incubation stages (see literature review and the framework of Moeen et al., 2020).

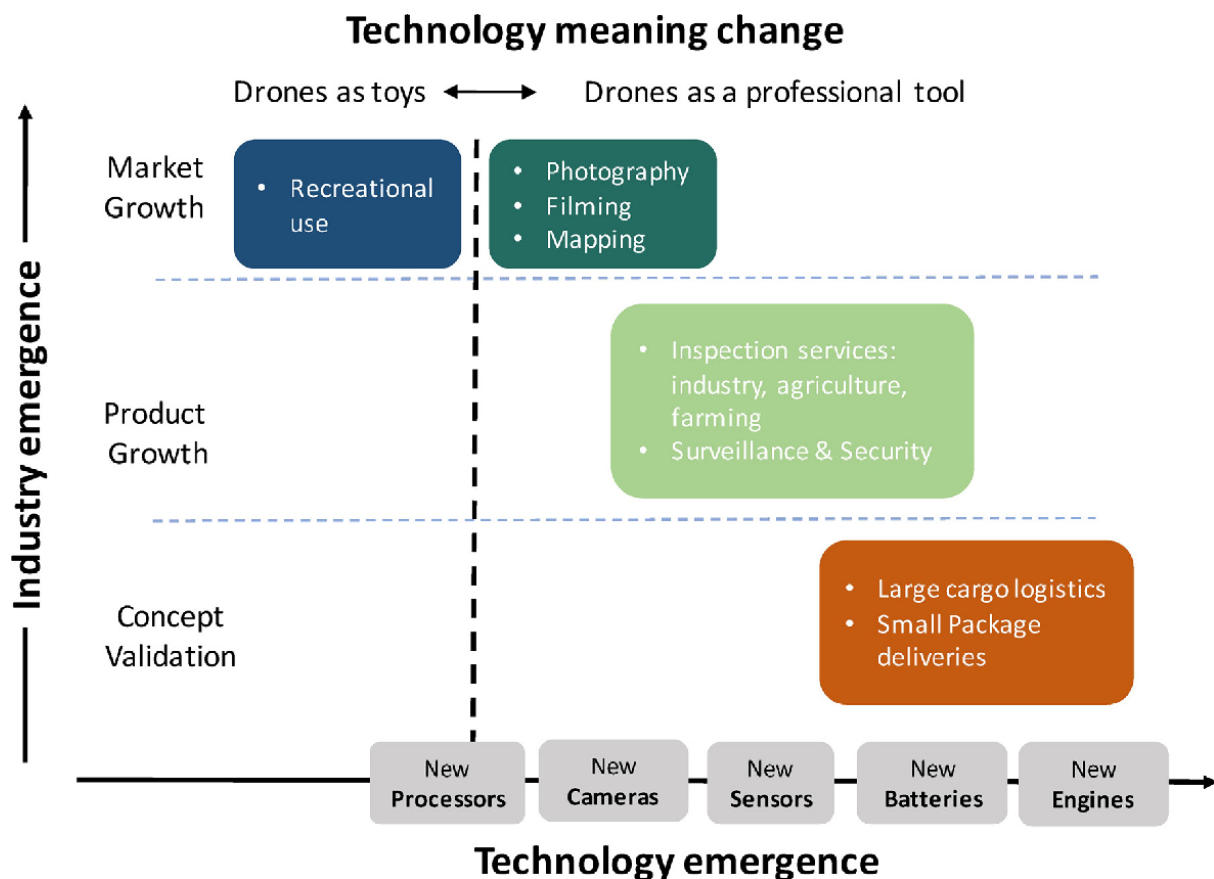


Figure 12 Industry Emergence and Technology Emergence (Giones and Brem, 2017)

4.1.7.1 Concluding remarks

The comparative analysis of Needs vs. Technology in this *chapter 4* of Deliverable 1.3 has demonstrated the evolution of the long standing debate about innovation and competitive markets, explained in the beginning of this document and recorded as a theoretical perspective in the OECD report “Competition and Innovation”¹²³. In D1.3 *chapter 3* primarily focused on non-agricultural market segments and their growth potential setting-out the comparative basis for analysing the agricultural segments (UC1 to UC4) and rural parcel deliveries (UC5) in *chapter 4*.

As the analysis has revealed, the adoption of new technology is not always an easy process, and all UCs of our project show different levels of such difficulties and regulatory hurdles. For instance, UC1, UC3 and UC4 experience more technical and scientific difficulties while UC2 and UC5 have to operate in a restrictive regulatory environment. These hurdles often turn into disincentives for new investors when they decide to allocate resources in new technology. And Aghion, Howitt (1992) especially focus in their research on the role of incentives and competition in determining investment in new technology and efforts by different firms. And while the ICAERUS Consortium understands the need for more competition and less monopoly power, we also do not underestimate the significant role of incentives to stimulate innovation in Europe. The Schumpeter-Arrow debate emphasises the balance between competition and incentives to innovate that our modern economies need to find. Therefore, our work in T1.3 *Comparative Analysis and Needs* makes few contributions into this debate as it derived from the experience of all Use Cases as local drivers of innovation the following factors¹²⁴:

- Local market needs
- Government or regional policy, and
- Impact on standards of rural life.

¹²³ OECD (2023). “Competition and Innovation: a theoretical perspective”, OECD Competition Policy Roundtable Background Note, <https://www.oecd.org/competition/the-relationship-between-competition-and-innovation.htm>

¹²⁴ See more in Table 27

Secondly, going into further details, recent research (Kolev et al., 2022) explores the role of universities and start-ups in the development and commercialisation of new technological products or services. The authors claim in their paper that “start-up ventures are an increasingly important organisational form in the commercialisation of university technologies”. The technological ecosystem provides good conditions for all actors (public and private) to fulfil their roles and achieve their objectives, and relations among all involved institutions have become increasingly perplexed in modern days as this was well illustrated by the stakeholders network analysis performed in T1.1 *Understanding the Drone Market*.

Finally, other research has found that “small firms prevail in the early stages and innovation tends to concentrate in larger firms as industries evolve towards maturity” (Revilla A et al., 2012), and this process was observed in the 1990s during the IT boom when many firms emerged and competed to be winners. Then in the early 2000s, it appeared that only a few large firms could continue to invest in IT innovation and we had observed the NASDAQ stock exchange crisis. Also, the historical overview of the civilian industry presented in *chapter 2* of this deliverable demonstrated the stages of development through which any nascent industry goes before reaching maturity, and this is associated with the activities of different-sized-firms that enter and exit. The European Commission supports the local SMEs in Europe extensively. Therefore, the whole process of innovation driven by market forces is complex and uncertain, requiring a solid accumulation of knowledge and information to be exchanged among the stakeholders in a network, shared and transferred into valuable assets such as new technology products.

5. Conclusions

This D1.3 *Comparative Analysis and Needs Report* aimed to accomplish a comparative analysis of needs vs. technology, and as the report has been structured in five major parts, it presents recent market needs and the global technological trends in the drone industry (chapter 3) as well as ICAERUS use cases' stakeholders needs matched to the existing technology solutions (chapter 4). At the start of the document, the introduction focuses on the modern characteristics of digital goods to illustrate some of the difficulties that stakeholders may experience in the process of innovation or technology adoption. Furthermore, this part will summarise them to be able to make conclusions:

Digital goods are defined as non-rival, infinitely extensible, discrete, aspatial and recombinant. A good is infinitely expandable if its quantity can grow arbitrarily large very quickly and without cost. Consumers and producers can have a copy that looks exactly like the original without the good being consumed by another producer or consumer – for example, several drones with the same algorithm or software. Expansibility describes a restriction on the quantity available to society at a marginal cost of zero in a period. Non-rivalry describes a restriction on marginal utility for each consumer.

The third characteristic is that they are initially discrete. This means that digital goods are indivisible. This is most obvious in computer programming while writing algorithms – the first half of the string of 0s and 1s as part of a computer algorithm will not perform half or even a positive part of the intended task of the programme and could instead damage the computer hardware. The importance of indivisibility, then, lies in the economic insight that if the first copy of a digital good requires significant investment - completing the first instance of a new computer operating system - this initial cost widens the gap between what is socially optimal and what competitive markets can deliver. Therefore, in the case of digital goods, the market equilibrium is not always socially efficient, and this partly explains the involvement of public institutions and requested public funding in framing policies and initiating innovative behaviour. Market failures are usually tackled by governmental policies. Thus, the nascent civilian drone industry is at an early emerging stage which explains the support of public institutions in the investment process to stimulate innovations and reach an industry's optimal equilibrium.

The fourth characteristic is that digital goods are aspatial - they are nowhere and everywhere at once. Just as every copy is the original for a digital good, the communication of a digital good/service is already its transport and distribution. They (for example, the drone software) can spread unhindered from one place to another through the transmission of a signal, and this makes it difficult to locate them geographically¹²⁵. And the fifth characteristic is that digital goods are recombinant - meaning that digital goods generate new ideas or new applications, and digital transmissions in ways that ordinary public goods such as public parks, clean air or national defence cannot. The generation of new digital apps can be exponential, and this is observable in all our UCs technological developments.

As it was mentioned in the introduction, these five characteristics raise some questions in terms of traditional market understandings and valuations in time of building-up solid foundations for the digital economy not only in Europe, but also globally. Competitive markets via stimulating severe competition drive the price of digital goods near to zero. Thus, the stream of rents generated in the future does not always provide an incentive to deploy such services on a significant scale now and the Arrow argument for more competition becomes obsolete.

Therefore, to alleviate some of these weaknesses or failures of competitive markets, regarding the innovation of new technology, ICAERUS Work Package 1 provides:

¹²⁵ We make a distinction between physical components of a drone and its software. Section 4.1.7 mainly focuses on the UAV architecture and its technological components while here the emphasis is on the economic characteristics of the software.

1. a thorough understanding of the drone industry landscape in Europe with detailed analysis of Use Cases' potential markets, supply and demand forces, future opportunities, and target customer groups; as well as involved stakeholders on a local basis, their interests, roles, needs and objectives to diminish the side effects of the third characteristic and utilise economies of scale (in T1.1).
2. a review of the drone regulatory environment including a presentation of legal requirements such as industry standards, safety regulations of the European Union and risk management as all these laws deal with the first characteristic of excludability or non-rivalry (in T1.4)¹²⁶.
3. a completed taxonomy of UAV technologies and mounting components to build structured knowledge such as a library of technological models that can be applied in sustainable agriculture and rural development in Europe dealing with the consequences of the second characteristic of digital goods, which is infinite extensibility (in T1.2 and additionally in WP2).
4. a comparative analysis of all Use Cases in T1.3 to recommend them future actions to be able to move forward on the innovative ladder. This task supports the fifth characteristic of digital goods.

All this information will be used as inputs for WP4, WP5 and WP6 in later developments of our project (see Figure 14).

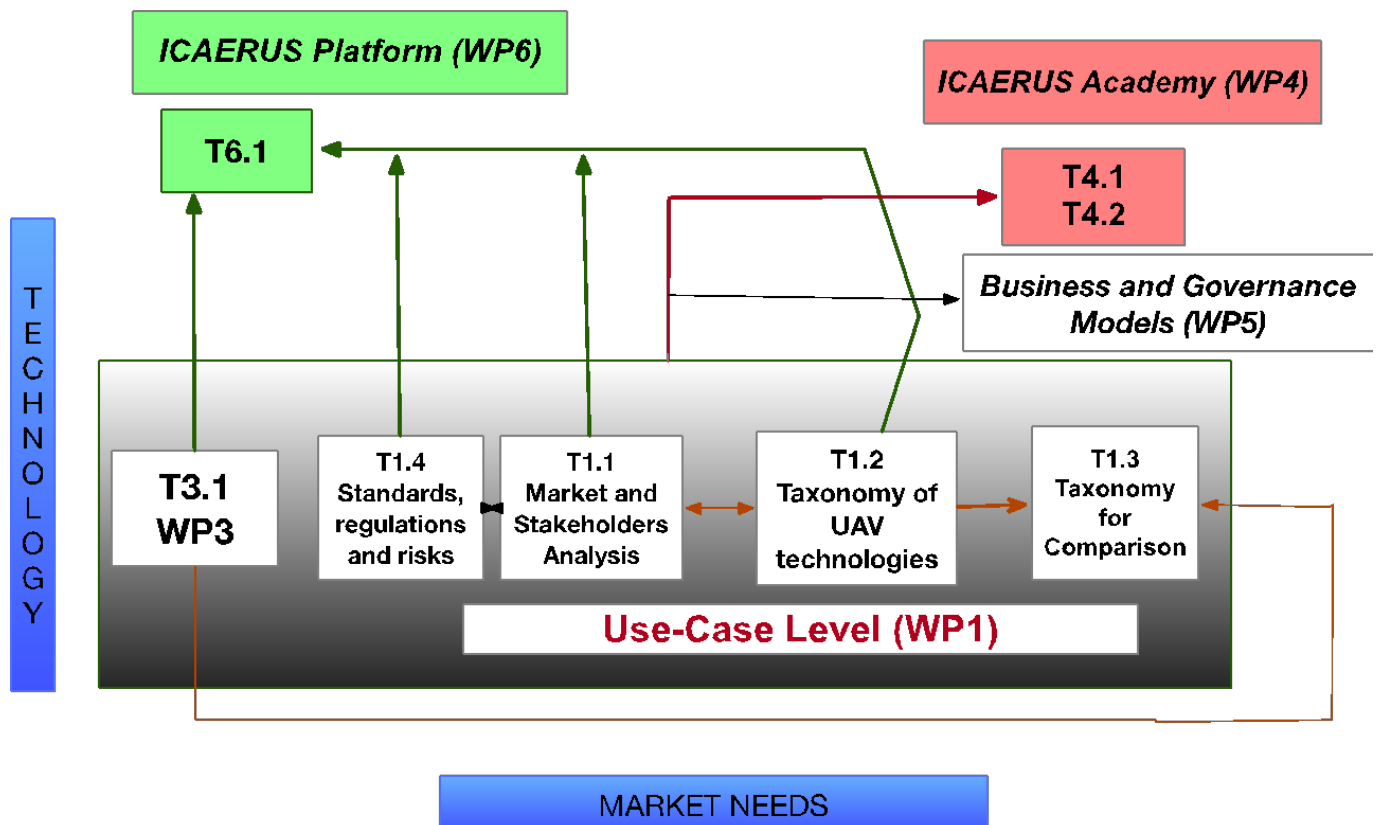


Figure 13 Outputs of WP1 and T1.3 during the project's timeframe

In the end, recommendations for the ICAERUS Use cases to drive their innovative activities and sustain their forward-looking expectations or actions beyond the project's timeframe, are summarised as five major conclusions derived from the presented analyses of chapter 3 and 4, and they follow below:

- ✓ **UC1: Radical innovation** – an emerging UC that needs to explore future market opportunities in the viticulture segment and target customers to get near to the market level.

¹²⁶ See more details in: D1.5 Drone Standards, Regulations and Risks, ICAERUS Consortium, June 2023

- ✓ **UC2: Radical in the method** – an emerging UC that operates in a very restrictive regulatory environment and needs to optimise its “drone spraying” method as well as push up frontier regulations to get near to the market level.
- ✓ **UC3: Breakthrough** – an experimental UC in livestock monitoring that needs to move forward with practical guidelines for real farming in France. The heavy involvement of research organisations at this stage guarantees the thorough investigation of what is needed for the case to be successfully developed.
- ✓ **UC4: Breakthrough** – an experimental UC in forestry & biodiversity monitoring that needs knowledge, algorithmic skills, and technology to move forward to the emerging level. Public-private partnerships are essential for the development of this case.
- ✓ **UC5: Radical in the technology** – an emerging UC that optimises the technology to be used for delivery of small parcels in rural settlements. It will have to explore the future market opportunities in the countries of the Balkans to get near to the market level.

References

- A Holistic Fire Management Ecosystem for Prevention, Detection and Restoration of Environmental Disasters. (2023, February 27). CORDIS | European Commission. <https://cordis.europa.eu/project/id/101036926>
- About us. (n.d.). Unifly. <https://www.unifly.aero/company/about-us>
- Acemoglu, D. (2003). Patterns of Skill Premia. *Review of Economic Studies*, 70(2), 199–230. <https://doi.org/10.1111/1467-937x.00242>
- ADAPTED SITUATION AWARENESS TOOLS AND TAILORED TRAINING SCENARIOS FOR INCREASING CAPABILITIES AND ENHANCING THE PROTECTION OF FIRST RESPONDERS. (2023, March 21). CORDIS | European Commission. <https://cordis.europa.eu/project/id/832576>
- Advanced Forest Fire Fighting. (2023, March 10). CORDIS | European Commission. <https://cordis.europa.eu/project/id/607276>
- Aerial robotic platform for indoor safety and security. (2023, February 26). CORDIS | European Commission. <https://cordis.europa.eu/project/id/953760>
- Aerial Robotic technologies for professional search and rescue. (2022, August 25). CORDIS | European Commission. <https://cordis.europa.eu/project/id/780960/reporting>
- Aerial Situational Awareness for Every Firefighter. (2022, August 25). CORDIS | European Commission. <https://cordis.europa.eu/project/id/880480>
- Aghion, P., & Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica*, 60(2), 323. <https://doi.org/10.2307/2951599>
- Ahmadian, N., Lim, G. J., Torabbeigi, M., & Kim, S. J. (2022). Smart border patrol using drones and wireless charging system under budget limitation. *Computers & Industrial Engineering*, 164, 107891. <https://doi.org/10.1016/j.cie.2021.107891>
- Air Mobility Initiative. (n.d.). Munich Aerospace. <https://www.munich-aerospace.de/en/all-news-en/air-mobility-initiative-en>
- Amarasingam, N., Ashan Salgadoe, A. S., Powell, K., Gonzalez, L. F., & Natarajan, S. (2022). A review of UAV platforms, sensors, and applications for monitoring of sugarcane crops. *Remote Sensing Applications: Society and Environment*, 26, 100712. <https://doi.org/10.1016/j.rsase.2022.100712>
- An Enhanced pre-frontier intelligence picture to Safeguard the European borders. (2022, March 28). CORDIS | European Commission. <https://cordis.europa.eu/project/id/101021851>
- Ariu, A., & Mion, G. (2011). Service Trade and Occupational Tasks: An Empirical Investigation. CEP Discussion Paper No 1107, LSE. <https://dokumen.tips/documents/cep-discussion-paper-no-1107-december-2011-service-trade-cep/seacukpubsdownload.html?page=7>
- Arrow, K. J. (1971). *Essays in the theory of risk-bearing* (pp. 144–160). North-Holland.
- Augmented Reality Enriched Situation awareness for Border security. (2023, June 13). CORDIS | European Commission. <https://cordis.europa.eu/project/id/833805>
- Autonomous swarm of heterogeneous robots for BORDER surveillance. (2022, June 13). CORDIS | European Commission. <https://cordis.europa.eu/project/id/740593>
- Baldwin, R., & Freeman, R. (2021). *Risks and Global Supply Chains: What We Know and What We Need to Know*. Working Paper 29444, National Bureau of Economic Research. <https://doi.org/10.3386/w29444>
- Bell, J. (2023, March 17). Dubai Customs innovates with drones, AI and the Metaverse to secure UAE's borders. *Al Arabiya English*. <https://english.alarabiya.net/News/world/2023/03/17/Dubai-Customs-innovates-with-drones-AI-and-the-Metaverse-to-secure-UAE-s-borders>
- Blay Puntas, I. (2022). The use of drones for maritime surveillance and border control. *Centre Delàs d'Estudis per la Pau*. https://centredelas.org/wp-content/uploads/2022/06/WP_DronesFrontex_ENG.pdf
- Bloom, N., Draca, M., & Van Reenen, J. (2008). Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity. https://www.aeaweb.org/annual_mtg_papers/2008/2008_130.pdf
- Bonds, J. A., Pai, N., Hovinga, S., Stump, K., Haynie, R., Flack, S., & Bui, T. (2024). Spray Drift, Operator Exposure, Crop Residue and Efficacy: Early Indications for Equivalency of Uncrewed Aerial Spray Systems with Conventional Application Techniques.

- Borrelli, L., Conforti, M., & Mercuri, M. (2019). LiDAR and UAV System Data to Analyse Recent Morphological Changes of a Small Drainage Basin. *ISPRS International Journal of Geo-Information*, 8(12), 536. <https://doi.org/10.3390/ijgi8120536>
- Bourgoin, C., Betbeder, J., Couteron, P., Blanc, L., Dessard, H., Oszwald, J., Le Roux, R., Cornu, G., Reymondin, L., Mazzei, L., Sist, P., Läderach, P., & Gond, V. (2020). UAV-based canopy textures assess changes in forest structure from long-term degradation. *Ecological Indicators*, 115, 106386. <https://doi.org/10.1016/j.ecolind.2020.106386>
- Bremner, R., Eisenhardt, K. M. (2022). Organising Form, Experimentation and Performance: Innovation in the Nascent Civilian Drone Industry. *Organisation Science*, 33(4): 1645 – 1674.
- Bulgarian President Wants EU to Fund New Fence on Common Border With Turkey. (2023, February 6). Schengen Visa News. <https://www.schengenvisainfo.com/news/bulgarian-president-wants-eu-to-fund-new-fence-on-common-border-with-turkey/>
- Burt, P., & Frew, J. (2020). Crossing A Line | The use of drones to control borders | . Drone Wars UK. <https://dronewars.net/wp-content/uploads/2020/12/DW-Crossing-a-Line-WEB.pdf>
- Caselli, F., Koren, M., Lisicky, M., & Tenreyro, S. (2020). Diversification Through Trade: Vols. 135, Issue 1 (pp. 449–502). *The Quarterly Journal of Economics*. <https://doi.org/10.1093/qje/qjz028>
- Commercial drone flight planning software | App for drones. (n.d.). AirMap. <https://www.airmap.com/manage/operators/airmap-app-for-drones>
- Coordinated Use of miniaturized Robotic equipment and advanced Sensors for search and rescue Operations. (2023, May 13). CORDIS | European Commission. <https://cordis.europa.eu/project/id/832790>
- Coordination Of Maritime assets for Persistent And Systematic Surveillance. (2022, October 20). CORDIS | European Commission. <https://cordis.europa.eu/project/id/833650>
- Cost advantageous and scalable drone alarm and protection system for urban contexts. (2022, August 16). CORDIS | European Commission. <https://cordis.europa.eu/project/id/768242>
- Costin, A., Eastman, C. M., & Issa, R. R. A. (2017). The Need for Taxonomies in the Ontological Approach for Interoperability of Heterogeneous Information Models. <https://doi.org/10.1061/9780784480830.002>
- CPSwarm. (2022, August 17). CORDIS | European Commission. <https://cordis.europa.eu/project/id/731946>
- Crumley, B. (2022a, January 21). French law allowing police drone use ruled (mostly) constitutional. DroneDJ. <https://dronedj.com/2022/01/21/french-law-allowing-police-drone-use-ruled-mostly-constitutional/>
- Crumley, B. (2022b, June 17). Ireland to deploy drones to battle sea-based drug smuggling. DroneDJ. <https://dronedj.com/2022/06/17/ireland-to-deploy-drones-to-battle-sea-based-drug-smuggling/>
- Cuenca, O. (2023a, February 24). Lincolnshire Police drone unit reports busy January. AirMed&Rescue. <https://www.airmedandrescue.com/latest/news/lincolnshire-police-drone-unit-reports-busy-january>
- Cuenca, O. (2023b, April 11). Devon and Cornwall Police introduce drones. AirMed&Rescue. <https://www.airmedandrescue.com/latest/news/devon-and-cornwall-police-introduce-drones>
- D. B. M. Yousefi, A. S. M. Rafie, S. A. R. Al-Haddad and S. Azrad. (2022). A Systematic Literature Review on the Use of Deep Learning in Precision Livestock Detection and Localization Using Unmanned Aerial Vehicles. *IEEE Access*, 10, 80071–80091. <https://doi.org/10.1109/ACCESS.2022.3194507>
- de Backer, K., & Yamano, N. (2011). International Comparative Evidence on Global Value Chains. *SSRN Electronic Journal*, 103–126. <https://doi.org/10.2139/ssrn.2179937>
- Deep Learning UAV Networks for Autonomous Forest Firefighting. (2022, August 15). CORDIS | European Commission. <https://cordis.europa.eu/project/id/752669>
- Donnellan, A., Lyzenga, G., Ansar, A., Goulet, C., Wang, J., & Pierce, M. (2020). Targeted High-Resolution Structure from Motion Observations over the Mw 6.4 and 7.1 Ruptures of the Ridgecrest Earthquake Sequence. *Seismological Research Letters*, 91(4), 2087–2095. <https://doi.org/10.1785/0220190274>
- Drone technology to fight Europe's growing forest fires. (n.d.). Danish Technological Institute. <https://www.dti.dk/services/drone-technology-to-fight-europe-s-growing-forest-fires/44842>
- Drones for frontex unmanned migration control at Europe's borders. (2020). Statewatch. <https://www.statewatch.org/analyses/2020/drones-for-frontex-unmanned-migration-control-at-europe-s-borders/#:~:text=Three%20EU%20>

- Duffi, R., (2018). Mapping the UK drone industry, Vol 2023: <https://www.nesta.org.uk/blog/uk-drone-industry-map/> : NESTA, UK
- Dushime, K., Nkenyereye, L., Yoo, S., & Song, J. S. (2021). A Review on Collision Avoidance Systems for Unmanned Aerial Vehicles: 12th International Conference on ICT Convergence. 2021 International Conference on ICT Convergence (ICTC), 1150–1155. <https://doi.org/10.1109/ICTC52510.2021.9621120>
- Economic benefit analysis of drones in Australia. (n.d.). Deloitte. <https://www.deloitte.com/au/en/Industries/government-public/analysis/economic-benefit-analysis-drones-australia.html>
- Emergency Drones Market Analysis By Type (Fixed Wing, Rotary Wing, Hybrid Wing), By End Users (Police & Homeland Security, Fire Departments, Disaster Management, Others), By Drone Type (Consumer/Civil, Commercial, Military), & Region- Global Market Insights 2023-2033. (2022, December). Fact.MR. <https://www.factmr.com/report/emergency-drones-market>
- EMERITUS - Environmental crimes' intelligence and investigation protocol based on multiple data sources. (n.d.). Zabala Innovation. <https://www.zabala.eu/projects/emeritus/>
- Engel, R. (n.d.). Above the Smoke: The Case for Using Drones for Firefighting. Verizon Enterprise. <https://www.verizon.com/business/resources/articles/s/the-case-for-using-drones-for-firefighting/>
- Fatima, N., Saxena, P., & Gupta, M. (2022). Integration of multi access edge computing with unmanned aerial vehicles: Current techniques, open issues and research directions. Physical Communication, 52, 101641. <https://doi.org/10.1016/j.phycom.2022.101641>
- Feenstra, R. C., & Hanson, G. H. (1999). The Impact of Outsourcing and High-Technology Capital on Wages: Estimates For the United States, 1979-1990. The Quarterly Journal of Economics, 114(3), 907–940. <https://doi.org/10.1162/003355399556179>
- Firefighting Drone Market by Type (Fixed Wing, Multi-rotor), by size (Micro Drones, Macro Drones), by Propulsion (Electric Motor, Piston Engine, Solar Powered), by Application (Scene Monitoring, Search and Rescue, Post Fire or Disaster Assessment, Firefighting): Global Opportunity Analysis and Industry Forecast, 2022-2031. (2022). In Allied Market Research. <https://www.alliedmarketresearch.com/firefighting-drone-market-A06280>
- Frederiksen, M., Pedersen, J., Mette, amp., & Knudsen, P. (2020). Drones for public safety and emergency response operations: Actual and planned use. The Danish Industry Foundation. <https://industriensfond.dk/wp-content/uploads/uniflip/1109899.pdf>
- French police cleared to use drones for crowd monitoring. (2023, April 21). Reuters. <https://www.reuters.com/world/europe/french-police-cleared-use-drones-crowd-monitoring-2023-04-21/>
- FUTURE OF CUSTOMS RESEARCH / Drones – Potential Impact on the Customs and Trade Environment. (2016, January 22). WORLD CUSTOMS ORGANIZATION ORGANISATION MONDIALE DES DOUANES. <https://www.wcoomd.org/-/media/wco/public/global/pdf/topics/facilitation/ressources/permanent-technical-committee/211-212/pc0445e1.doc?la=en>
- G. Poley, L., & J. McDermid, G. (2020). A Systematic Review of the Factors Influencing the Estimation of Vegetation Aboveground Biomass Using Unmanned Aerial Systems. Remote Sensing, 12(7), 1052. <https://doi.org/10.3390/rs12071052>
- Garousi, V., Felderer, M., & Mäntylä, M. V. (2019). Guidelines for including grey literature and conducting multivocal literature reviews in software engineering. Information and Software Technology, 106, 101–121. <https://doi.org/10.1016/j.infsof.2018.09.006>
- GEOSENSE. (2022). ICAERUS, D3.1 Use Case Plan, Version A, WP3.
- Ghazali, M. H. M., Teoh, K., & Rahiman, W. (2021). A Systematic Review of Real-Time Deployments of UAV-Based LoRa Communication Network. IEEE Access, 9, 124817–124830. <https://doi.org/10.1109/access.2021.3110872>
- Giones, F., & Brem, A. (2017). From toys to tools: The co-evolution of technological and entrepreneurial developments in the drone industry. Business Horizons, 60(6), 875–884. <https://doi.org/10.1016/j.bushor.2017.08.001>
- Goldberg, S. J., Kirby, J. T., & Licht, S. (2016). Applications of Aerial Multi-Spectral Imagery for Algal Bloom Monitoring in Rhode Island. In Researchgate (pp. 28–32).

- https://www.researchgate.net/publication/338435382_Applications_of_Aerial_Multi-Spectral_Imagery_for_Algal_Bloom_Monitoring_in_Rhode_Island
- Gonzalez-Dugo, V., Hernandez, P., Solis, I., & Zarco-Tejada, P. (2015). Using High-Resolution Hyperspectral and Thermal Airborne Imagery to Assess Physiological Condition in the Context of Wheat Phenotyping. *Remote Sensing*, 7(10), 13586–13605. <https://doi.org/10.3390/rs71013586>
- Granstrand, O., & Holgersson, M. (2020). Innovation ecosystems: A conceptual review and a new definition. *Technovation*, 90-91(0166-4972), 102098. <https://doi.org/10.1016/j.technovation.2019.102098>
- Grazioso, C. (2022, February 8). Using Drones for Police: Real-World Benefits, Use Cases and ROI. DARTdrones. <https://www.dartdrones.com/drones-for-police/>
- Griffith, R., J. Van Reenen, (2021). “Product Market Competition, Creative Destruction and Innovation”, *EPR Discussion Paper* 16763
- He, X. (2018). Rapid development of unmanned aerial vehicles (UAV) for plant protection and application technology in China. *Outlooks on Pest Management*, 29 (4), 162-167.
- HEIMDALL - MULTI-HAZARD COOPERATIVE MANAGEMENT TOOL FOR DATA EXCHANGE, RESPONSE PLANNING AND SCENARIO BUILDING. (2022, August 23). CORDIS | European Commission. <https://cordis.europa.eu/project/id/740689/reporting>
- Henderson, R. M., & Clark, K. B. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, 35(1), 9–30. <https://www.jstor.org/stable/2393549>
- High-Accuracy Indoor Tracking and Augmented Sensing using Swarms of UAVs. (2022, August 18). CORDIS | European Commission. <https://cordis.europa.eu/project/id/793581>
- How The Swedish Police Uses Drones to Increase Safety and Security of Citizens. (2021, February 4). Geo-Matching; DJI ENTERPRISE. <https://geo-matching.com/content/how-the-swedish-police-uses-drones-to-increase-safety-and-security-of-citizens#:~:text=There%20are%20>
- Hummels, D. L. (2001). Time as a Trade Barrier. *Purdue CIBER Working Papers*. Paper 7, Purdue University. <https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1006&context=ciberwp>
- Hyun, C.-U., Park, M., & Lee, W. Y. (2020). Remotely Piloted Aircraft System (RPAS)-Based Wildlife Detection: A Review and Case Studies in Maritime Antarctica. *Animals*, 10(12), 2387. <https://doi.org/10.3390/ani10122387>
- Integrated holographic management map for safety and crisis events. (2022, October 21). CORDIS | European Commission. <https://cordis.europa.eu/project/id/101082320>
- Integrated spectroscopic sensors for the risk assessment of fires. (2022, August 5). CORDIS | European Commission. <https://cordis.europa.eu/project/id/693447>
- INTERPOL convenes global summit on the use of drones. (2022, June 24). INTERPOL. <https://www.interpol.int/en/News-and-Events/News/2022/INTERPOL-convenes-global-summit-on-the-use-of-drones>
- INTERPOL to issue drone guidelines for first responders. (2018, December 17). INTERPOL. <https://www.interpol.int/en/News-and-Events/News/2018/INTERPOL-to-issue-drone-guidelines-for-first-responders>
- Jacobides, M. G., Cennamo, C., & Gawer, A. (2018). Towards a Theory of Ecosystems. *SSRN Electronic Journal*, 39(8). <https://doi.org/10.2139/ssrn.3218233>
- Jager, W. de. (2022, January 20). Dutch Customs are increasingly using drones to combat drug smuggling. *Dronewatch Europe*. <https://www.dronewatch.eu/dutch-customs-are-increasingly-using-drones-to-combat-drug-smuggling/>
- Jameii, S. M., Zamirnaddafi, R. S., & Rezaabakhsh, R. (2022). Internet of Flying Things security: A systematic review. *Concurrency and Computation: Practice and Experience*, 34(24). <https://doi.org/10.1002/cpe.7213>
- Joseph Alois Schumpeter. (1934 [1911]). The theory of economic development : an inquiry into profits, capital, credit, interest, and the business cycle. Cambridge MA. *Harvard University Press*
- Kierans, J. (2023, March 12). Gardaí to deploy fleet of drones in bid to “monitor” members of crime underworld. *Irish Mirror*. <https://www.irishmirror.ie/news/irish-news/crime/garda-deploy-fleet-drones-bid-29437150>

- Kitchenham, B., & Charters, S. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering. Keele University & University of Durham.
https://www.elsevier.com/_data/promis_misc/525444systematicreviewsguide.pdf
- Kitchenham, B., Pretorius, R., Budgen, D., Pearl Brereton, O., Turner, M., Niazi, M., & Linkman, S. (2010). Systematic literature reviews in software engineering – A tertiary study. *Information and Software Technology*, 52(8), 792–805. <https://doi.org/10.1016/j.infsof.2010.03.006>
- Kolev, J., Haughey, A., Murray, F., & Stern, S. (2022, August 1). Of Academics and Creative Destruction: Startup Advantage in the Process of Innovation. National Bureau of Economic Research.
<https://doi.org/10.3386/w30362>
- Krugman, P. (1980). Scale Economies, Product Differentiation, and the Pattern of Trade. *The American Economic Review*, 70(5), 950–959. https://www.princeton.edu/~pkrugman/scale_econ.pdf
- Leslie, J. (n.d.). Police Drones at Night in the UK: How to Spot Them. Drone Survey Services.
<https://skykam.co.uk/police-drones-at-night-in-the-uk/#:~:text=As%20the%20use%20of%20>
- Librán-Embí, F., Klaus, F., Tschamtker, T., & Grass, I. (2020). Unmanned aerial vehicles for biodiversity-friendly agricultural landscapes - A systematic review. *Science of the Total Environment*, 732, 139204.
<https://doi.org/10.1016/j.scitotenv.2020.139204>
- Markets. (n.d.). Thales Group. <https://www.thalesgroup.com/en/worldwide/activities>
- Mamehgoi Yousefi, D. B., Mohd Rafie, A. S., Al-Haddad, S. A. R. & Azrad, S. (2022) A Systematic Literature Review on the Use of Deep Learning in Precision Livestock Detection and Localization Using Unmanned Aerial Vehicles. *IEEE Access*, 1. issn: 2169-3536
- May, T. (2022, October 18). Rome Fiumicino Launches Europe's First Airport Innovation Hub. *Airport Industry-News*. <https://airportindustry-news.com/rome-fiumicino-launches-europes-first-airport-innovation-hub/>
- Melitz, M. J. (2003). The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71(6), 1695–1725. <https://doi.org/10.1111/1468-0262.00467>
- Mendoza, M. A., Alfonso, M. R., Lhuillery, S., (2021). A battle of drones: Utilising legitimacy strategies for the transfer and diffusion of dual-use technologies. *Technological forecasting and Social change*, 166.
- Moeen, M., Agarwal, R., & Shah, S. K. (2020). Building Industries by Building Knowledge: Uncertainty Reduction over Industry Milestones. *Strategy Science*, 5(3), 218–244. <https://doi.org/10.1287/stsc.2020.0103>
- Moore, J. (1993). Predators and Prey: A New Ecology of Competition. *Harvard Business Review*.
<https://hbr.org/1993/05/predators-and-prey-a-new-ecology-of-competition>
- Mualla, Y., Najjar, A., Daoud, A., Galland, S., Nicolle, C., Yasar, A.-U.-H., & Shakshuki, E. (2019). Agent-based simulation of unmanned aerial vehicles in civilian applications: A systematic literature review and research directions. *Future Generation Computer Systems*, 100, 344–364. <https://doi.org/10.1016/j.future.2019.04.051>
- Natarajan, S., Basnayake, J., Wei, X., & Lakshmanan, P. (2019). High-Throughput Phenotyping of Indirect Traits for Early-Stage Selection in Sugarcane Breeding. *Remote Sensing*, 11(24), 2952.
<https://doi.org/10.3390/rs11242952>
- Nelson, R., (ed.) (1962). "Economic welfare and the allocation of resources for invention" by K. Arrow
- Nex, F., Armenakis, C., Gramer, M., Cucci, D.A., Gerke, M., Honkavaara, E., Kukko, A., Persello, C., Skaloud, J., (2022). UAV in the advent of the twenties: Where we stand and what is next. *ISPRS Journal of Photogrammetry and Remote Sensing*, 184: 214-242.
- Next-generation equipment tools and mission-critical strategies for First Responders. (2023, August 8). CORDIS | European Commission. <https://cordis.europa.eu/project/id/883371>
- NIHR Centre for Reviews and Dissemination - CRD Database. (n.d.). University of York / Centre for Reviews and Dissemination. <https://www.crd.york.ac.uk/CRDWeb/AboutPage.asp>
- Nilsen, T. (2023, January 23). Finnish Border Guard deploys surveillance drones, Norway not. *The Independent Barents Observer*. <https://thebarentsobserver.com/en/borders/2023/01/finnish-border-guard-deploys-surveillance-drones-norway-not#:~:text=The%20>
- Nokia's 5G-Connected Drone Platform Selected By Belgium's Citymesh For World's First Nationwide Drone Network. (2023, May 17). *Eurasia Review*. <https://www.eurasiareview.com/17052023-nokias-5g-connected-drone-platform-selected-by-belgiums-citymesh-for-worlds-first-nationwide-drone-network/>
- NOOSWARE. (2023a). ICAERUS, D1.1 European Landscape of Drone Innovations and Technologies, WP1.

- NOOSWARE. (2023b). ICAERUS, D1.1 European Landscape of Drone Innovations and Technologies, WP1 (p. 60, 131, 134).
- NOOSWARE. (2023). ICAERUS, D1.5 Drone Standards, Regulations and Risks, WP1
- Nordås, H., Pinali, E., & Geloso Grosso, M. (2006). Logistics and Time as a Trade Barrier. OECD Trade Policy Papers, No. 35, OECD Publishing. <https://doi.org/10.1787/664220308873>
- NOVEL INTEGRATED SOLUTION OF OPERATING A FLEET OF DRONES WITH MULTIPLE SYNCHRONIZED MISSIONS FOR DISASTER RESPONSES. (2023, September 8). CORDIS | European Commission. <https://cordis.europa.eu/project/id/833717>
- Ocampo, Y. (2023, May 11). Robotics and UAVs Advance Singapore Police Force Capabilities - OpenGov Asia. OpenGov Asia. <https://opengovasia.com/robotics-and-uavs-advance-singapore-police-force-capabilities/>
- OECD (2023). "Competition and Innovation: a theoretical perspective", OECD Competition Policy Roundtable Background Note, <https://www.oecd.org/competition/the-relationship-between-competition-and-innovation.htm>
- OECD. (2015). The Innovation Imperative Contributing to Productivity, Growth and Well-Being. OECD Publishing. https://read.oecd-ilibrary.org/science-and-technology/the-innovation-imperative_9789264239814-en#page4
- Ozberk, T. (2021, October 28). Unmanned tech dominates Turkey's border security summit. Defense News. <https://www.defensenews.com/unmanned/2021/10/28/unmanned-tech-dominates-turkeys-border-security-summit/>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & McGuinness, L. A. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews*, 10(1). <https://doi.org/10.1186/s13643-021-01626-4>
- Paying the Price of War, OECD Economic Outlook, Interim Report. (2022, September 26). OECD. <https://www.oecd.org/economic-outlook/september-2022/>
- Poley, L., McDermid, G., (2020). A systematic review of the factors influencing the estimation of vegetation aboveground biomass using unmanned aerial systems. *Remote Sensing* 12
- Pulsiri, N., Vatananan-Thesenvitz, R., (2021). Drones in Emergency Medical Services: A Systematic Literature Review with Bibliometric Analysis. *International Journal of Innovation and Technology Management*, 18(04).
- Reducing the impact of environmental disasters: AI-based assistant for frontline emergency management. (2022, November 25). CORDIS | European Commission. <https://cordis.europa.eu/project/id/101010486>
- Remotely Operated CBRNe Scene Assessment Forensic Examination. (2023, September 1). CORDIS | European Commission. <https://cordis.europa.eu/project/id/700264>
- Research. (n.d.). The Finnish UAV Ecosystem (FUAVE). <https://www.fuave.fi/research/>
- Revilla, A. J., & Fernández, Z. (2012). The relation between firm size and R&D productivity in different technological regimes. *Technovation*, 32(11), 609–623. <https://doi.org/10.1016/j.technovation.2012.06.004>
- RPAS : The Global Perspective (17th, Vol. 1). (2022). Blyenborough & Co.
- Sandino, J., Pegg, G., Gonzalez, F., & Smith, G. (2018). Aerial Mapping of Forests Affected by Pathogens Using UAVs, Hyperspectral Sensors, and Artificial Intelligence. *Sensors*, 18(4), 944. <https://doi.org/10.3390/s18040944>
- Sarasvathy, S. D., & Venkataraman, S. (2011). Entrepreneurship as Method: Open Questions for an Entrepreneurial Future. *Entrepreneurship Theory and Practice*, 35(1), 113–135. <https://doi.org/10.1111/j.1540-6520.2010.00425.x>
- Schäffer, B., Pieren, R., Heutschi, K., Wunderli, J. M., & Becker, S. (2021). Drone Noise Emission Characteristics and Noise Effects on Humans—A Systematic Review. *International Journal of Environmental Research and Public Health*, 18(11), 5940. <https://doi.org/10.3390/ijerph18115940>
- Schumpeter, J. (1942). *Capitalism, Socialism, And Democracy*. Harper & Brothers.
- Search and Rescue: Emerging technologies for the Early location of Entrapped victims under Collapsed Structures and Advanced Wearables for risk assessment and First Responders Safety in SAR operations. (2022, December 16). CORDIS | European Commission. <https://cordis.europa.eu/project/id/882897>

- Seletar Aerospace Park to Support Advanced Air Mobility Growth. (2022, February 15). EDP Singapore. <https://www.edb.gov.sg/en/about-edb/media-releases-publications/seletar-aerospace-park-to-support-advanced-air-mobility-growth.html>
- Semi-autonomous border surveillance platform combining next generation unmanned aerial vehicles with ultra-high-resolution multi-sensor surveillance payload. (2023, March 10). CORDIS | European Commission. <https://cordis.europa.eu/project/id/883272>
- Shapiro, C., (2012). "Competition and innovation. Did Arrow Hit the Bull's eye? In the Rate and Direction of Inventive Activity Revisited" *University of Chicago Press*
- Shermon, A., & Moeen, M. (2022). Zooming In or Zooming Out: Entrants' Product Portfolios in the Nascent Drone Industry. *Strategic Management Journal*, 43(11), 2217–2252. <https://doi.org/10.1002/smj.3407>
- Shi, X., Liang, X., & Luo, Y. (2023). Unpacking the intellectual structure of ecosystem research in innovation studies. *Research Policy*, 52(6), 104783–104783. <https://doi.org/10.1016/j.respol.2023.104783>
- Silver, B., Mazur, M., Wisniewski, A., & Babicz, A. (2017). Communications Review / Insights for telecom, cable, satellite, and Internet executives. <https://www.pwc.com/gx/en/communications/pdf/communications-review-july-2017.pdf>
- Solving the greatest problem of surveillance: To see without being seen. (2022, August 15). CORDIS | European Commission. <https://cordis.europa.eu/project/id/867637>
- SURVEIRON: Advanced surveillance system for the protection of urban soft targets and urban critical infrastructures. (2022, August 9). CORDIS | European Commission. <https://cordis.europa.eu/project/id/711264>
- Sustainable use of pesticides. (n.d.). Food.ec.europa.eu. https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides_en
- Takekawa, J. Y., Hagani, J. S., Edmunds, T. J., Collins, J. M., Chappell, S. C., & Reynolds, W. H. (2023). *The Sky is Not the Limit: Use of a Spray Drone for the Precise Application of Herbicide and Control of an Invasive Plant in Managed Wetlands*. *Remote Sensing*, 15(15), 3845.
- Tan, T. (2020, May 22). Airborne Drones for a Crime-free Zone. Ministry of Home Affairs . <https://www.mha.gov.sg/home-team-news/story/detail/airborne-drones-for-a-crime-free-zone/>
- Technology | Reuters Events | Supply Chain & Logistics Business Intelligence. (n.d.). Reuters Events. <https://www.reutersevents.com/supplychain/technology>
- The First Responder (FR) of the Future: a Next Generation Integrated Toolkit (NGIT) for Collaborative Response, increasing protection and augmenting operational capacity. (2022, December 28). CORDIS | European Commission. <https://cordis.europa.eu/project/id/833435>
- The Game Changer Free-wing VTOL Drone for Commercial and Governmental Missions. (2023, May 4). CORDIS | European Commission. <https://cordis.europa.eu/project/id/816552>
- Thorp, H., & Goldstein, B. (2013). *Engines of Innovation / The Entrepreneurial University in the Twenty-First Century* (2nd ed.). UNC Press Books.
- Tools for early and Effective Reconnaissance in cbRne Incidents providing First responders Faster Information and enabling better management of the Control zone. (2023, March 10). CORDIS | European Commission. <https://cordis.europa.eu/project/id/786729>
- UAV ENGINEER FOR OPTIMISATION OF FIREFIGHTING DRONE STABILISATION. (2022, September 15). CORDIS | European Commission. <https://cordis.europa.eu/project/id/101000154>
- Unmanned Aerial Vehicle for protecting soft/critical urban infrastructures, and the general public in extreme environments. (2022, August 11). CORDIS | European Commission. <https://cordis.europa.eu/project/id/717915>
- UNODC explains the combined use of Unmanned Aerial Vehicles and Ground Surveillance Systems. (n.d.). United Nations Office on Drugs and Crime. <https://www.unodc.org/centralasia/en/news/unodc-explains-the-combined-use-of-unmanned-aerial-vehicles-and-ground-surveillance-systems.html>
- UNODC provides a technological edge to address drug trafficking on the Mekong River. (n.d.). United Nations Office on Drugs and Crime. <https://www.unodc.org/roseap/2021/09/drug-trafficking-mekong-river/story.html>
- Wallis, E. (2023, May 12). French police deploy drones at Italian border to track migrants. InfoMigrants. <https://www.infomigrants.net/en/post/48890/french-police-deploy-drones-at-italian-border-to-track-migrants>

- Yaprak, U., Kilic, F., Okumus, A., (2021). Ist he COVID-19 pandemic strong enough to change the online order delivery methods? Changes in the relationship between attitude and behaviour towards order delivery by drone. Technological forecasting and Social change, 169.
- Zailani, M. A. H., Sabudin, R. Z. A. R., Rahman, R. A., Saiboon, I. M., Ismail, A., & Mahdy, Z. A. (2020). Drone for medical products transportation in maternal healthcare: A systematic review and framework for future research. Medicine, 99(36), e21967. <https://doi.org/10.1097/md.00000000000021967>
- Zhang, P., Zhang, W., Sun, H., Fu, H., & Liu, J. (2021). EFFECT OF THE DOWNWASH FLOW FIELD OF A SINGLE-ROTOR UAV ON DROPLET VELOCITY IN SUGARCANE PLANT PROTECTION. Engenharia Agrícola, 41(2), 235–244. <https://doi.org/10.1590/1809-4430-eng.agric.v41n2p235-244/2021>

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