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# Research and Innovation on Drones in Europe

*An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)*

Stepniak, M., Cheimariotis, I., Lodi, C., Rataj, M.,
Zawieska, J., Grosso, M., Marotta, A.

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**Contact information**
Name: Alessandro Marotta
Address: European Commission, Joint Research Centre, Vie E. Fermi 2749, I-21027, Ispra (VA) — Italy
Email: alessandro.marotta@ec.europa.eu
Tel.: +39 0332 78 9463

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## Contents

## Abstract

The European Commission's Drone Strategy 2.0 aims to create the right environment for a vibrant and competitive European drone economy. This report provides a review of recent trends, challenges, and achievements of European research and innovation projects. It identifies relevant projects that focus on public transport using the Transport Research and Innovation Monitoring and Information System (TRIMIS) database. It assesses the contributions of identified projects to the progress in drone technologies, their research on environmental and socio-economic impacts, and their alignment with European policy aims. The report's conclusions highlight future research directions.

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***Authors***

Marcin Stępniak, European Commission, Joint Research Centre, Ispra, Italy

Ilias Cheimariotis, European Commission, Joint Research Centre, Ispra, Italy

Chiara Lodi, Piksel srl, Milan, Italy

Michał Rataj, European Commission, Joint Research Centre, Ispra, Italy

Jakub Zawieska, European Commission, Joint Research Centre, Ispra, Italy

Monica Grosso, European Commission, Joint Research Centre, Ispra, Italy

Alessandro Marotta, European Commission, Joint Research Centre, Ispra, Italy

## Executive summary

The report presents an analysis of the research and innovation activities on drones in Europe. It assesses the scope and main achievements of European Union projects. The study uses the Transport Research and Innovation Monitoring and Information System (TRIMIS) database to identify relevant projects. The report provides a review of recent trends, challenges and achievements of European research and innovation initiatives on drones. This includes their main technological advances, progress in research on environmental and socio-economic impacts of drones, and the alignment of project scopes with the European policy agenda.

### *Policy context*

In 2022 the European Commission published the Drone Strategy 2.0. The strategy aims towards creating the right environment for a vibrant and competitive European drone economy. Achieving this requires the safe and sustainable integration of drones in European airspace, emphasizing transport safety, security, sustainability, and innovation. The Drone Strategy also focuses on societal acceptance, regulatory progress, and the development of environmentally friendly drone technologies to support EU sustainability and climate goals. The strategy aims to establish clear and effective regulatory frameworks to support safe and efficient drone operation, driving positive societal and economic outcomes. The document reflects the growing importance of research and innovation in drone technologies, aligning with the EU's broader policy framework for sustainable and smart mobility. Moreover, the development of the drone sector in Europe has been guided by key policy documents, including the European Commission's Sustainable and Smart Mobility Strategy and the Aviation Strategy for Europe, addressing safety rules, research and innovation strategies, and civil, security, and defence industry capabilities.

### *Key conclusions*

A comprehensive analysis was conducted for all identified projects, concentrating on technological aspects, socio-economic and environmental impacts of drones as well as the support of research and innovation activities to the European drone-related policies. Key conclusions are:

- Within the domain of **aircraft and their subsystems**, considerable progress has been noted in technologies towards the holistic design of drones, as well as in propulsion systems, enhancing energy efficiency, extending range, and increasing payload capacity.
- **U-space** development initiatives have tackled crucial challenges including traffic management in the urban airspace, increased flight operation density, trajectory optimization, and the necessity for legal regulations.
- In the area of **infrastructure for drones**, main achievements have been related to improvement of power supply, charging infrastructure, and landing systems. There are few projects on physical infrastructure, fact which can be attributed to the need for prior development of vehicles and U-space capabilities.
- About half of the reviewed projects explored **environmental** or **socio-economic impacts of** drones or focused on regulation and standardisation topics. Safety is the most frequently studied topic, followed by regulations, security and privacy issues, noise pollution and energy and emissions.
- In general, over 72% of the research and innovation projects analysed for this report, have their scope **aligned with the policy aims**, contributing to several flagship actions as listed in the Drone Strategy 2.0. Projects primarily focused on safety rules and requirements for airspace and aircraft, research and innovation strategies, and civil, security, and defence industry capabilities and synergies.

### *Main findings*

Using the TRIMIS database we identified 152 European projects which concentrate on drone research and innovation. It is noteworthy that there is a high diversity of funding sources for these projects. While most of them (118) are funded within Framework Programmes (primarily from Horizon 2020, with a few from Horizon Europe and one from FP7), the remaining projects are funded by ten different programmes, including the Connecting Europe Facility, Interreg, European Defence Fund, or the European Investment Bank. The total EU contribution for these projects varies from 50 000 EUR to over 50 million EUR. Thirty-two projects have been supported through funding programs for small and medium enterprises. Organizations from Spain, Germany, France, Italy and Belgium are among the most active participants in European drone research and innovation activities. Moreover, Spanish organizations led 20% of all analysed projects (31).

Main achievements in **technologies for drones:**

1. **Vehicles and their subsystems:**
    - improvement in energy and propulsion systems by reducing energy consumption, improving aerodynamics, to extend the flight range;
    - enhancement of drone resilience in challenging environmental conditions, such as strong wind, high temperatures, or fire;
    - increase in drone safety, with advancements in sensor systems, communication with other drones and the infrastructure, collision avoidance systems, autonomous navigation, and emergency parachutes and propulsion systems.
2. **Infrastructure for drones**:
    - systems for precise landing in challenging weather conditions;
    - adaptation of digital telecommunications infrastructure to improve and secure communication, navigation, and surveillance for future air traffic management;
    - application of GNSS and EGNOS services for navigation and positioning of drones in urban air mobility setting.
3. **U-space:**
    - development of concepts of operations for drones, particularly in urban air mobility and U-space/air traffic management integration;
    - incorporation of remotely piloted aircraft into air traffic control procedures;
    - progress in traffic management systems (definitions of minimum separation distances, collision avoidance methods, air traffic management automation).

Main research directions on **environmental and socio-economic impacts of drones**, arranged from the most to the least common research directions**:**

1. **Safety:**
    - collision avoidance systems;
    - air traffic management;
    - navigation, communication and interaction;
    - human-machine interface design;
    - best practices.
2. **Regulation and standardisation:**
    - new regulations and standardisation;
    - review of regulations and standards.
3. **Security and privacy:**
    - cybersecurity;
    - privacy;
    - counter-drone systems.
4. **Noise pollution:**
    - aircraft noise certification;
    - propulsion systems for noise reduction;
    - noise measurement;
    - perception of noise from drones.
5. **Emissions and energy use:**
    - energy efficiency and emission reduction;
    - emission modelling.
6. **Visual pollution:**
    - visual pollution maps;
    - visual influence factors;
    - visual perception.
7. **Land use:**
    - traffic structure impact on airspace capacity;
    - land use for U-space and urban air mobility activities.

***Related and future JRC work***

In the recent years JRC has conducted several studies related to drones, analysing their progress and role from various angles, including technological perspective (Carrara, 2023), risk assessment (Hansen and Pinto Faria, 2023 and Karlos and Larcher, 2023), review of regulations and standardisation (Baldini and Cano-Pons 2016), the role of drones in civil society (Boucher, 2014) or an estimation of last mile delivery market potential (Aurambout et al. 2019).

Moreover, since 2017 TRIMIS reports cover a wide range of the transport-related analyses on research and innovation initiatives in Europe. The recent TRIMIS reports concentrated on specific, transport-related topics: public transport, urban mobility and logistics and transport safety and resilience. The forthcoming TRIMIS reports will focus on heavy duty vehicles, waterborne transport and on new and emerging transport technologies.

***Quick guide***

Section 1 provides the context of the report, highlighting the increasing role of drones in modern transport systems and introducing the policy background. Section 2 lists all definitions used throughout the report, presents the policy background, a literature review on technologies for drones, and the socio-economic and environmental impact of drones. Additionally, it includes an extract from previous, related JRC studies. Section 3 describes the detailed methodology and the project selection procedure. Section 4 provides an in-depth assessment of the relevant research and innovation projects, focusing on progress in drone technologies. Section 5 concentrates on the outputs of projects that concern the impact of drones on society and the environment. The following section describes how and to what extent the analysed projects support the EU policy agenda. The final section concludes and identifies the remaining research topics.

# 1 Introduction

The rapid growth of research and innovation (R&I) in drone technologies has brought about significant changes in the transport landscape, shaping the future of aerial mobility and logistics. As a result, the European Commission (EC) has recognized the need to address the potential of drones and develop a comprehensive strategy to ensure their safe and sustainable integration into European airspace - the European Drone Strategy 2.0 (EC, 2022a).

The Drone Strategy 2.0 aims to achieve several objectives related to transport safety, security and sustainability, increase of innovation and competitiveness of European Union (EU) transport sector. It also aims to address social acceptability and progress in the regulatory framework. The strategy focuses on safe and secure integration of drones into European airspace, with a strong emphasis on minimizing operational risks and addressing concerns related to privacy and security. Additionally, it aims to foster research and innovation in drone technologies to maintain Europe's competitive edge in the global drone industry, driving economic growth, job creation, and technological leadership. The strategy promotes collaboration between industry, academia, and government to achieve these goals, while also fostering the development and implementation of environmentally friendly drone technologies, aligning with the EU's sustainability and climate goals. It also aims to encourage the social acceptability of drone technology by addressing public concerns, ensuring responsible and ethical use, and gaining public trust in the benefits of drone applications. Finally, the strategy focuses on establishing clear and effective regulatory frameworks that support the safe, secure, and efficient operation of drones, while enabling innovation and growth in the industry. Overall, the EU's Drone Strategy 2.0 aims to leverage the potential of drone technologies to drive positive societal and economic outcomes while addressing the associated challenges and risks.

The increasing use of drones and the potential benefits they offer make it essential to understand the current state of research and innovation in this field. Drones have the potential to revolutionize various industries, from agriculture to healthcare, with their ability to enhance efficiency and productivity. However, their widespread deployment may also lead to societal hesitation and anxiety, particularly regarding, for example, privacy concerns and the potential for misuse. Thus, understanding the current state of research and innovation in drone technology is crucial not only for their successful integration into various sectors but also for addressing issues related to social acceptance and regulatory frameworks. In response, the ambition of this report is to provide a comprehensive overview of European R&I projects related to drones, with a focus on their achievements. By examining the latest developments in drone technology and their applications, this report aims to contribute to informed policy decisions and support the implementation of the Drone Strategy 2.0.

The report primarily focuses on the advancement of drones as vehicles, the development of infrastructure for drones, and their operational aspects, including air traffic management and related operations. This includes projects related to propulsion, energy, navigation, and other aspects that contribute to the technological progress of drones. Additionally, the report includes the use of drones for transport of people or freight and the management of transport infrastructure, provided that the project's focus aligns with the explicit scope of drones. However, projects primarily involving the use of drones for carrying measurement equipment or surveillance purposes, except for traffic or mobility tracking and transport infrastructure maintenance, are considered out of scope for this report.

The aim of the report is to provide a comprehensive overview of the research and innovation landscape related to drones in the European Union. The report encompasses the identification and review of various projects and initiatives focused on the development and integration of drone technologies, infrastructure, and operational capabilities. Additionally, it seeks to offer a state-of-the-art review of current trends and challenges in the drone research and innovation, with a specific focus on technological advancements in drone aircraft, infrastructure, and operations. To offer a broader context to a reader, the review of projects' achievements is preceded by a literature review of recent achievements, essential definitions, and ongoing challenges concerning the environmental and socio-economic impact of drones. It also compares the achievements of European projects with this review, providing a comprehensive assessment of how these projects align with the current state of research and development in the field.

The report also aims to assess the contribution of research and innovation activities to progress towards EU policy aims, particularly the objectives outlined in the Drone Strategy 2.0. Finally, the report provides a comprehensive review of the achievements of research and innovation projects. This includes technological advancements, the results of projects related to the assessment of environmental and socio-economic impacts of drones, and progress towards contributing to EU policies. In conclusion, the report offers a summary of identified remaining research gaps and barriers for the development and implementation of drone technologies, providing valuable insights for future research and innovation activities and policy development in this field.

The report is based on the Transport Research and Innovation Monitoring and Information System (TRIMIS) database of R&I projects. TRIMIS is a comprehensive platform that provides detailed information on research and innovation activities in the field of transport across Europe. It offers detailed data on projects, initiatives, and technological developments, serving as a valuable resource for analysing the research and innovation transport landscape. Additionally, as part of the report's scope, the TRIMIS database was updated, and new projects were added through extensive efforts to identify other R&I projects beyond the database. This enriches the database and ensures a comprehensive review of the European research and innovation landscape in the field of drones.

The structure of the report reflects its aims. The following section provides a broad overview of the European drone research and innovation landscape. It includes key definitions used in the document and the policy background, including the evolution of EU drone policies and the significance of the Drone Strategy 2.0. These are followed by a literature review on technologies used for drones, and an overview of the current state-of-the-art on the environmental and socio-economic impact of drones. The chapter concludes with a summary of recent Joint Research Centre (JRC) works on drones. The third section of the report defines applied methods, describes data collection procedures, and presents an overview of identified R&I projects and the main actors involved in research and innovation activities.

The three following chapters of the report (chapters 4-6) are based on the review of scopes and deliverables of identified projects. Chapter 4 presents an overview of progress in technologies for drones, divided into three main subareas: technologies for aircraft, infrastructure, and operations, including air traffic management. The subsequent chapter includes a review of projects focused on their achievements towards better understanding of the environmental and socio-economic impacts of drones. It also summarises works on standardisation and regulations related to drone operations. Finally, Chapter 6 shows the role of research and innovation activities in supporting and contributing to EU policy initiatives, particularly the objectives outlined in the Drone Strategy 2.0. The final section concludes by providing a synthetic summary of the main findings. Moreover, it discusses remaining research gaps and open policy questions that should be addressed in future research.

# 2 Definitions, background and key challenges

## 2.1 Definitions

The following definitions are used in the presented report:

- **Drones** – following the Drone Strategy 2.0 (EC, 2022a), this is the term to describe **unmanned aircraft systems (UAS)**, meaning an **unmanned aircraft (UA)**[1] and the equipment to control it remotely. Unmanned aircraft encompasses a wide range of vehicles, in terms of size, reach, and application domain. It is an aircraft without a human pilot on board that is remotely or autonomously controlled.
- **Innovative Air Mobility** (**IAM**)[2] refers to operations with novel aviation systems. Innovative Air Mobility covers a wide range of novel aircraft technologies and concepts, which include electric vertical take-off and landing (eVTOL) capability, specific propulsion features such as distributed propulsion or tilt-rotor, and can be either manned or unmanned, autonomously or remotely controlled. **Urban Air Mobility (UAM)** is a part of Innovative Air Mobility[3], aiming to enable on-demand mobility, reduce congestion and expand transport options in congested urban areas.
- **Unmanned Aircraft System Traffic Management** (**UTM**) is a set of services designed for the automated management of the airspace, ensuring the safe and secure unmanned aircraft flights in both controlled and uncontrolled airspace. Controlled airspace refers to the airspace that is under the authority of air traffic control (Hamissi and Dhraief, 2023).
- While "Unmanned Aircraft System Traffic Management" refers to the operational concept under research, **U-space** airspace management is the European framework aimed at its practical implementation. This includes the development of the regulatory framework and an execution roadmap with clearly defined steps and milestones. U-space encompasses the digital infrastructure, services and automation of functions designed to support safe, secure and efficient access to urban airspace and safe integration with other air traffic, for a large number of unmanned aircraft systems (EC, 2021a). The Single European Sky Air Traffic Management Research (SESAR) partnership identifies four phases of development of the U-space services: **U1 - foundation** (e-registration, e-identification and pre-tactical geofencing), **U2 - initial** (tactical geofencing, flight planning management, weather information, tracking, monitoring, drone aeronautical information management, procedural interface with air traffic control, emergency management and strategic deconfliction), **U3 - advanced** (dynamic geofencing, collaborative interface with air traffic control, tactical deconfliction and dynamic capacity management) and **U4 - full services** (which are yet to be defined).
- **Vertical take-off and landing** (**VTOL**) aircraft – refers to an aircraft capable to take off and land vertically, without requiring a runway, however after vertical ascent they can also transition to horizontal flight. European Union Aviation Safety Association (EASA) adds that unlike helicopters, VTOL aircrafts are using more than two propulsion units, referred to as distributed propulsion[4]. Electric VTOL aircraft uses electric power to hover, take off, and land vertically.

(1) The terms "Unmanned Aircraft" and "Unmanned Aircraft System" are also referred to in literature as "Unmanned Aerial Vehicle" (UAV) and "Unmanned Aerial System" (UAS), respectively. The report will use the former terms, as per the Drone Strategy and Commission Implementing Regulation (EU) 2019/947, except when a reference contains the latter in its title.

(2) The term "Innovative Air Mobility" is also referred to in literature as "Advanced Air Mobility" (AAM). The report will use the former term, as per the Drone Strategy and Commission Implementing Regulation (EU) 2019/947, except when a reference contains the latter in its title.

(3) Regional and international are equally subcategories of Innovative Air Mobility not covered in this report. It seems like there is a word missing in the sentence, it might be better to rephrase the sentence to make it clearer. "Regional and international are both subcategories of Innovative Air Mobility that are not covered in this report.

(4) https://www.easa.europa.eu/en/light/topics/vertical-take-and-landing-vtol (accessed 17.11.2023)

## 2.2 Policy background

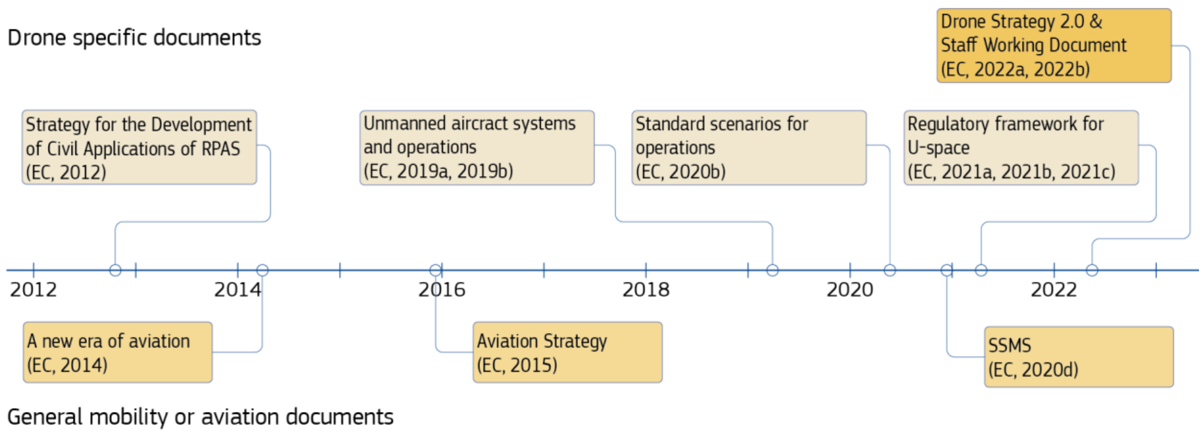
### 2.2.1 Towards Drone Strategy 2.0: an evolution of EU drone policies

The policy guidelines for the development of the drone sector in Europe are derived from general transport and mobility documents, as well as specific regulations pertaining to drones (Figure 1). The first European Commission's document relevant for drones is the Staff Working Document on "Towards a European Strategy for the Development of Civil Applications of Remotely Piloted Aircraft Systems" (EC, 2012) published in 2012 which reviewed potential benefits and challenges of drones and their potential integration into European airspace. It was followed by the Commission's Communication "A new era for aviation" (EC, 2014) which set up the foundations of the EU policy in the field of drones.

An Aviation Strategy for Europe aimed to create a comprehensive framework to support the development of the European aviation sector (EC, 2015). It proposed to create a basic legal framework for the safe development of drone operations. In addition, the Commission adopted in 2019 a series of rules regulating operations with drones (EC, 2019b; EC, 2019a) and adopted in 2021 three Implementing Regulations on U-space, which provide the air traffic management system for drones (EC, 2021a; EC, 2021b; EC, 2021c). In addition, the Commission also supported the development of standard scenarios to reduce the administrative burden related to the operational authorisation process (EC, 2020b).

In the Commission's Sustainable and Smart Mobility Strategy (EC, 2020d), a document that outlines an ambitious roadmap to ensure a sustainable, smart, and resilient future for European transport, the Commission announced its plans to develop a Drone Strategy 2.0 for a smart and sustainable unmanned aircraft ecosystem in Europe. The strategy set out possible ways to guide the further development of this technology and its regulatory and commercial environment (EC, 2022a). The document is accompanied by a Staff Working Document (EC, 2022b) which provides an overview of the Commission services' assessment of the challenges that the drone sector faces as well as the analysis and data underpinning the Drone Strategy.

**Figure 1.** Timeline for drone-related EC documents

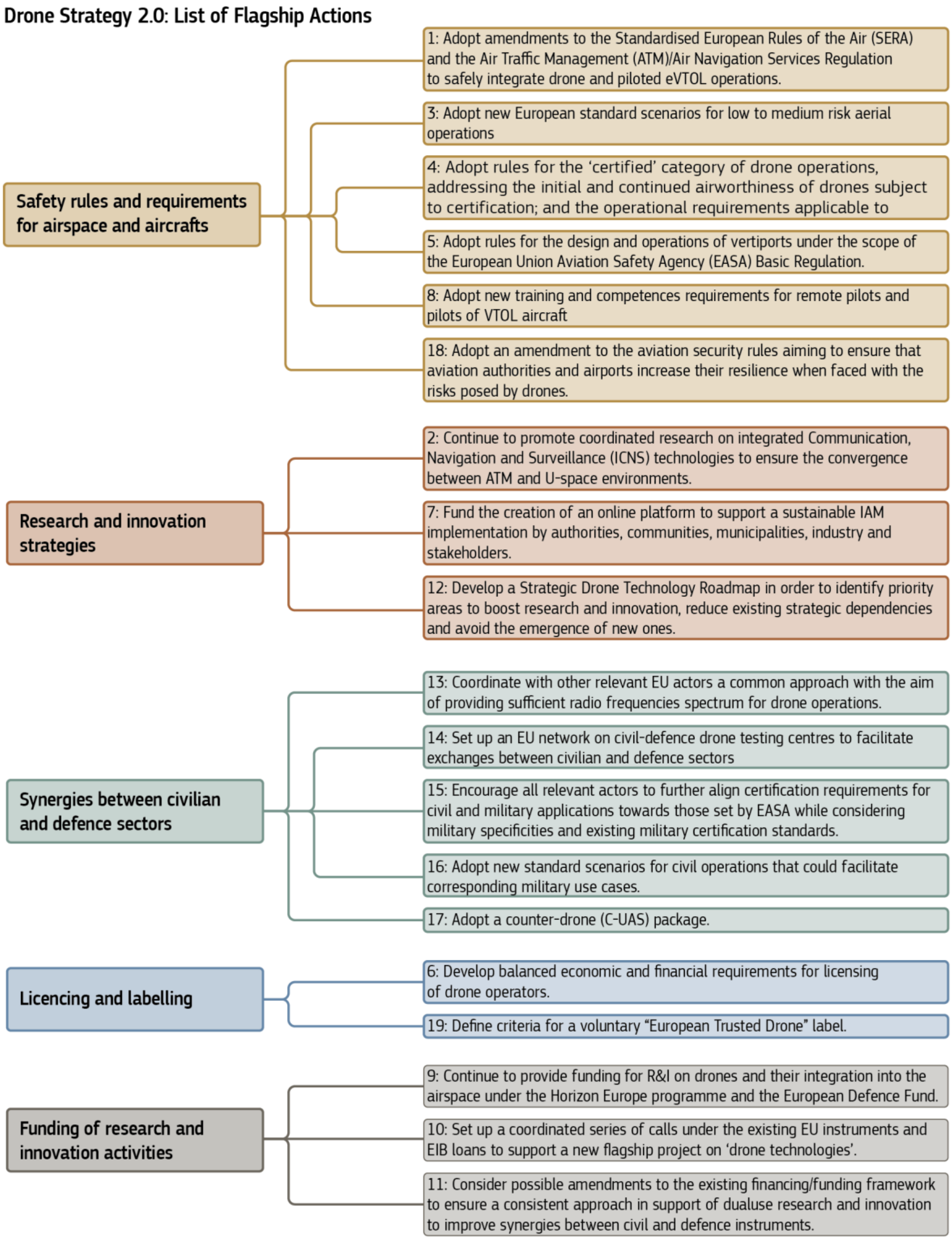



*Source: TRIMIS, JRC, 2024*

### 2.2.2 Drone Strategy 2.0: European Policy Actions on Drones research and innovation

The summary of flagship actions outlined in Drone Strategy 2.0 is organised into four distinct policy areas. The alignment of flagship actions with these areas is presented in Figure 2. Some Flagship Actions from the Strategy are not a subject of research and innovation activities, but instead, they focus on organisation of funding of R&I projects (Flagship Action 9), organisation of respective calls for projects and actions (Flagship Action 10) or amendments of financing / funding frameworks (Flagship Action 11). Furthermore, flagship actions concerning licensing and labelling (Flagship Actions 6 and 19) are not within the scope of research and innovation activities. Flagship Action 19 specifically focuses on the establishment of licensing drone operator systems and drone labelling with an emphasis on enhancing safety and cybersecurity. While the revision of the Commission's regulations aims to facilitate fair market access through standardized requirements, these actions are not aligned with the objectives of R&I projects. Therefore, they are excluded them from the description below.

**Figure 2.** Alignment of flagship actions with broader policy areas




*Source: TRIMIS, JRC, 2024*

### ***Safety rules and requirements for airspace and aircrafts***

Policy initiatives are centred around the development of U-space and its integration with Air Traffic Management (ATM), as well as the advancement of Innovative Air Mobility (IAM). This **involves revising existing aviation safety rules and certifications**, as well as creating new ones specifically tailored to the needs of **Urban Air Mobility**. The aim is to ensure safe and unrestricted airspace operation, promote collaboration between aviation and cellular communities, and establish standards for altitude, separation, and safe operating distances (i.e. common altitude reference system; CARS). Standardisation and interoperability of the enabling technological building blocks are identified in the Drone Strategy 2.0 as key enablers for faster product development (EC, 2022a). Additionally, research and innovation efforts should focus on facilitating the development of use cases for drone operations, including cross-border operations. Finally, **partnerships between research, universities, and industry in education** should be promoted, as they can fulfil the need for a highly educated, qualified, and experienced workforce both on the ground and in the air.

### ***Research and innovation strategies***

According to the Drone Strategy 2.0, research and innovation strategies should focus on works on assessment of environmental impacts, societal acceptance of drones and identification of key technology building blocks that are vital for the innovative and competitive drone ecosystem. The environmental impact assessment should address a range of factors, such as noise mitigation, impact on wildlife (especially in urban areas), and the potential generation of visual disturbance. The EU research should also look to Integrated Communication, Navigation and Surveillance (ICNS) as the mechanism by which all airspace users can interoperate safely, while reducing costs and environmental impact through rationalisation and multiuse of existing and developmental technologies. Additionally, research and innovation initiatives should concentrate on key underlying technology enablers such as Artificial Intelligence (AI), robotics, semiconductors, batteries, EU space services and mobile telecommunications with the aim of reducing the EU dependency on external suppliers. Furthermore, it is essential for research and innovation initiatives to establish clear pricing and data sharing rules necessary for the development of the U-space market.

### ***Civil, security and defence industry capabilities and synergies***

An improvement of the availability, connectivity, and geographic distribution of test sites is crucial for further development of drone industry in the EU. Research and innovation efforts should facilitate a transition from concept to deployment and to showcase prototypes' potential for various business cases. Standardisation, particularly in Information and Communication Technology (ICT), should be supported by research and innovation. It should focus on developing 'hybrid standards' applicable to civil, security, and defence drone technologies. Furthermore, research and innovation initiatives should concentrate on countering unauthorized drone usage by developing cyber-resilient drones equipped with secure communication links, identification systems, or utilizing open-source code.

## 2.2.3 Role of EU partnerships in drone innovation

### ***Climate, energy and mobility partnerships***

The Clean Aviation Joint Undertaking is a public-private partnership between the European Union (represented by the European Commission) and the European aviation sector. Its objective is to foster the decarbonisation and competitively of European aviation via research and innovation programmes and projects on propulsion, power systems, aircraft design and manufacturing, as well as an aviation impact assessment.

Clean Aviation and former Clean Sky projects do not address directly drones or urban air mobility, but rather focus on regional and long-range flight. Nevertheless, the aircraft developed for short-range and regional aviation are of interest since there is provision in the Clean Aviation Strategic Research and Innovation Agenda (SRIA) for technology transfer towards commuter and vertical lift applications (Clean Aviation, 2021).

The partnership aims to the complete evaluation of the feasibility of these solutions, by prototyping and testing up to full-scale demonstrator aircraft. The technologies that Clean Aviation projects develop that can be transferred to urban air mobility include a tiltrotor aircraft configuration which can allow for vertical take-off and landing, a prerequisite for urban air mobility. They also include hybrid-electric and hydrogen fuel cell propulsion and energy systems.

The SESAR 3 JU[5] is a partnership between the EU, Eurocontrol, and organisations representing the aviation value chain, from airports, airspace users of all categories, air navigation service providers, drone operators and service providers, the manufacturing industry and scientific community. The SESAR Partnership has the objective of leveraging digitalisation to achieve efficient, safe, secure and resilient air traffic management for all airspace users. In this context it seeks to develop U-space for the traffic management of UAs as defined in section 2.1.

SESAR and the U-space account for the largest number of projects and funding amount, as the presence of U-space is a prerequisite for the presence of UA traffic and the deployment of urban air mobility under safety and efficiency, and therefore to unlock the potential of the drone economy.

The BATT4EU partnership strategic research and innovation agenda has provision to collaborate with mobility partnerships to develop application-specific battery integrations, however this has not yet materialised as a project for drones. Within the Framework Programme 7, the Clean Hydrogen has in implemented fuel cell solutions for powering small-scale UAs (project SUAV).

***Enabler technologies - Digital, industry and space partnerships***

Drones as cyber-physical technology objects depend on enabling technologies. The Key Digital Technologies, Artificial Intelligence, Data and Robotics, and Smart Networks partnerships, all identify drones in their strategic research agendas as an application domain for their innovation.

As part of their development objectives destined for drones, the AI, Data and Robotics SRIA (ADRA, The AI Data Robotics Association, 2020) identifies, among other applications, the knowledge and learning technologies, the reasoning and decision-making AI, as well as autonomous operation. The Key Digital Technologies - CHIPS partnership targets to develop control software, power electronics, actuators and diagnostics for small drones (Electronic Components and Systems technology platform, 2022).

The Smart Networks partnership strategic agenda discusses a pathway towards troposphere networking, as the network serving every device between the ground and ~20 km altitude. This covers control and communication services for the drone and urban air mobility applications. It lists several technology solutions to be explored, such as novel device to device (D2D), mesh, and cellular solutions. The agenda identifies troposphere networking as a challenge if supported only by terrestrial technologies." ("ANNEX II to the 2023 SNS Work Programme 2023 SNS R&I Work Programme for 2023-2024", p. 15).

***The European Institute of Innovation and Technology***

The European Institute of Innovation and Technology (EIT), through its accelerator programmes, supports early-stage start-ups towards raising investment and reaching their first customers and helps them scale their business.

In this context, the EIT Climate-KIC[6] has supported LILIUM, an aviation start-up that will produce an electric jet for urban air mobility. The EIT Climate-KIC's supported LILIUM through its Accelerator programme in 2014. The programme helped the company validate its business model and lay the groundwork for significant future investment. By 2017, the Accelerator helped them raise USD 90 million towards the commercialisation of its electric jet, that was flight tested in 2017[7], and raised further EUR 224 million in funding in 2020[8].

## 2.3 Technologies for drones: literature review

The current scientific literature has limited visibility into industrial research and development, as well as aspects of manufacturing, production capacity, and supply chains which are critical technological elements for the adoption of drones. The following literature review is based on comprehensive review papers to provide a global overview of current drone research and position reviewed projects' main achievements in a broader context. When available, it is supplemented with other resources, such as press articles and reports from authorities or consulting companies.

(5) 'SESAR Joint Undertaking', https://www.sesarju.eu/discover-sesar, accessed 14/03/2024

(6) 'EIT Climate-KIC Accelerator for EIT Regional Innovation Scheme countries', https://eit.europa.eu/news-events/news/eit-climate-kic-accelerator-eit-regional-innovation-scheme-countries, accessed 16/01/2024

(7) 'World first: EIT Climate-KIC supported LILIUM's zero emissions electric plane takes off', https://eit.europa.eu/news-events/news/world-first-eit-climate-kic-supported-liliums-zero-emissions-electric-plane-takes, accessed 16/01/2024

(8) 'EIT Climate-KIC supported LILIUM raises over €224 million', https://eit.europa.eu/news-events/news/eit-climate-kic-supported-lilium-raises-over-eu224-million, accessed 16/01/2024

Following definitions presented in the section 2.1, the literature review is organized in three main sections:

- **Unmanned Aircraft Systems.** There are mature technologies, both in the military/defence and civilian sectors. Technology research focuses on improving operational characteristics and minimising impacts, leveraging advancement in enabler domains such as AI, telecommunications, and sensors.
- **Innovative Air Mobility** and **Urban Air Mobility** for passengers (manned and unmanned). Manned passenger Innovative Air Mobility and Urban Air Mobility vehicles are currently undergoing intense industrial development (Bushey et al., 2023) due to their market potential. This section of the review covers vehicle and infrastructure requirements.
- **U-space and Unmanned Aircraft System Traffic Management**. A potential increase in drone traffic requires the establishment of an overall traffic planning and management system for drones to optimise routing and ensure safe conflict resolution. A significant amount of EU research and innovation efforts are dedicated to defining and progressively implementing U-space, following the roadmap set by the SESAR3 Partnership.

The review concludes with a paragraph on technology convergence and integration, where the previous elements are examined together as comprehensive systems that achieve the drone transport and mobility objectives.

### 2.3.1 Unmanned Aircraft Systems

UASs, or unmanned aircraft systems, are defined as pilotless aircraft equipped with advanced components for communication, propulsion, ground control stations, and sensors. They are classified based on parameters such as size, weight, power, and lift style. While they have a historical context rooted in military use, the development of drones saw significant advancements in miniaturisation and automation, opening to civilian applications in multiple domains. These UASs integrate off-the-shelf technologies, sensors and communication systems, to produce subscale flight systems, weighting less than 100 kg.

Pinpointing the technological state of the art of UASs is challenging, provided the wide variety of civilian drones and applications, as well as the confidential nature of military applications. Recent review papers provide an overview of the various types, categories, design, functionality, and research domains related to drones (Martinez and Cardona, 2018; Chen et al., 2016; Ahmed et al., 2022). F. Ahmed et al. (2022) report improvements in flight capability (maximum roll angle, turn angle, path length, and flexibility in manoeuvring) and deployment capacity of UA systems with high scalability, portability and mobility. Straubinger et al. (2020) also report progress in power electronics, communications, sensors and data analytics, combined with large cost reductions due to the availability of high performing commercial off-the-shelf components, which led to new opportunities for small unmanned aircraft.

Ahmed et al. (2022), Telli et al. (2023) and Kraus et al. (2020) performed comprehensive reviews on UAS research, consulting diverse sources including scientific literature, patents, web intelligence, and collaborative project outcomes. A summary of these review papers provides an opportunity to classify open research items in UAS research, with the main classes outlined in the following paragraphs.

**Technical capabilities and needs, operability and flight range**: several sources report that battery capacity and energy density, limited flight time, and limited payload carrying capability are major UA limitations requiring improvement (Chen et al., 2016; Telli et al., 2023; Johnson and Silva, 2022). The research investigates methods to extend the battery life of UAs and develop efficient power management strategies. It also explores the utilisation of alternative energy sources, such as hydrogen fuel cell propulsion or sustainable aviation fuels (Afonso et al., 2021).

**Navigation and flight controls, autonomous flight**: Chen et al. (2016) state that because UAs have 6 degrees of movement freedom and are moving at a high speed, manual remote control is challenging when working in geometrically complex environments. In such scenarios, developing autonomous navigation technologies is necessary to reach higher traffic volumes. Detect-and-avoid systems need further development to allow to fly drones in complex airspace with a higher level of traffic (Kraus et al., 2020). Telli et al. (2023) emphasize the potential of integrating machine learning and artificial intelligence (AI) into UA systems to enhance perception, functionality, and decision-making capabilities. They also discuss the challenges associated with swarm operations and drone collaboration, including decision making, control, path planning, communication, monitoring, tracking, targeting, collision avoidance, and obstacle avoidance (Telli et al., 2023).

**Safety and reliability**: Kraus et al. (2020) highlight the importance of further developing the reliability of individual parts of UA, such as control system and propellers, as well as ensuring reliable communications between the control station and the drone. They also address the potential impact of electromagnetic fields on drone electronics. Furthermore, **cybersecurity** is identified as a critical research issue, which should focus on protecting UA systems from cyber-attacks or hijacking. This involves implementing robust encryption, authentication mechanisms, and effective countermeasures against cyberattacks.

The presented review shows that there are several open challenges that need to be addressed to fully realize the potential of UASs in terms of payload capacity, flight time, functionality, and enhanced autonomous flight capabilities. This is particularly important in the context of achieving urban air mobility.

### 2.3.2 Innovative Air Mobility and Urban Air Mobility

An important driving force for the drone sector is the integration of drones into cities, both for logistics and delivery, as well as for urban air mobility (Hader et al., 2020). Urban air mobility is envisioned as a component of the broader innovative air mobility concept. The aim behind innovative air mobility is to develop an air transport system which uses new electric air vehicles for passengers and cargo shipments to serve regions that have been underserved by traditional aviation (Bauranov and Rakas, 2021). Uber has published a white paper outlining the operational requirements for successful passenger transport using urban air mobility vehicles, reflecting the growing interest in innovative air mobility (Uber Elevate, 2018). Companies worldwide are racing to create urban aircraft prototypes and partner with major aerospace suppliers to certify technologies for urban flying (Bauranov and Rakas, 2021). The AAM Reality Index and AAM Infrastructure Index (SMG Consulting, 2023) are tools designed to monitor industrial and ecosystem progress in achieving innovative air mobility.

Urban air mobility is already a reality today, as evidenced by the provision of charter-based passenger transportation services using helicopters in various cities. In addition to passenger transport, urban air mobility covers a wide range of operational concepts, including medical emergency missions, logistics, or surveillance. During the last decade, technological progress regarding distributed electric propulsion and battery storage have led to the development of many flying vehicle concepts and demonstrators for personal air transport typically designed for one to five passengers (Straubinger et al., 2020).

Scientific literature examines vehicle-related aspects, such as aircraft requirements (Straubinger et al., 2020) and design (Johnson and Silva, 2022; Afonso et al., 2021), and aircraft classification for intra- and inter-city passenger transport. Literature focuses on services enabled by novel aircraft types with the capability for vertical take-off and landing. Moreover, it discusses technical hurdles for successful introduction of VTOL capable aircrafts and operations (Filippone and Barakos, 2021). The literature also considers the Unmanned Aircraft System Traffic Management and the need for appropriate digital infrastructure (Straubinger et al., 2020). A significant part of the EU-funded collaborative research and innovation activities, further analysed in Section 4, target the progressive implementation of U-space, the UTM in urban airspace in Europe. Within this context, Capitán et al. (2021) present the proposed software architecture for UTM, towards providing the required services for automated decision-making during real-time threat management and conflict resolution. Firmly connected to the UTM is the notion of the urban airspace. Bauranov and Rakas (2021) examine the literature on the design and management of urban airspace, analysing proposed airspace concepts and providing recommendations for research. Finally, literature also examines urban air mobility ground-based infrastructure with a focus on the adequate location for intermodal integration and land use requirements, rather than technological aspects such as charging infrastructure and telecommunications (Mavraj et al., 2022).

***Aircraft requirements***

The literature identifies the following aircraft requirements for a successful deployment of urban air mobility:

- **VTOL capability**, which requires rotorcraft technological advances in noise, structures, propulsion, automation and control. Filippone and Barakos (2021) argue that significant technology gap exists between a commercial UA drone and a full-size vehicle that is capable to navigate over complex terrain with passengers on board.
- **Energy system**, with a high level of battery technology, in particular high energy per weight at the pack level, which is indispensable to enable manageable size of the aircraft for urban operations and enable sufficient operating range.
- **Safety and reliability**, which demand the implementation of new and rigorous requirements to ensure that multirotor configurations utilizing electric propulsion can adequately respond to failures.

Concept vehicles in simulation studies suggest that designing aircraft for low probability of failure and for low external noise will be possible, with the trade-off that they will require aircraft that are larger and heavier than conventional rotorcraft (Johnson and Silva, 2022). Furthermore, all-electric propulsion is possible, yet from a performance perspective, a hybrid-electric version would be preferable (Afonso et al., 2021). The studies also highlight the necessity for manufacturing methods, and engineering tools for VTOL aircraft design and analysis.

***Infrastructure***

As most transport systems, urban air mobility also requires adequate infrastructure. This infrastructure does not only encompass physical ground infrastructure for take-off and landing (vertiports), but also the digital infrastructure for navigation, traffic management and communication, including datacentres and telecommunications, and facilities for maintenance and energy supply (Straubinger et al., 2020; Mavraj et al., 2022; SMG Consulting, 2023).

There is little research on urban air mobility ground infrastructure with a focus on ground infrastructure location (Brunelli et al., 2023) within the urban landscape, and vertiport design and topology (arrangement of multiple landing pads) based on existing heliports as foundation. Research articles primarily deal with demand-based location of vertiports and resulting time-saving potentials. Further subjects for vertiport and vertiport network design, such as modelling of ground-based operations, routing and vehicle allocation and the design of network topologies, should be further investigated (Mavraj et al., 2022; Brunelli et al., 2023).

For providing telecommunications, cellular networks are feasible candidates due to ubiquitous availability and high capacity especially in urban areas. Further research is required for ensuring cybersecurity and considering the quality-of-service limitations of commercial networks (Straubinger et al., 2020).

### 2.3.3 U-space and Unmanned Aircraft System Traffic Management

Another major challenge for urban air transport (both urban air mobility and logistics) is that the current air traffic management system cannot properly manage urban airspace (Bauranov and Rakas, 2021; Straubinger et al., 2020). Several challenges hinder the integration of existing airspace and urban operations, including the increased number and density of operations at lower altitudes, as well as the varying performance capabilities of different operators and air vehicles. Urban air mobility requires full airspace integration and represents high-risk operation, especially as passenger operations are implied. Moreover, Bauranov and Rakas (2021) shows the need for appropriate digital infrastructure, and that while current Unmanned Aircraft System Traffic Management (UTM) concepts focus principally on safety, they neglect social factors, and rely on technologies that are still not available.

UTM is described as a distributed network of highly automated systems that exchange information via application programming interfaces, facilitating the management of Beyond Visual Line of Sight (BVLOS) operations. This contrasts with standard air traffic management and communication between pilots and air traffic controllers via voice (Straubinger et al., 2020), which limits the number of operations and overall system scalability (Capitán et al., 2021). Nevertheless, the automatized UTM should not restrict operations of traditional airspace users and meet appropriate safety requirements. There are initiatives to integrate UASs into civil airspace and fulfil their operational requirements. In Europe, the U-space framework sets a clear roadmap towards UTM implementation (Single European Sky ATM Research 3 Joint Undertaking, 2017). The European Union Aviation Safety Association has subsequently proposed an operational overview and regulatory outline of U-space (European Union Aviation Safety Agency, 2021), that paved the way for the EU regulation on U-space . (European Commission 2021a). For U-space, the concept contains as its core a U-space service provider platform, which is a server running on the cloud. There, the system consists of a software architecture that provides U-space services (such as pre-flight checks, geolocation, trajectory optimisation and navigation, information systems, and conflict and separation handling) to the different actors in the U-space ecosystem. The U-space Service Manager (USM), a specific module of the system, coordinates the operation of the services. Finally, U-space, as a collaborative effort among researchers, industry, and regulators, aims to facilitate the integration of UA operations in civil airspace. It provides UA situational awareness and enables digital communication between unmanned and manned aviation, ATM service providers, and legal authorities.

While U-space services are currently under development and experimental evaluation, such as through on desk Hardware-in-Loop simulations, the technology maturity remains low. As a result, the pathway towards real-world implementation is still long. Capitán et al. (2021) assessed the level of implementation of the four phases of U-space, as defined in 2.1. According to their assessment, the overall implementation level varies between 17 and 23% for the foundation services, 3 to 20% for initial services, 0 to 8% for advanced services and 0% for full ones (Capitán et al. 2021, table 1).

### 2.3.4 Technology integration

Future drones are envisioned as cyber-physical systems (CPS) that integrate sensing ability, on-board computing and connectivity to other drones, ground networks and infrastructure (Straubinger et al., 2020). Future airspace scenarios require a high level of convergence between ground and airborne technologies, data integration from on-board and ground sensors, using on- and off-board intelligence for safe navigation, robust telecommunications for operations and cooperative flight routing, as well as real-time database-representation of airspace information for ultimate situational awareness. Several technological challenges remain, including development of reliable and robust technologies for sense-and-avoid and flight control, contingency management procedures, cooperative route planning, weather consideration, high-precision localisation systems for low-level, automated flight as well as development of required infrastructure. Concerning the effort repartition, Straubinger et al. (2020) indicates that several companies currently focus on the development and prototyping of air vehicles to improve the maturity of urban air mobility technologies, while the research communities, in collaboration with regulatory bodies, are focusing on realising airspace integration.

## 2.4 Impact of drones on society and environment

Drone adoption in transport poses several non-technology-related challenges, primarily related to their impact on environment, society and economy along with regulatory issues. A study conducted by the European Union Aviation Safety Association on societal acceptance of urban air mobility (EASA, 2021) identified **noise** and **safety** as major barriers to societal acceptance, followed by concerns about **privacy, security or negative impact on environment**. Other concerns raised include affordability or potential job losses, however these topics have not been a direct focus of identified R&I projects on drones. Thus, they are not included in the presented review, even though social acceptance is recognized of being of key importance for drone implementation, as outlined in the Staff Working Document accompanying the Drone Strategy 2.0 (EC, 2022b).

***Noise pollution***

Noise pollution in drone transport refers to noise generated by the vehicles when they take-off and landing, as well as during the flight. The level of noise depends on the design of the vehicle and its vertical proximity to the ground infrastructure (Filippone and Barakos, 2021). Various noise sources can be found in a VTOL aircraft, including thermal engine, rotor, electric motor, gearbox and other rotating internal components (Afonso et al., 2021).

Noise pollution is considered a significant risk in urban air mobility (Eißfeldt, 2020; EASA, 2021; Afonso et al., 2021). Studies suggest that drone noise is often perceived as more bothersome than noise from road traffic or conventional aircraft due to its unique acoustic characteristics (Schäffer et al., 2021). Torija et al. (Torija et al., 2020) found that road traffic can mask drone noise, thereby reducing its impact on residents.

The European Commission has introduced regulations to address noise pollution in the context of drone operations. Specifically, for small drones weighing less than 4 kg that may be flown in close proximity to people, Regulation (EU) 2019/945 (EC, 2019a) sets limits that align with the current state of the market. These limits are expected to become even stricter in the future. Additionally, local authorities have the ability to implement further noise restrictions within specific UA geographical zones. Furthermore, the Environment Noise Directive (EC, 2002) requires urban areas with populations exceeding 100,000 people to develop action plans aimed at managing and minimizing noise from air operations, including those involving drones.

According to the Drone Strategy 2.0 (EC, 2022a), EASA should continue to develop appropriate **noise modelling methodologies** for drones and eVTOL aircrafts. These methodologies should be considered by the Commission for the upcoming amendment of Annex II of the Environment Noise Directive. In addition, EASA has recently developed Guidelines on noise measurement of unmanned aircraft systems lighter than 600 kg, operating in the specific category (EASA, 2023). There is also a need to examine **noise perception and annoyance** (Schäffer et al., 2021), **impact of noise from drones on local fauna** (EC, 2022b), apart from research on **cabin noise**, which could directly affect passengers (Filippone and Barakos, 2021). Finally, stakeholders should focus on **manufacturing** quieter vehicles or defining **flying routes** that minimize noise exposure (Bauranov and Rakas, 2021).

***Visual pollution***

Visual pollution is the negative impact that the view of some artificial structure or object and its movement might have on a person (Thomas and Granberg, 2023). Visual pollution can cause health problems and may induce indirect costs or property value loss (Thomas and Granberg, 2023). Simultaneously, a visual impact of aircraft and infrastructure should be limited, and city landscape should be preserved (EASA, 2021).

Limited research exists on the contribution of drones to visual pollution (Thomas and Granberg, 2023), however, their impact will likely be more disruptive compared to existing road traffic (Straubinger, 2019). Thomas and Granberg (Thomas and Granberg, 2023) stated that among the main factors influencing visual pollution there are the number of drones and the distance between a drone and an observer. Their study also indicates that drones used for emergency medical services are more tolerable, and visual pollution caused by drones is similar in both urban and rural areas. The study also provides conclusions on research gaps in the area of visual pollution from drones. Future research should define methodology on **quantification of visual impact**, explore the **impact of movement** on visual pollution, as well as development of **path planning algorithms** that can consider trade-offs between visual pollution, noise pollution, risk, efficiency, and other relevant factors (Thomas and Granberg, 2023).

***Land use impact***

Drone operations require specific infrastructure which may cause pressure on land use (EASA, 2021), particularly in urbanized areas (Brunelli et al., 2023). EASA estimates (EASA, 2021) as much as 20-45 landing pads for medium cities and 40-60 for large ones. In some cases, existing helipads or airports, including smaller aerodromes, could be repurposed as vertiports. Moreover, Antcliff et al. (Antcliff et al., 2016) proposed the use of cloverleaf interchanges as vertiports, offering advantages such as minimized land consumption, reduced overflight of private properties, shorter ground travel times, and decreased noise impacts. Nevertheless, the Drone Strategy 2.0 (EC, 2022a) emphasizes the need of systematic **analysis of suitable locations** for new enabling infrastructure, such as vertiports, telecommunication and energy distribution equipment or alternative energy supplies like hydrogen. Additionally, the improved accessibility provided by drones may **indirectly influence land use patterns**, motivating people and businesses to relocate away from densely populated urban areas (EC, 2022a).

***Energy and emissions***

Most drones are powered by electricity and produce zero tailpipe emissions creating no direct (scope 1) greenhouse gas emissions (EC, 2022a). Moreover, the Commission's regulation already imposes that small drones must be powered by electricity (EC, 2019a). The quantity of energy consumed and its related emissions (scope 2), depend on drone's design, payload, the energy sources employed in electricity generation, and the means of electricity transmission to the battery. The production and disposal of drones at the end of their lifecycle consume energy and contribute to indirect emissions (scope 3).

The potential for emissions reduction in Europe by shifting cargo and last-mile express deliveries from traditional transport methods to drone services is estimated to be around 120,000 tons of CO2 by 2030 (EC, 2022b). According to a study by Kasliwal et al. (2019), fully loaded VTOL aircrafts (with three passengers) have GHG emissions per passenger-kilometre that are 52% lower compared to ground-based internal combustion engine (ICE) cars with an average occupancy of 1.54. The emissions of fully loaded VTOL aircrafts are also 6% lower than battery electric vehicles (BEVs). Furthermore, the study indicates that a 100 km point-to-point travel with one pilot in a VTOL aircraft results in 35% lower well-to-wing/wheel GHG emissions than a one-occupant internal combustion engine vehicle (ICEV), but 28% higher emissions compared to a one-occupant battery electric vehicle (BEV). Results presented by Kim et al. (2023) shows that current ICEV emissions are 4.7 times higher than estimated emissions from passenger drones. Finally, Goodchild and Toy (2018) showed that drones offer a CO2 emissions advantage over trucks in service zones that are either in close proximity to the depot or have a smaller number of recipients, or both.

Nevertheless, Ahmed at al. argue that the overall environmental impact of widespread deployment of drones, using different **energy sources** and **propulsion systems** needs to be further investigated, together with life-cycle assessment of drones under different operational scenarios such as personal ownership, shared mobility service, and a mixture of both (Ahmed et al., 2020). Moreover, research and innovation projects should address an issue of recycling or reuse of batteries from drones to **reduce emissions** (Kellermann et al., 2020). Finally, new propulsion systems, as well as drone design should be evaluated from their life-cycle impact on emissions and energy use (Ahmed et al., 2020).

### *Safety concerns*

Safety of drone operations requires an efficient **air traffic management**, allowing safe airspace operations, promote collaboration between aviation and cellular communities, including issues like altitude, separation, and safe operating distances. Moreover, at the level of aircrafts, it entails **sensors** to detect other airspace users or ground-based obstacles to avoid collision (e.g. detect-and-avoid systems), robust integrated **communication, navigation and surveillance** systems to interact with other drones and ground infrastructure.

Under the Basic Regulation adopted in 2018 (EU, 2018), all drones, regardless of their weight, are required to adhere to the harmonised safety rules established by the Union. To further ensure the safety of drone operations in airspace, the Commission introduced a series of regulations in 2019 that specifically govern the use of drones (EC, 2019a; EC, 2019b). Additionally, in 2020, the Commission implemented three regulations on U-space, which establish the air traffic management system for drones and contribute to their safe operation within airspace (EC, 2021a; EC, 2021b; EC, 2021c).

The Drone Strategy 2.0 (EC, 2022a) indicates that the integration of drones in the airspace requires a thorough review of existing aviation safety rules. In the first step of integration, the airspace for drones is separated from the airspace used for manned operations. The following phase aims to achieve full integration, enabling all airspace users can safely and freely operate within the same airspace or transition between airspaces. That would include manned and unmanned operations, as well as both individual aircraft and regular air traffic, including state and military operators.

### *Security and privacy concerns*

Society may be concerned about privacy and data protection, as urban air mobility aircraft may fly above or close to places of residence (EASA, 2021). In particular, the capability of drones to carry cameras raises significant privacy concerns (Baldini and Cano-Pons, 2017; Luppicini and So, 2016; Lee et al., 2022), in particular, perceived privacy losses (Bauranov and Rakas, 2021).

Proposed solutions for mitigating potential privacy violations include technical and legal strategies. **Technological solutions** encompass built-in remote identification systems, the integration of preventative measures into drone designs, and the establishment of geofencing or no-fly zones. **Legal solutions** involve the implementation of mandatory drone registration, the development of codes of conduct, and the expansion of regulatory frameworks to provide stronger protection for privacy rights (Kellermann et al., 2020).

Privacy issues are frequently interconnected with **security** (including **cybersecurity**), because the personal data and personally identifiable information collected by drones can also pose challenges to private and governmental security (Lee et al., 2022). Drones can move near sensitive areas (e.g., nuclear facility) or they can use the camera to take pictures or videos of sensitive operations (e.g., public safety or military operations) (Baldini and Cano-Pons, 2017). Moreover, drones can be deployed in groups to complete common tasks, for example, to collectively monitor an area more comprehensively than a single aircraft could. While the so-called cooperative drones may not be directly employed to carry out threats such as terrorist attacks, they can still be utilized to gather sensitive information that may be exploited by criminals in subsequent phases (Baldini and Cano-Pons, 2017).

Both the 2020 EU Security Union Strategy (EC, 2020c) and Counter-Terrorism Agenda (EC, 2020a) clearly state that the threat of non-cooperative drones is a serious concern in Europe that needs to be addressed (EC, 2022b). The Commission has been supporting Member States in addressing the threats from non-cooperative drones, implementing a wide range of activities including information sharing, testing, research and funding support and legislative measures (EC, 2022b).

### *Regulatory issues*

The Commission's implementing rules (EC, 2019a; EC, 2019b) set out common technical and operational requirements for drones to facilitate the development of the drone industry and market. In addition, the Commission took a significant step towards ensuring the scalability and safety of drone operations by adopting three Implementing Regulations on U-space in 2021 (EC, 2021a; EC, 2021b; EC, 2021c). However, there are still regulatory gaps that need to be addressed to enable the operation of all drones in the European Union (EC, 2022c).

In particular, there is the need to roll out the rules for the ‘certified category’, which involves common rules for the **certification of aircraft, operators and remote pilots** (EC, 2022a). This also includes developing a **regulatory framework for vertiports** and other ground infrastructure (EC, 2022b). In case of the latter, it is crucial to give due consideration to the interface with aerodromes, interoperability, and the open access of equipment to ground infrastructures by drone operators. In this regard, the regulatory framework should ensure that these ground infrastructures do not become proprietary and instead adhere to the same open model as airports and heliports. Regarding operating licenses for operators, it is essential to appropriately adapt and simplify the rules outlined in Regulation (EC) 1008/2008 to encompass drone operators.

There is also the need to define global standards for **cybersecurity** (EC, 2022a). Finally, in relation to rules on **data protection**, it would be beneficial to develop specific and user-friendly guidelines or checklists that explain to drone operators how to comply with data protection and privacy requirements.

## 2.5 JRC works on drones

The JRC works on unmanned aircraft systems have primarily focused on security and safety. This emphasis stems from the increasing number of incidents involving drones reported in Europe. Many of these incidents are attributed to actors with criminal, illegal, or even terrorist intent. In response to these threats, the JRC recently published two handbooks that provide insights into countering drone-driven threats. The “Handbook on UAV protection of critical infrastructure and public space…” (Hansen and Pinto Faria, 2023) offers guidelines, references, approaches, and considerations on safeguarding against malicious UA. It also emphasizes the importance of involving various stakeholders to create comprehensive solutions. The Handbook on UAS Risk Assessment and Principles for Physical Hardening of Buildings and Sites (Karlos and Larcher, 2023) aims to guide those responsible for securing infrastructure and public spaces against threats posed by the malicious use of UAS.

Moreover, JRC prepared a study on regulatory and standardisation (Baldini and Cano-Pons, 2016), where JRC researchers identified and evaluated available techniques that support various drone functions. These include operational transparency, 4-D geo-fencing, and data collection minimisation, with a focus on assessing their technical, economic, legal, and security aspects.

A JRC study titled "Last mile delivery by drones: An estimation of viable market potential and access to citizens across European cities" (Aurambout et al., 2019) explored various scenarios of citizens' potential use of drone technology. The study aimed to estimate the optimal location of drone-beehives based on their economic viability and the number of EU citizens who could benefit from such services. The findings indicated that, in an improved technological scenario, up to 30% of EU citizens could potentially access these services. Additionally, the study highlighted the heterogeneous potential drone coverage across Europe, influenced by differences in population and land use patterns. Germany, Italy, and France emerged as the countries where drone-beehives could potentially experience the most efficient development.

Ethical principles and citizens' acceptability have been thoroughly investigated at the JRC through public engagement activities and ethics evaluations. The JRC's work on civil drones in society (Boucher, 2014), which examines consultation and development in the European context, specifically focuses on privacy and data protection, law enforcement, and the portrayal of the relationship between civil and military drones. In a subsequent study, the methodological approach of “Ethics dialogues” (Vesnić-Alujević et al., 2015) about science and technology is presented, highlighting the combination of public engagement and ethics evaluations. This approach is applied to the case study of civil drone technology, recognizing the societal transformation it entails. Public engagement activities were conducted to explore citizens' perspectives on civil drones, with a particular emphasis on understanding the role citizens can play in their development and ensuring that drones are acceptable to the public (Boucher, 2015).

Finally, the JRC report on critical raw materials presents review of the access to raw materials used in drone manufacturing. The report highlights that while the EU is the second-largest producer of processed materials for drones (18%), it remains highly dependent on external sources, particularly China, for the processing of these materials. Notably, ferroniobium, Pt-Ru alloys, and other processed materials used in Li-ion battery production are among the materials where EU's dependence is significant. Additionally, the EU relies on external supply for other critical raw materials as well (Carrara et al., 2023).

# 3 Methods and data

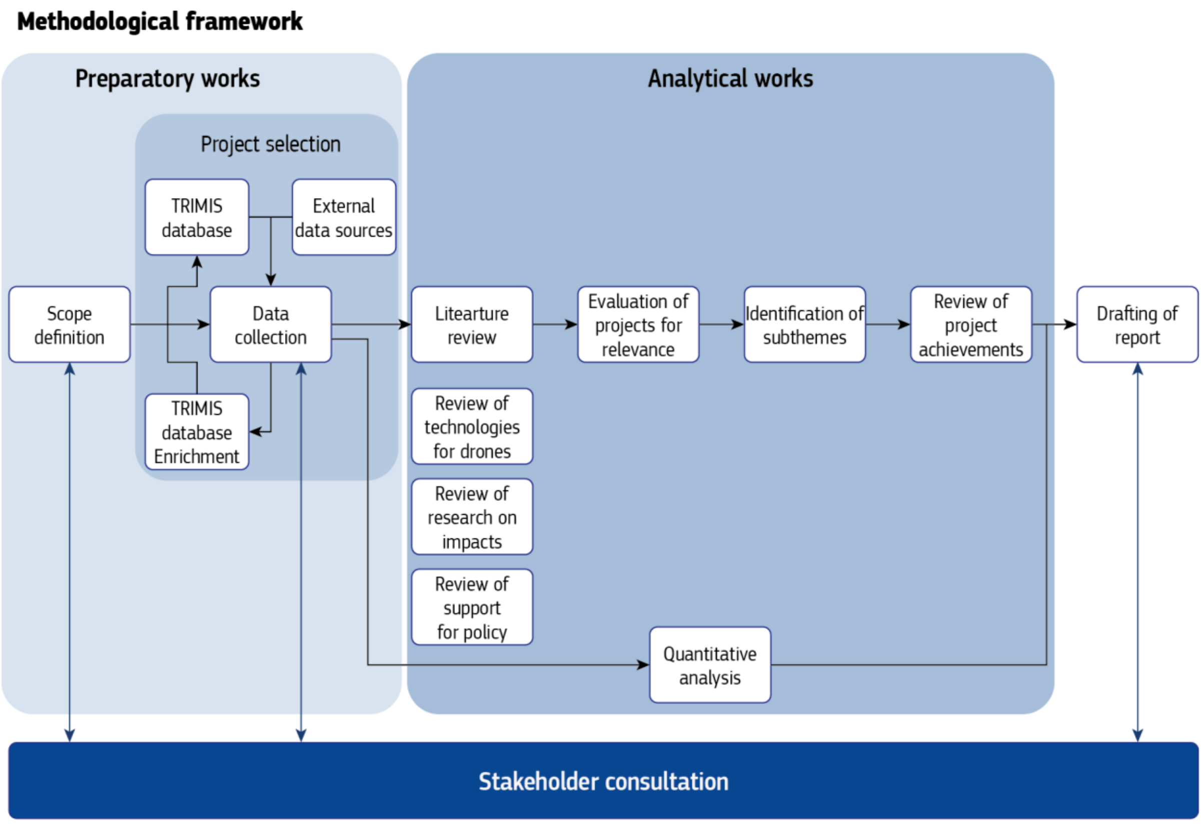
## 3.1 Methodological approach

Figure 3 presents methodological approach applied in the presented report. Once the projects were identified and all the information is collected, their scope, achievements and deliverables were analysed to assess their contribution in three distinct areas:

- progress in technologies for drones (chapter 4),
- research on environmental and socio-economic impact of drones and regulations and standardisation (chapter 5),
- support for policy initiatives (chapter 6).

Each of the three areas has its own dedicated chapter. Every project was evaluated individually for its relevance to the three topics. Projects found to be relevant were then extensively reviewed, and the summaries of the main findings were organized into subsections based on the identified subthemes within each topic. Finally, the conclusions section provides a general summary of all the findings, presenting aggregated and generalized information about the main findings.

**Figure 3.** Methodological approach




*Source: TRIMIS, JRC, 2024*

## 3.2 Data collection

The data collection procedure involves several steps to ensure a comprehensive identification of research and innovation projects relevant for the report. It begins with the keyword search through the **TRIMIS database** as the starting point. TRIMIS database, managed by the European Commission's Joint Research Centre (JRC), serves as the primary source of data for transport research and innovation projects. It gathers information about research and innovation projects funded from various programmes, including Horizon 2020 (H2020), Horizon Europe (HE), or Framework Programme 7 (FP7), as well as other European initiatives. It currently contains detailed information about nearly 9,000 projects. This includes over 2,000 projects funded within the H2020 Framework Programme and a growing number of projects started under Horizon Europe. The database ensures the availability of reliable and up-to-date information for the identification and analysis of R&I projects in the field of transport.

The keyword search included descriptive fields contained in TRIMIS, such as project aims, as well as project descriptions available directly in the CORDIS database, including summaries, work performed, and final results. The search was specifically limited to projects funded under H2020, HE, and included only one FP7 project, METROPOLIS, due to its continuation within the H2020 program. Additionally, a search was conducted for other European projects that began since 2014, aligning with the start of H2020. This initial search yielded 144 projects, which were then manually reviewed to confirm their relevance for the report. As a result, a total of 67 projects were identified in this stage.

Next, the CORTEX platform was utilized to conduct a keyword search using terms such as "drones," "Urban Air Mobility," or "UAV." The 200 most relevant projects resulting from this search were individually reviewed. From this review, 50 projects were selected and added to the list. These projects encompass funding from H2020, HE, and other European programs including CEF and COSME.

To ensure comprehensive coverage of the European research and innovation landscape, a manual check was performed to identify any additional projects awarded from drone-related calls that were not previously identified in the TRIMIS or CORTEX searches. This step only yielded the addition of one project that had not been previously identified. Furthermore, additional project lists from the European Defence Fund (EDF), European Investment Bank (EIB), European Innovation Council (EIC), Interreg, as well as projects mentioned in Drone Strategy 2.0 (Staff Working Document), were examined. Any relevant projects found in these lists were included in the tentative list. The list was then consulted with The European Climate, Infrastructure, and Environment Executive Agency (CINEA), resulting in the addition of eight projects. CINEA plays a vital role towards achieving the Commission's research and innovation goals and objectives through its implementation of several relevant EU funding programmes. Finally, 13 projects were added to the list during the review process. The final list includes 152 projects, which underwent in-depth review in the subsequent steps of analysis, and can be consulted at JRC Open Data Repository.[9]

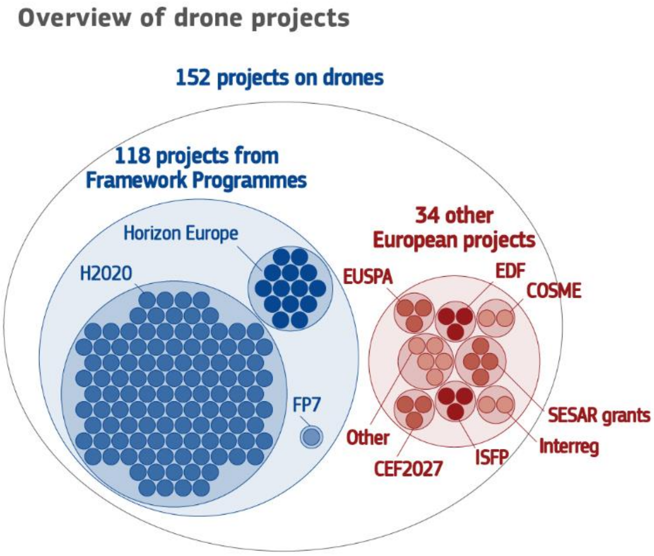
## 3.3 Overview of projects

Out of 152 projects reviewed for the report, most are funded within framework programmes: H2020 (nearly 75 percent of all identified projects), HE and FP7 (only 1 project – METROPOLIS, which had a continuation in H2020 METROPOLIS 2 project). They are all funded within main existing funding schemes: Research and Innovation Actions (RIA), Innovative Actions (IA), Coordination and Support Actions (CSA) and dedicated funds for small and medium enterprises (SME): concept and feasibility assessment (phase one – SME-1) and innovation project (phase 2 – SME-2), as well as their continuation European Innovation Council's (EIC) Accelerator programme, which replaces SME Instruments (both, phase 1 and phase 2). Additionally, few projects received EU support through funding for scientific and technological research from the European Research Council (ERC) or fellowships within Marie Skłodowska-Curie Actions (MSCA). Moreover, 34 drone-related projects reviewed for the report were funded within other European programmes (Figure 4).

Figure 5 presents a distribution of projects by the received EU contribution. The funding varies between 50 000 to over 56.7 million EUR. The average amount of EU contribution exceeds 3.3 million EUR. However, the median of EU contribution is significantly lower (1.5 million EUR) due to high number of SME-1 projects with the lump sum of 50 000 EUR.

(9) Direct link to the dataset: https://data.jrc.cec.eu.int/dataset/eb94ade1-42c3-4b5d-919d-5befd14e1f38

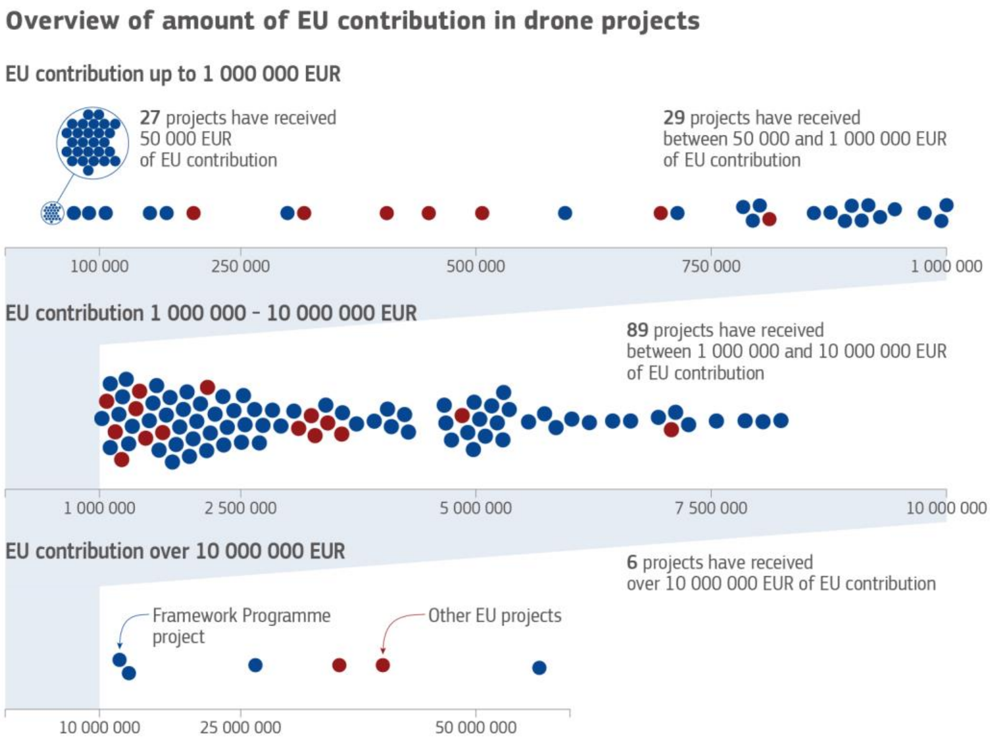
**Figure 4.** Overview of selected projects




*Footnote: EUSPA - EU Agency for the Space Programme; EDF - European Defence Fund; COSME - Internal Market, Industry, Entrepreneurship and Small and Medium Enterprises; SESAR grants - Delivering the Digital European Sky Joint Undertaking grants; ISFP - Internal Security Fund; Connecting Europe Facility (CEF).*
*Other include single projects funded from Digital Europe Programme (DIGITAL), European Union Aviation Safety Agency (EASA), European Defence Agency (EDA), European Investment Bank (EIB) and Hercule III grant programme (HERC).*

*Source: TRIMIS, JRC, 2024 based on TRIMIS data*

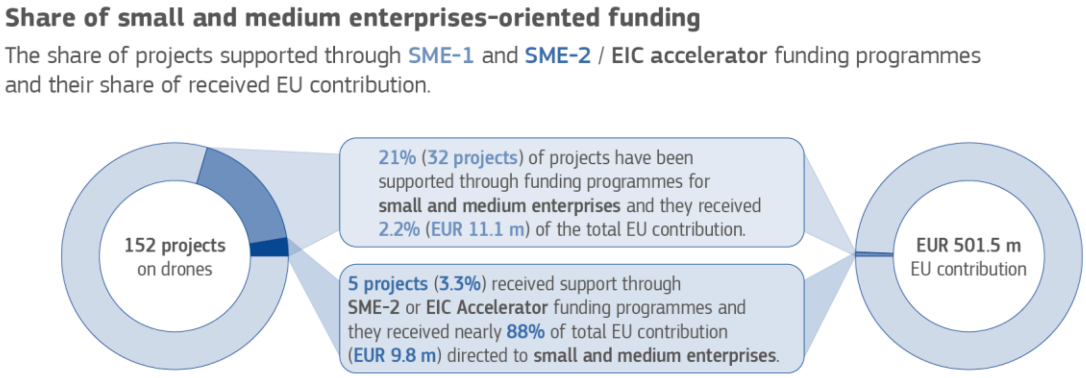
**Figure 5.** EU contribution overview of selected projects




*Source: Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

The SME-1 projects are most projects directed for small and medium enterprises (Figure 6). In consequence, even though projects for small and medium enterprises constitute 21% of all analysed projects, the total funding directed through these funds is around 2.2% (11 million out of a total 501.5 million in all reviewed projects). Only 5 projects concentrate on more advanced, innovative ideas funded within SME-2 programme or its successor – EIC Accelerator programme for development and scaling up innovations. In their case, the EU contribution varies between 1.2 to 2.5 million EUR with a total budget up to 3.5 million EUR.

**Figure 6.** Research and innovation support for small and medium enterprises




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

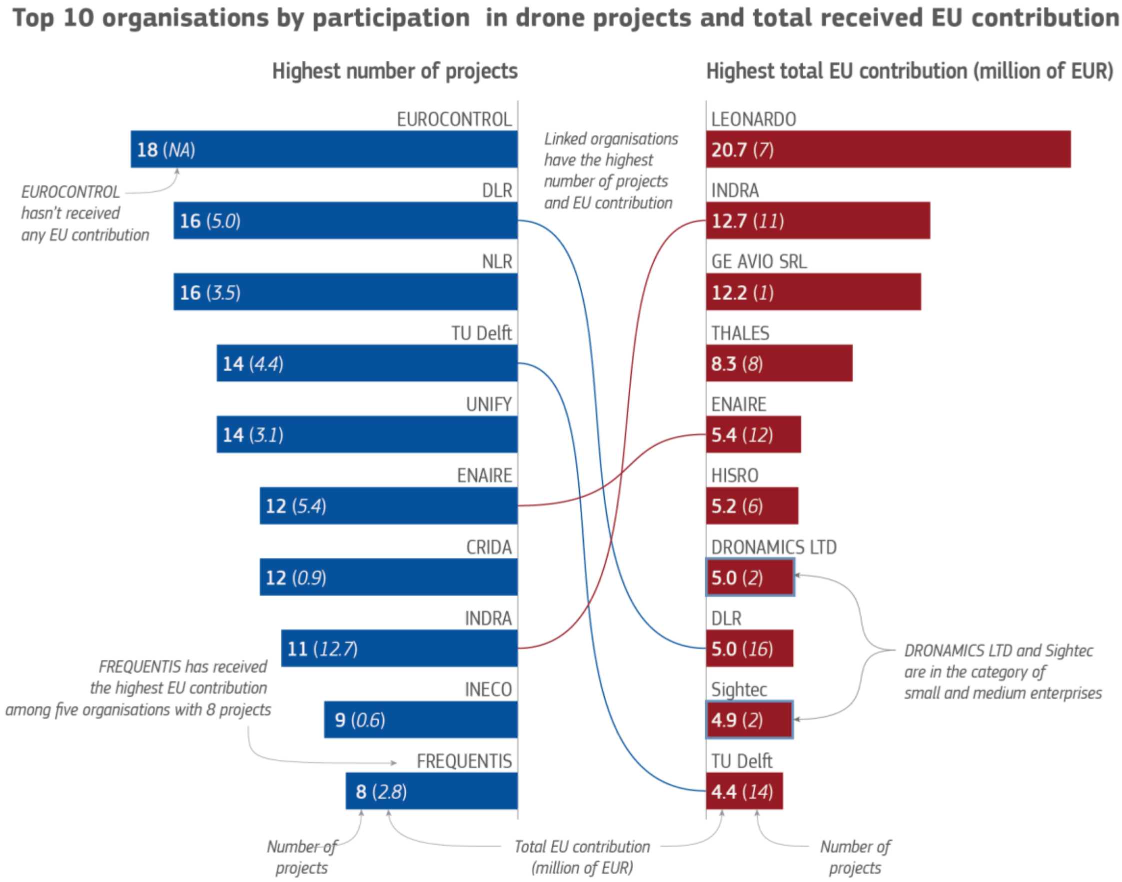
## 3.4 Main actors

In total, 1438 project partners have been participating in all 152 analysed projects, with some organisations participating in multiple of them. Using the CORDIS database, it was possible to collect detailed data for 1223 project partners. The relevant, detailed information includes name of organisation, its ID (as used in the CORDIS database), country of their location, the role in the project (coordinator or participant) and received EU contribution (if applicable). In total, the data was collected for partners in 122 analysed projects. For the remaining 217 partners in 30 projects, the available data was collected manually. In all cases it includes a country of an organisation and the role of organisation in a project, and, wherever possible, also an information about EU contribution (64 partners).

In total, 742 different organisations participated in 122 projects. Eight of them has been participating in more than 10 different projects, with EUROCONTROL being the most active one (18 projects; Figure 7). Three organisations received over 10 million EUR: Italian Leonardo (7 projects and 20.7 million EUR) and GE AVIO SRL (one project - GAM-2020-FRC – and over 12.2 million EUR) and Spanish Indra (11 projects and 12.7 million EUR). Four organisations were among the most active in terms of number of projects they participated in) as well as in terms of received EU contribution at the same time: German DLR, Dutch NLR, Spanish Indra and CRIDA.

Among the most active participants in drone related projects, two organisations belong to the category small and medium enterprises. Dronamics LTD and Sightec Israel LTD are both in the category of the highest received EU contribution (5.0 and 4.9 million EUR, respectively).

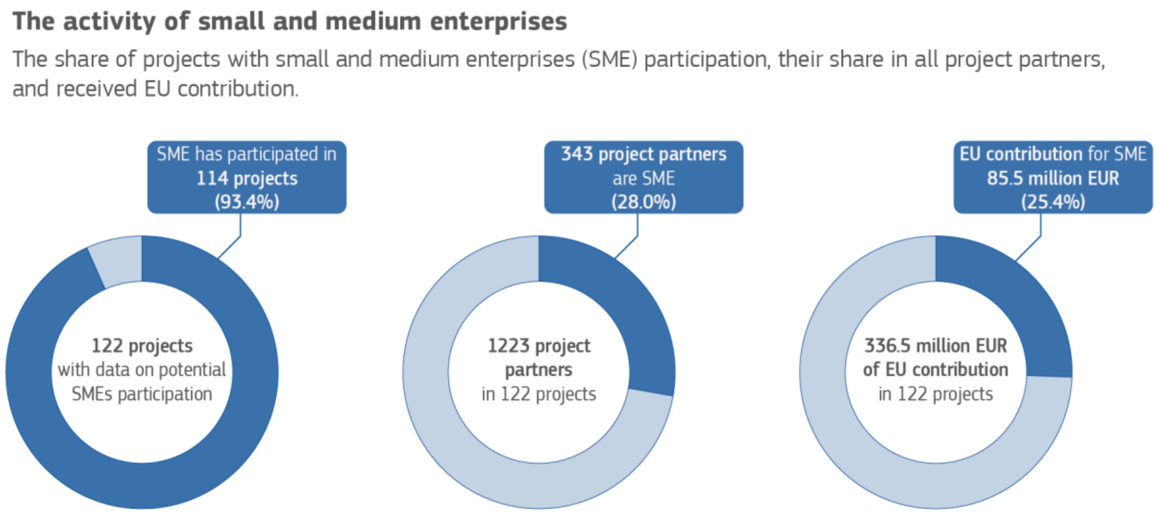
**Figure 7.** Organisations with the highest number of projects and the highest received total EU contribution




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

Small and medium enterprises constitute 28% of all identified project partners Figure 8. They have participated in 114 projects, which is over 93% of all projects for which it was possible to collect detailed information for all the participants (i.e. 122 projects out of 152 analysed ones). Over one-fourth part of EU contribution in those projects has been directed to small and medium enterprises (85.5 million EUR).

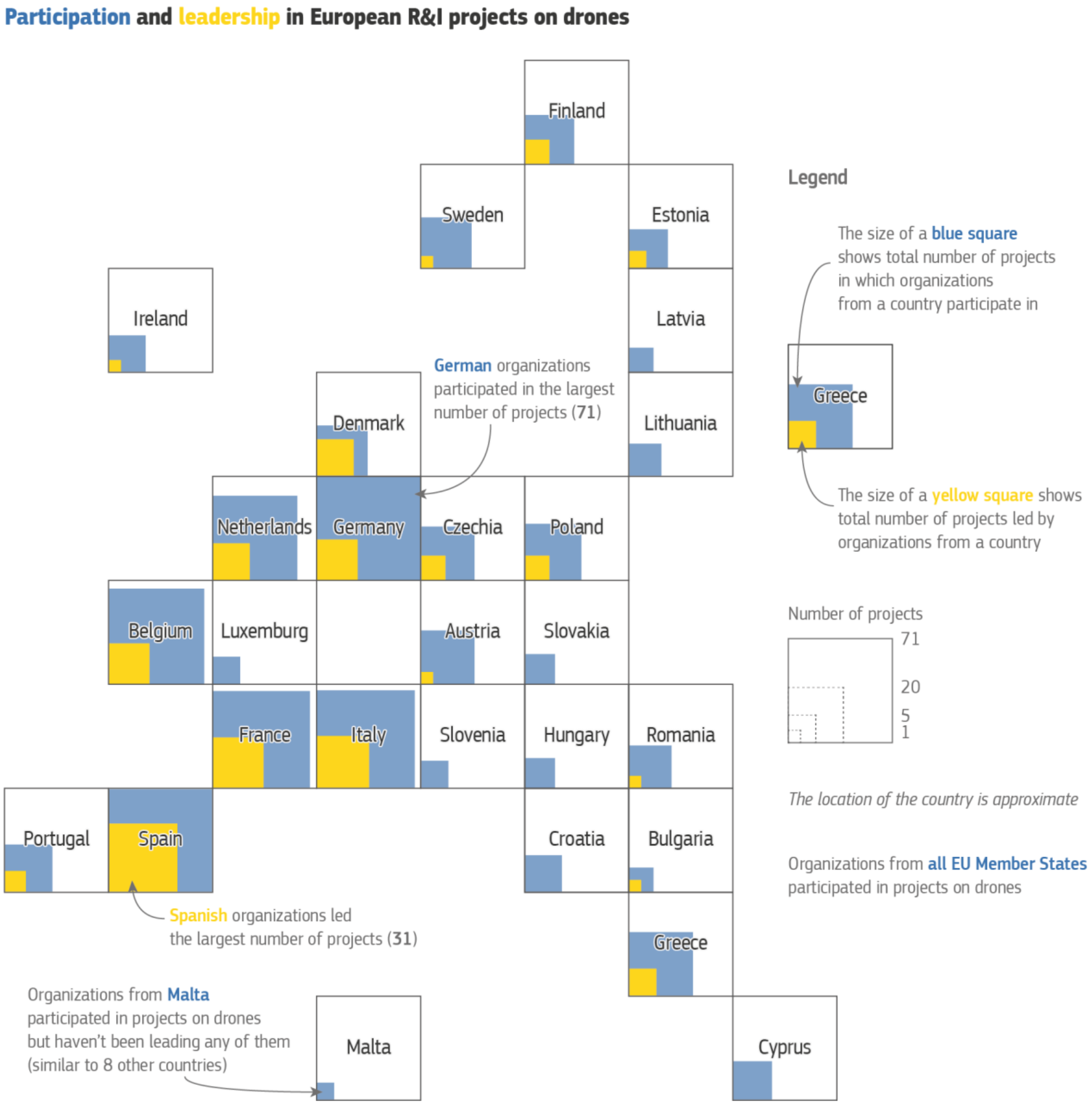
**Figure 8.** Participation of small and medium enterprises in research and innovation projects on drones




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

The information about a location of a country of all participants and project coordinators has been collected for nearly all analysed projects (151 out of 152). Figure 9 summarises information about participation and coordination of the projects by country. Organisations from Germany, Spain, France, Italy and Belgium participated in the highest number of projects (up to 71 – Germany). Organisations from these countries, followed by organisations from the Netherlands and Denmark, have been the most active in project coordination. Spanish organisations coordinated the highest number of projects – 31. The figure also shows that organisations from Central and Eastern Europe have been relatively less active in terms of participation in or coordination of drone projects, however, there are some exceptions (e.g. Greece, Poland, or Romania).

**Figure 9.** Participation and coordination of research and innovation projects by country




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

# 4 EU research and innovation in drone technologies

This section provides an overview of the drone technologies investigated by the projects taken into consideration. Following an introduction on the typology and funding sources of the various initiatives, the technologies and respective projects are then presented in three separate subchapters devoted to vehicles and subsystems, drone infrastructure and U-space.

The report concentrates on the projects that aimed at advancing the drone technology itself, and for that reason the activities which instead focused on application of drones to a specific domain were omitted. Nevertheless, also the latter type of initiatives is worth mentioning since it provides a more complete picture of research and innovation activities in the realm of drones. Among such projects it is possible to identify some areas which attracted particular attention. Out of the total 152 projects identified in the report, 140 are examined in detail for the following subsections as having a technological content.

## 4.1 Overview of drone technologies projects

### 4.1.1 Research and innovation policy and funding sources

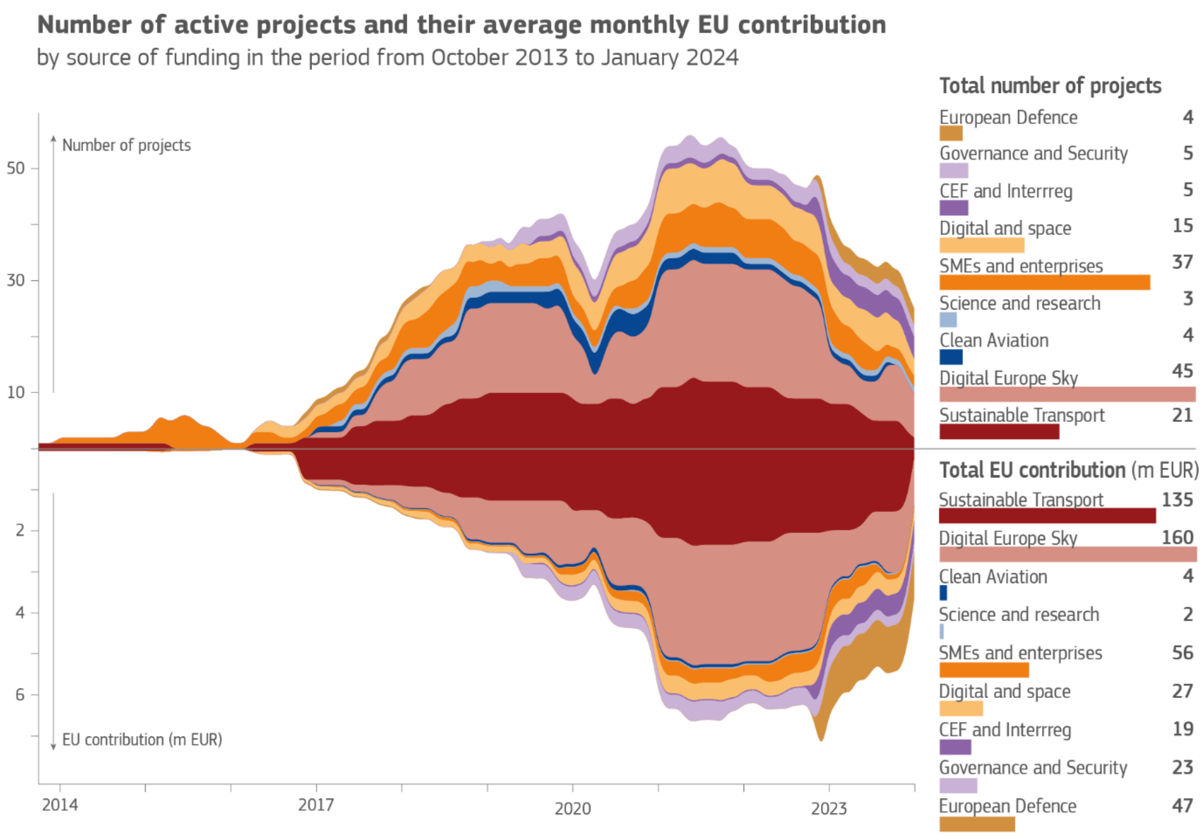
The European Union fosters drone innovation with the funding and support of research, innovation, and market deployment initiatives. While most of the support is channelled through the EU Framework Programmes, it is worth exploring in more detail the different pathways for the examined 140 projects.

- **Sustainable transport** calls in the Framework Programmes (21 projects). This includes the *Transport (including Aeronautics)* theme in FP7, *Smart, green and integrated transport* in H2020, and Destination *Clean and competitive solutions for all transport modes* in Horizon Europe. Projects from Sustainable transport calls cover all aspects of drones' technologies, with a focus on traffic management and U-space.
- **Digital European Sky** SESAR EU partnership (45 projects) and CleanSky2/**Clean Aviation** Partnership (4 projects). These European Public-Private Partnerships, in the domain of Air Traffic Management (ATM) and sustainable aviation respectively, establish research and innovation roadmaps and programmes for research and innovation. SESAR is the most active entity in the effort of preparing U-space, the highly automated drone traffic management system which is a prerequisite for the uptake of urban air mobility. While most of SESAR activity is channelled through the H2020 and Horizon Europe Framework Programme calls, Very Large Demonstration Activities (5 projects) were also funded by SESAR directly through a Delegation Agreement, and Digital Sky Demonstrators are funded through the CEF.
- **CEF and Interreg**, with deployment and large-scale demonstrations also being funded under the Connecting Europe Facility and Interreg funds (5 projects). These large-scale demonstrations allow to evaluate in real conditions the urban airspace integration of drones and the technical maturity of traffic management solutions.
- Support to **SMEs and Enterprises**, with enterprise supporting instruments including small and medium enterprise (SME) calls and accelerator programmes (35 projects). This includes 27 SME-1 or CSA “lump sum” projects, and larger projects supported by the COSME, SME-2, and more recently EIC accelerator grants and programmes. To these can be added the financial support in terms of accelerator grants and fundraising by the European Institute of Innovation and Technology, and direct investment by the European Investment Bank on promising start-up companies. Most SMEs were active in the development of drone vehicles and their components.
- **Digital and Space** are represented by enabling technologies calls and partnerships (15 projects). These include:
    - Destination 5.i. Information and Communication Technologies in H2020, with 2 projects on 5G telecommunications for drones,
    - Destination 5.iii Leadership in Enabling and Industrial Technologies – Space in H2020 (7 projects) and European Union Agency for the Space Programme (4 projects) for the development and use of GNSS (Global Navigation Satellite System) and the European Geostationary Navigation Overlay Service (EGNOS) for safe navigation and traffic monitoring of drones.

- Key Digital Technologies EU partnership (2 projects), and DIGITAL programme (1 project) managed by the Directorate General for Communications Networks, Content and Technology. The three projects focus on drone computing hardware and software architectures, robust sensing and telecommunications, AI and testing of autonomous flight capabilities.

- **European Defence** includes European Defence Agency grants and European Defence Fund, accounting for 4 projects, focusing on the development of propulsion and energy systems, sensing capabilities, fuel cell powered drones, and detect-and-avoidance standards.
- **Governance and security** funding covers the application of drones in crucial EU matters. Three projects were funded by the Secure societies theme of H2020 for border surveillance, one project was funded by the Hercule III programme by the European Anti-Fraud Office, and one by the Governance, environmental observations, and digital solutions for the safe use of drones in agricultural production, forestry, and rural communities.
- Basic **science and research** are represented by European Research Council (ERC) Consolidator grants and Marie Skłodowska-Curie Actions (3 projects). These projects focus on the technical challenges of autonomous flight and precise geolocation even in confined spaces and overarching European drone ecosystem analysis.

**Figure 10.** Number of active projects and their average monthly EU contribution by project type




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

Figure 10 shows that the bulk of drone research and innovation activity kicked off with the 2016-2017 H2020 work programme, including the sustainable transport calls, SME, Clean Aviation and SESAR calls. The chart displays that SESAR is leading the EU effort on drones in terms of number of projects (45) and EU contribution (€160 million). Thirty-seven SMEs were supported in developing the business model for their drone innovations. In 2022 there are some significant new entries with the launch of the European Defence Fund drone activities, the EIB €40 million investment on Wingcopter GMBH, and the launch of the Digital Sky Demonstrator projects within the CEF programme. No precise information was available on the EU contribution by the EIT Climate-KIC accelerator programme in its support to the LILIUM, therefore 139 projects are listed in the chart.

### 4.1.2 Funding schemes and expected technology readiness

The TRIMIS project database contains information about the funding scheme (see Annex 1 for details). This information can serve as a proxy of the targeted technology maturity level (TRL**Error! Reference source not found.**), as adopted in the EU Framework Programmes (Héder, 2017). The report adopts a modified version of the TRIMIS technology development phases (Gkoumas et al., 2020) which uses aggregated development phases (Table 1). The outputs of projects range from technical specification documents, such as concepts of operation or U-space architecture, lab prototypes of drone and traffic management subsystems, to system and traffic testing and demonstration.

**Table 1.** Technology development phase and corresponding readiness levels.

| **Development phase** | **TRL range** | **Example project outputs** |
|---|---|---|
| Research | 0-2 | Technical specifications, concepts |
| Prototyping and testing | 3-5 | Lab prototype |
| Pilot production and demonstration | 6-7 | Full vehicle prototype, drone traffic demonstration |
| Deployment | 8-9 | Large scale demonstration, Product deployment |

*Source: TRIMIS, JRC, 2024*

The funding source also indicates the receiving entity that conducts the research, innovation, development, and market deployment. **Error! Not a valid bookmark self-reference.** lists funding sources combined with an estimated targeted TRL.

**Table 2.** EU funding schemes for drone innovation.

| **Source** | **Source Type/ Programme** | **Receiving entities** | **Funding / Grant / Investment ceiling levels** | **Targeted TRL**[a] |
|---|---|---|---|---|
| MSCA | H2020/HE Pillar I | Doctoral and postdoctoral Fellowships | Grants: ca. €170 thousand for individual fellowships | 0 to 1 |
| ERC | H2020/HE Pillar I | Research Team | Consolidator grants: €2 million | 0 to 1 |
| RIA | H2020/HE Pillar II | Consortium of partners | Funding level: 100% of project costs | 2 to 6 |
| IA | H2020/HE Pillar II | Consortium of partners | Funding level: 70% of project costs | 6 to 8 |
| EDF | European Union fund | Consortium of partners | Funding level: 100% of project costs for research, 90% for development | 4 to 5 (R[b])<br>5 to 8 (D[c'])) |
| SME-1 | H2020/HE Pillar II | SME, start-up or scale-up | Grants: €50 thousand lump sum | 5 to 8 |
| SME-2 | H2020/HE Pillar II | SME, start-up or scale-up | Grants: €0.5 to €2.5 million | 5 to 8 |
| EIC | H2020/HE Pillar III | SME, start-up or scale-up | Accelerator:<br>Grants: €0.5 to €2.5 million<br>Direct investment: €15 million | 5 to 9 |
| CSA | H2020/HE Pillar II | Consortium of partners | Funding level: 100% of project costs | N/A |
| SESAR grant | H2020/HE Pillar II | Consortium of partners | Funding level: 50% of project costs | 7 to 8 |
| CEF | European Union fund | Consortium of partners | Funding level: 30% to 50% of project costs | 8 to deployment |
| Interreg | Interregional cooperation programme | Consortium of partners | Funding level: 80% of project costs | 8 to deployment |
| EIT | Funding and support program | SME, start-up or scale-up | Accelerator:<br>Grant or investment depending on the size of the project and corporation | 6 to 9 |
| EIB | Long term lending and support | SME to large scale corporations | Investment depending on the size of the project and corporation | 6 to 9 |

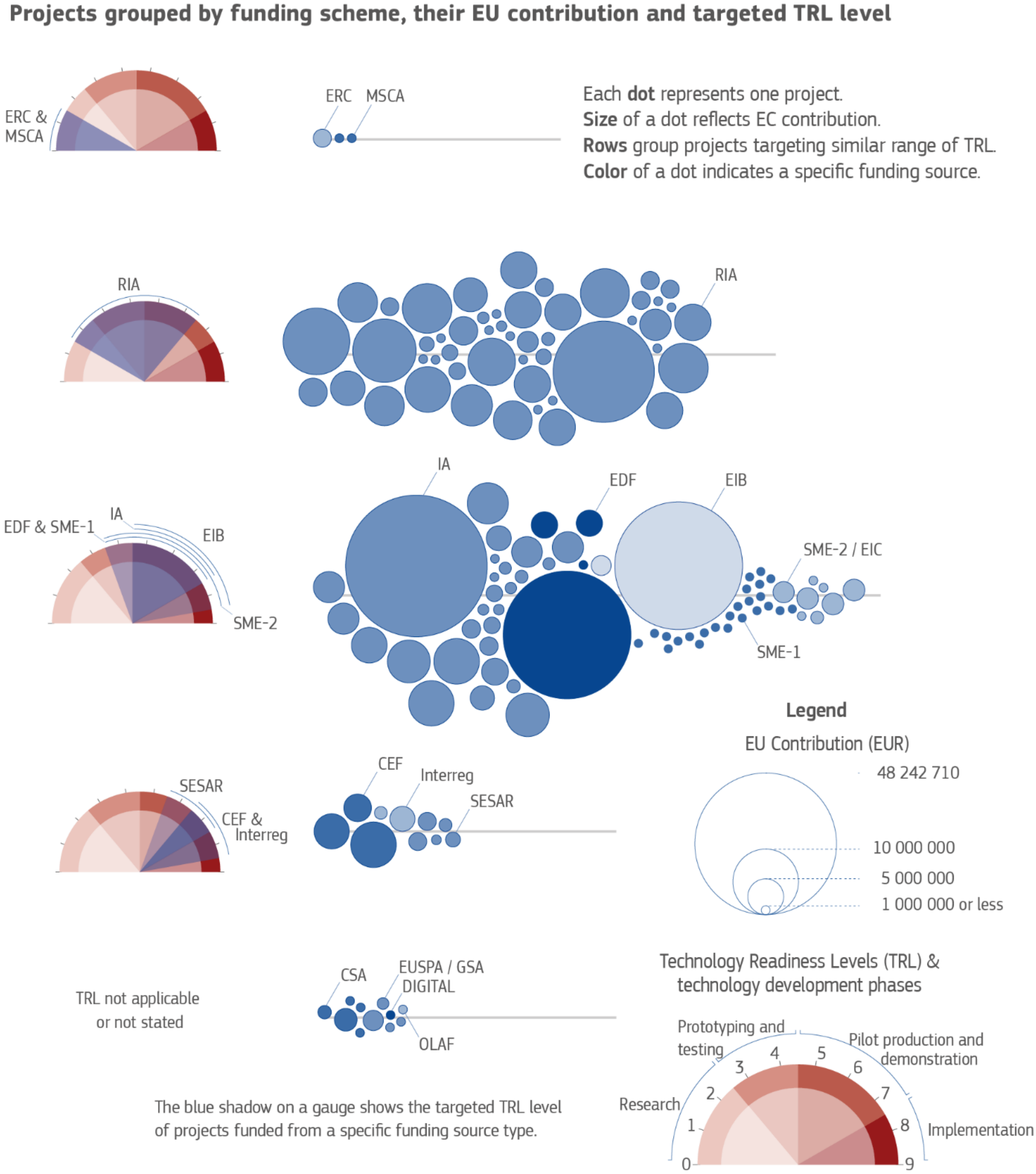
*[a] MSCA and ERC Consolidator grants correspond to basic high-risk research, therefore the target TRL level is only an indication. SME-1 projects are desk studies on business plan development for existing innovations. CSA actions do not have a technology component.*
*[b] Research*

^c^ Development

*Source: TRIMIS, JRC, 2024*

Figure 11 provides an overview of the analysed drone technology projects in terms of numbers, EU funding, funding schemes, grouped together by expected technology readiness. It combines information presented in the Table 2 with quantitative data on number of projects in the technology development phase range. Additionally, it distinguishes type of projects by their funding source and provide information about their EU contribution.

**Figure 11.** Distribution of projects by funding scheme



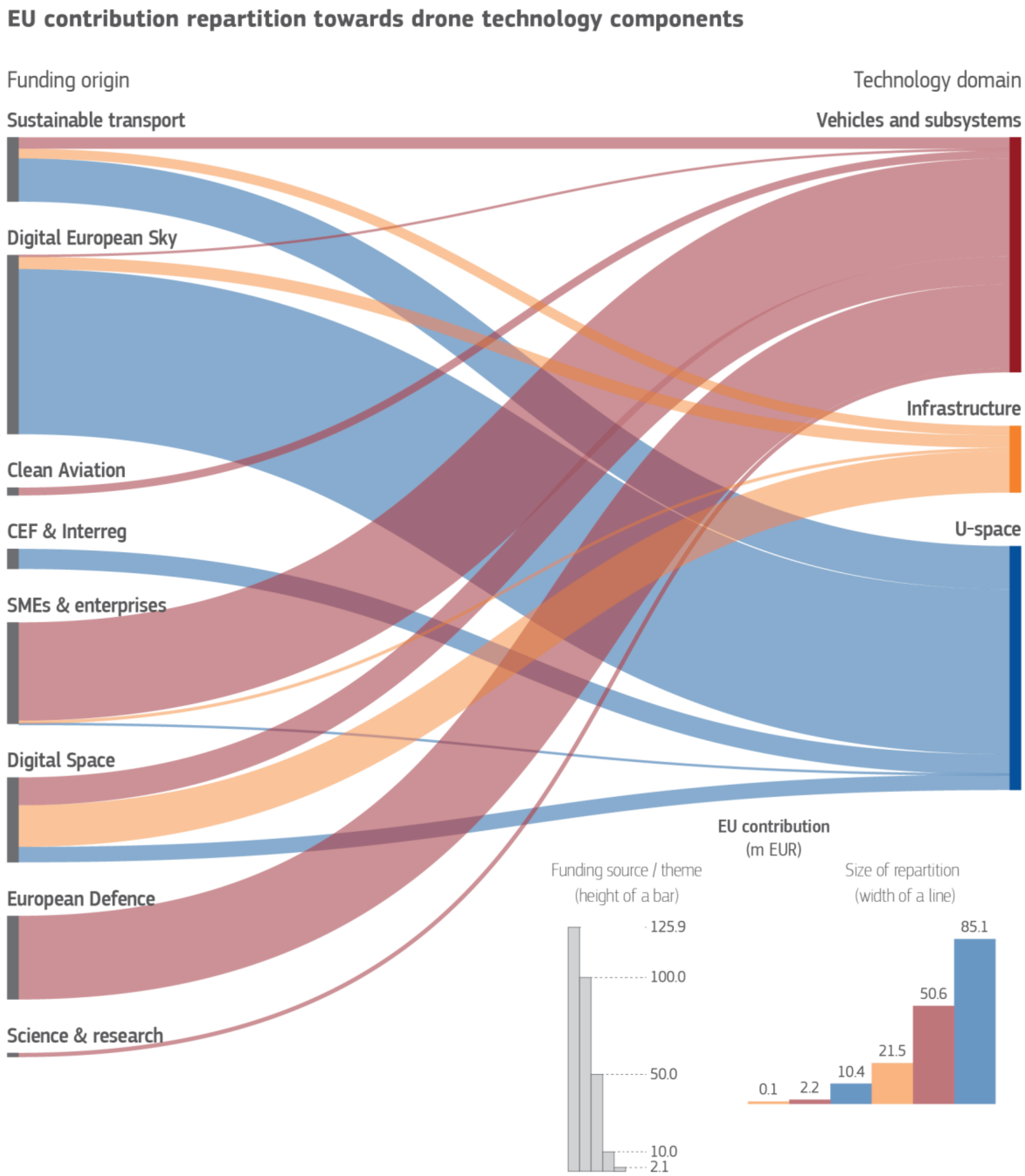

*Footnote: ERC - European Research Council grants, MSCA - Marie Skłodowska-Curie Individual Fellowships, RIA - Research and Innovation Action, IA - Innovative Actions, EDF - European Defence Fund, EIB - European Investment Bank, SME-1 / SME-2 - Small and Medium-sized Enterprises phase 1 / phase 2, EIC - European Innovation Council (Accelerator), CEF - Connecting Europe Facility, SESAR - Delivering the Digital European Sky Joint Undertaking grants, CSA - Coordination and Support Actions, EUSPA / GSA - EU Agency for the Space Programme / European Space Agency grants, DIGITAL - Digital Europe Programme, OLAF - European Anti-Fraud Office grants.*

*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

### 4.1.3 Technology themes and effort repartition

The following sub sections provide an overview of the drone technologies under investigation. Their qualitative assessment provides a summary of the project activities and how they address open challenges and perspectives for the wider adoption of drones. The qualitative assessment is organised into three main sections corresponding to vehicles and subsystems, infrastructure, and U-space.

**Figure 12.** EU contribution repartition towards drone technology components




*Source: TRIMIS, JRC, 2024 on TRIMIS and CORDIS data*

The Figure 12 summarises effort distribution between the different funding origins, and towards which aspects of drone technologies the funds were directed. As anticipated, SESAR – Digital Europe Sky projects mostly address the development of the U-space, with CEF and Interreg projects complementing with several large-scale demonstrations that evaluate the performance of the solutions. SME and enterprise efforts are principally directed towards the development of innovation for drone vehicles and subsystems. This is also the focus of European Defence Fund. Finally, Digital and Space calls and partnerships are distributed in a balanced way, underlying the connecting role of geolocation and communications between individual vehicles, the infrastructure, and air traffic. Moreover, infrastructure projects concern mostly the digital infrastructure, while physical landing and charging infrastructure received less attention as possibly a potentially less challenging aspect.

Certain projects are not described in detail in the following sections, as their analysis showed that they explore the use of drones in given applications, rather than developing drone technology components. They are mentioned here as examples of the application of drones in crucial societal matters. A popular field of application is transport infrastructure state-of-health monitoring, particularly for road transport (HERON (IA), INFRAROB (IA), OMICRON (IA), PANOPTIS (IA)). Some projects employed drones for the maintenance of railway infrastructure (RADIUS (IA)) and airports and waterways (5D-AEROSAFE (IA)). Other topics include agriculture (APMAV (SME-1), ICAERUS (IA)) or border surveillance (ALFA (IA), BORDERUAS (IA), HEFESTOS (Hercule III grant – Union Anti-fraud Programme). Further relevant subjects are medical aid distribution (AIRMOUR (IA)), landmine detection (ALDRONE (SME-1) and environmental surveillance (PROJECT SENSE (SME-1)).

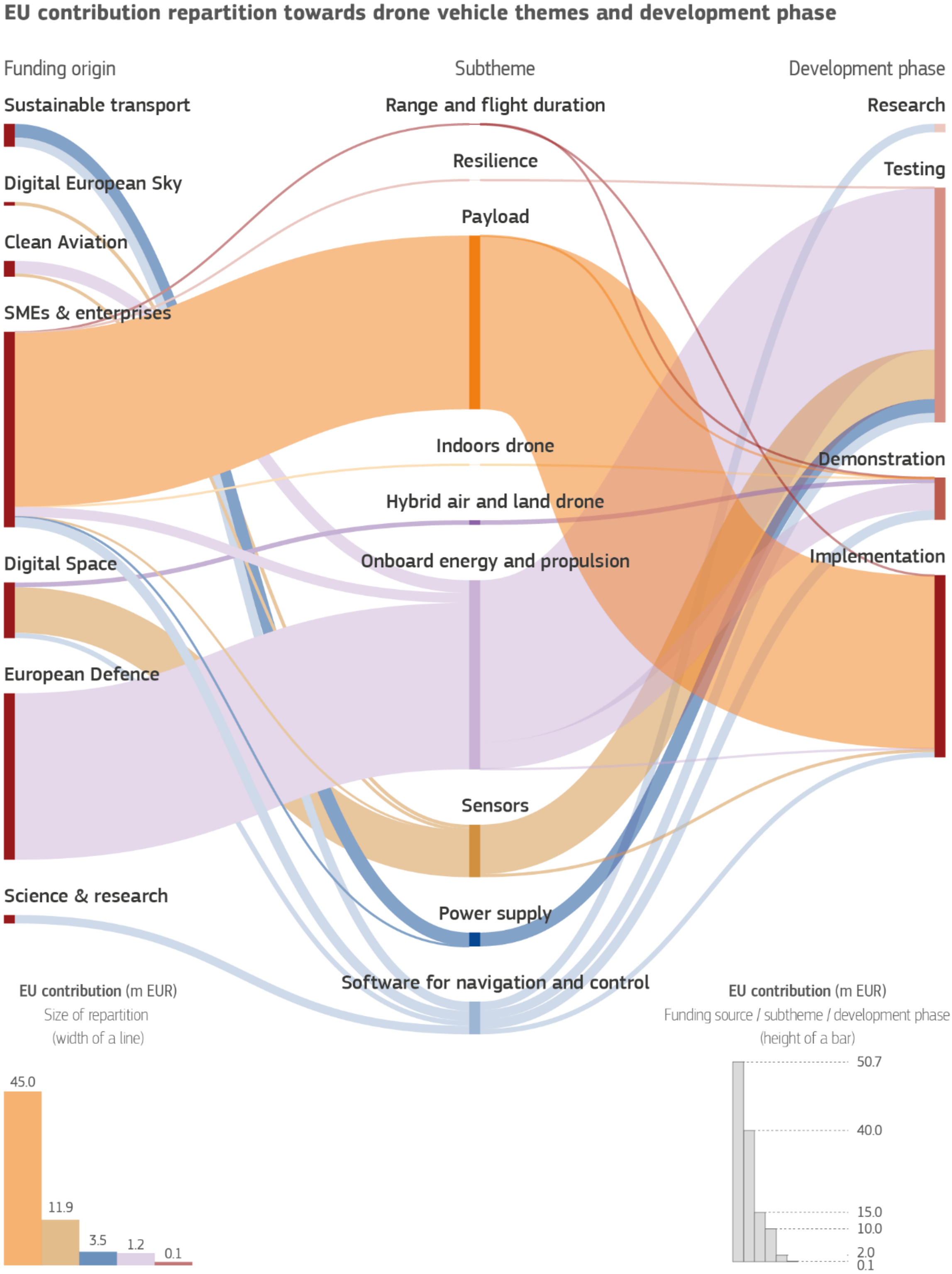
## 4.2 Vehicles and subsystems

### 4.2.1 Overview

One of the categories of projects are those focused on vehicles and their subsystems. The identified projects mainly address unmanned aircraft destined to carry payload but not passengers, with some rare exceptions. Within this domain the projects can be further divided into those focused on development of holistic drone concepts and the ones addressing specific components. The projects were categorised by the challenge they address or the innovation that they propose. These include range and flight duration, payload, innovative concepts as indoors drones and hybrid drone for land and air use, onboard energy and propulsion systems, sensors, power supply, and software for navigation and control.

On drone vehicle innovations, certain observations can be made. In terms of funding, the main effort has been rather recent with the European Defence Fund funding of two projects on onboard hybrid fuel cell energy systems and rotorcraft propulsion (HYBRID and ENGRT EUR 43 million). The EUR 40 million European Investment Bank investment in WINGCOPTER is directed towards increasing the payload of sensitive logistics drones, and towards the increase of their production. Five projects funded under the RIA scheme received roughly EUR 21 million, and directed their efforts towards sensors, a crucial aspect for navigation and avoiding collisions with traffic and the environment, but also navigation software and controls. Navigation software and controls projects were funded under diverse sources and cover all stages of technological development, from basic research (AGILEFLIGHT – ERC) to implementation (HUUVER IA). Innovations fostered in 13 SME-1 and 4 SME-2 projects cover all aspects of drone vehicles. The following section explores the results of the projects for each identified category.

**Figure 13.** Repartition of EU funds towards drone vehicle technology components and their development phase




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

### 4.2.2 Project analysis

In the first of these two groups, one of the most frequently addressed challenges is the range and flight duration. High operational times and distances are essential for many specific drone applications. The UAV-FUVEX (SME-1) project developed a hybrid (airplane/multirotor) drone for maritime sector and coastal surveillance, able to reach up to 300 km, with doubled level of autonomy and considerable cost reduction (on average 50%) compared to similar solutions existing on the market. QLEX CREO (SME-1) developed a concept vehicle intended for deliveries of medical supplies. Thanks to patented innovations in aerodynamics, aircraft architecture and propulsion the drone can fly 2-3 times longer than competitive solutions (up to 4-5 hours), corresponding to a range of more than 250 km. Apart from the increased range, the drone developed by ARCOPTER (SME-1) is also designed to successfully operate in windy conditions. Thanks to an innovative control system enabling the wings to rotate 360°, the aircraft effectively manages heavy winds, at the same time reducing energy consumption. The prototype can fly up to 120 km for more than 2 hours and execute a vertical take-off with wind as strong as 25 knots. The AUDAX AEREO (SME-1) project developed a concept of a manned UA able to cover large distances (300 km/2 hours). The vehicle combines several elements in a novel way, such as hybrid engine (two-stroke and electric), ballistic parachute for very low altitudes and independent emergency propulsion system. The solution targets mainly cargo delivery companies, commuters and emergency forces.

In case of emergency services also other crucial design aspects exist, apart from the range and flight duration. One of the key points is resilience of the drone when exposed to severe environmental conditions. This problem was addressed by EXTREMDRON (SME-1), which developed an UA concept for aerial monitoring applications in extreme operating environments, involving very high temperatures, fire, nuclear radiation, industrial chemical spills or strong electromagnetic fields. The vehicle takes advantage of hybrid composite materials, heat dissipation systems, and sensors able to detect explosive compounds to enable the exposure to such harsh conditions.

Apart from resilience, in case of firefighting applications, the use of drones is constrained by the relatively low payload, limiting their application mainly to fire monitoring and data collection. This problem was investigated by the HOPPERSUP (CSA) project, which developed a heavy-duty commercial drone, designed for transport of large water volumes and equipped with a system for spraying liquids able to cover a large intervention area. The central effort was the improvement of the flight control system to ensure stable and robust operations for the increased water payload (up to 600 litres). Undoubtedly, limited payload is not a challenge exclusive to the case of fire services. WINGTRAONE (SME-2) combined heavy payload capacity with long operational range and the possibility of vertical take-off and landing. The outcome is an autonomous hybrid drone able to land in confined areas as small as 2m x 2m, able to cover an area of more than 100 ha in a single flight. The vehicle is foreseen, among others, to be used for agricultural mapping, where it is reported to reduce the monitoring cost by over 70% and lead to significant $CO_2$ reduction. A cargo drone developed by the DRONAMICS (EIC) project can carry a 350 kg payload within a 2500 km flight range and requires only 400m of runway. The vehicle is 90% more affordable to produce and run than comparable alternatives. A fleet of such drones was applied to provide the first drone system for fuel-efficient, same-day, cross-border and long-haul cargo deliveries. The WINGCOPTER (EIB) project led to deployment of the world's first triple-drop delivery drone, intended for middle- and last-mile time-sensitive logistics. The vehicle can deliver up to three separate packages to different locations with a total weight of 5 kg during a single flight. The drone combines vertical take-off with speed of a fixed-wing aircraft, covering ranges up to 110 km in a single flight at a speed reaching 240 km/h.

The SKYE (SME-1) project proposed a drone concept for indoor operations, tackling some typical challenges for this type of applications. The risk of malfunction and resulting safety concerns was addressed by a helium-filled hull and a redundant propulsion system. As a result, the drone can fly safely above crowds with minimal adverse impact in case of malfunction. Moreover, it is equipped with a novel indoor GPS solution allowing for fully autonomous operation, and small and powerful impellers ensuring higher flight duration.

A distinctive example among the projects working on holistic vehicle concepts is HUUVER (IA). It is the unique initiative that attempted at integrating two different transport modalities into a single vehicle. The resulting UGV-UAV (unmanned ground vehicle – unmanned aerial vehicle) employs two types of propulsion systems and combines flying and driving capabilities in one compact autonomous drone. In addition to the vehicle itself, the project also developed a core management system with features like mission planning navigation, guidance and control.

Next to the projects developing holistic drone concepts, there is also the other large group – the ones focused on specific subsystems or functionalities. One of the recurrent themes is on-board energy and propulsion. Several initiatives were engaged in the research of fuel cell powered drones. UAVENDURE I (SME-1) and UAVENDURE II (SME-2) projects set out on a mission of enabling a small, light, long endurance electric drone able to operate without any landing infrastructure, which could provide an alternative to gasoline-propelled aircrafts usually employed for long-haul flights. The central element of the proposed design is a novel fuel cell technology combining multiple fuel cells into a system of fuel cell stacks able to provide required power output in the range of 250W. The resulting on-board energy system is expected to extend the range of small-winged UAs by the factor of 5-10. Short endurance of electric-propelled drones was also tackled by the HYBRID (EDF) project. However, in this case the scope is again more holistic, combining hydrogen fuel cell propulsion unit with ruggedised avionics and video detection into a compact system, intended specifically for military intelligence applications.

Several projects worked on propulsion technologies. APOLLO (SME-1) developed an electric turbine with both static thrust for vertical take-off and landing dynamic thrust for linear flight. The turbines are 2-4 times more efficient than other electric ducted fans. The technology is intended for distributed propulsion systems, where several small electric propulsion units is distributed on the surface of the aircraft. The turbines are foreseen mainly for urban air mobility applications. Distributed propulsion is also the focus of the SILENTPROP (IA) project, which investigated the problem of noise generated by such systems. The project deepened the understanding of the impact of flight conditions and propellers configuration on noise levels. Some of the outcomes include novel numerical methods for noise level predictions and techniques for noise mitigation, such as propeller phase locking, propeller shielding, locally resonant metamaterials and porous-media fuselage filling. B25TR (SME-1) designed a new compact and highly efficient turbocharged engine, producing high power output with a very high power-to-weight ratio. Thanks to 50% reduction of fuel consumption the engine enables aircrafts to reach higher altitudes at lower environmental cost. The solution can be applied to both drones and general aviation. Improvement of rotorcrafts fuel efficiency was also among the central objectives of the DREAM (IA) project. It was achieved by innovative design of the main elements constituting the engine compartment such as cowlings (composite coverings housing the engine), air intake and engine bay ventilation. Moreover, the new design contributes to higher cruising speed and is hoped to bring the performance of rotorcrafts closer to propeller-driven planes. ENGRT (EDF) focuses on the next generation rotorcraft technologies, analysing the future needs, key future rotorcraft features and capabilities, alternative rotorcraft platforms, flight demonstrators and simulators. Some of the investigated topics are hybrid propulsion, use of advanced materials, novel structural solutions, and modular open system architecture.

A significant amount of attention was devoted to the topic of sensors. MAGYCO (SME-1) contributed to development of Communication, Navigation and Surveillance (CNS) systems used to measure attitude of an aircraft. They are composed of a set of inertial sensors called gyros and accelerometers. The project developed an innovative aerospace grade Inertial Unit based on miniaturized vibratory gyros with autonomous north-finding capabilities. Sensors are particularly relevant for collision avoidance. PERCEVITE (IA) addressed the challenge of avoiding ground-based obstacles such as trees and buildings by developing a sense-and-avoid technology for small drones. The solution makes use of cheap, light and widely available hardware to avoid compromising the vehicle payload and maintain low cost. A lightweight sensor and processing package was designed, detecting obstacles by fusion of stereo vision, motion, appearance, ranging and audio information. The weight of the suite amounts to a mere 46 grams. The package allows also for collaborative collision avoidance by exchanging information with other UASs. In a similar manner, the ODESSA (IA) project employed mature and low-cost technologies from automotive sector for developing a novel collision avoidance technology for drones. The result is a small and lightweight sensor for short-range obstacle detection, combining radar technology derived from advanced driver assistance systems with advanced image processing algorithms. The sensor can be also applied to airplanes and helicopters, especially for take-off and on-ground manoeuvres. Leveraging of automotive solutions in the drone domain is quite common, as it allows to take advantage of their reliability and low cost. ADACORSA (IA) is yet another project employing this approach. It focused on improving safety of beyond visual line of sight drone operations, by advancing research in components and systems for sensing, telecommunication and data processing. Several technologies from automotive domain were applied, such as radar and LiDAR sensors and 3D cameras, along with hardware and software for accurate sensor fusion and data analytics. The project also developed technologies for secure and reliable drone communication.

Some projects investigated the topic of power supply. DRONES4SAFETY (IA) explored the broad subject of drone application to bridge and railway inspection. Within this domain, one of the achievements was a design of energy harvesters able to tap energy from the overhead electricity infrastructures of railways and power lines for drones recharging. The ELISTAIR (SME-1) project investigated a wired power supply system, able to provide extended flying time for inspection and surveillance drones operating in a fixed radius.

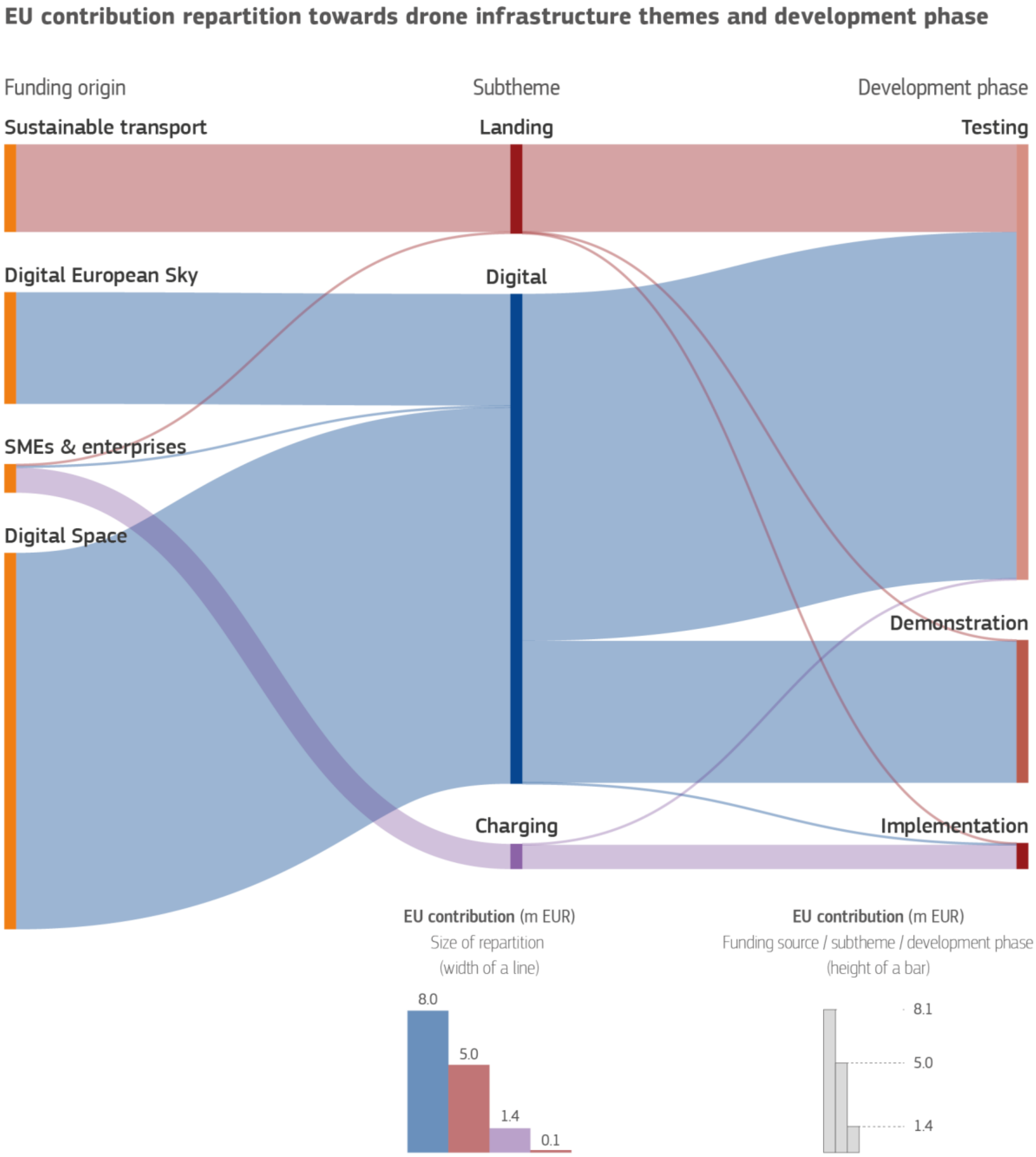
Other than the physical subsystems described above, there is also the other large category of projects, focusing on more software-oriented vehicle components. Noticeable attention was paid to drone flight control systems. INCEPTION (IA) addressed shortcomings of the traditional control systems design, based on linear control theory. The project developed an adaptive control system applying a nonlinear approach, able to autonomously reallocate control resources under unconventional and unforeseen failure scenarios, ensuring safe and steady aircraft control even in the presence of actuator failures or configuration changes. The AST-FCS_VF (SME-1) project proposed an Adaptive Self-Tuning Flight Control System, a novel solution to be integrated into the existing flight control systems for better conformity with the UA-specific control requirements. The underlying objective of CORVID (SME-1) was to find a remedy for the ever-increasing shortage of qualified pilots, further aggravated by the emerging market of flying taxis. The project set out to develop an AI-based autopilot able to replace a human pilot, in particular for this new transport mode. A common challenge in the flight control domain is autonomous navigation in GPS-denied environments. The AGILEFLIGHT (ERC) project investigated methods for enabling manoeuvres in such circumstances, and even more complex ones, characterized by cluttered and moving objects. The main outcome of the project were novel algorithms combining inputs from standard cameras and event cameras. In the same vein, AUTOFLY (EIC) developed a platform for autonomous operation of drones in similar, complex environments. The platform utilizes advanced algorithms for vision-based orientation and navigation, real-time detection and tracking, visual positioning and autonomous inspection. It also enables constant communication to mission control with minimal network bandwidth use. GEONAV_IOT (IA) delivered a positioning and navigation system combining data from a high-precision positioning algorithm, based on a fusion of GNSS with Internet of Things (IoT) network. Lastly, the AIRSENS (MSCA) project also inquired navigation and control in GPS-deprived settings, but specifically for the case of drone swarms. The project investigated swarms mapping capabilities enhanced by crowd-sensing mechanisms and information-seeking control for navigation. In this approach each drone in the swarm acts as an autonomous agent, communicating and collaborating with the surrounding drones to detect and avoid the obstacles.

## 4.3 Infrastructure

### 4.3.1 Overview

Drone infrastructure is the physical infrastructure, including landing pads, vertiports, and the charging infrastructure, as well as the digital infrastructure for telecommunications and data centres for navigation and traffic management. In the identified list, few projects investigated physical infrastructure for drones, and for those projects, landing and charging was not the main focal point. Digital infrastructure on the other hand has attracted significant attention, as robust space geolocation services and telecommunications are prerequisites for unmanned air traffic. The projects include 6 under RIA actions (ca. EUR 20 million of EU funding, 4 under IA (ca. EUR 8 million), and 2 SME-1 projects. The following section investigates the results and innovations of the identified projects.

**Figure 14.** Repartition of EU funds on drone infrastructure components and their development phase




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

### 4.3.2 Project analysis

Few projects investigated physical infrastructure for drones. Again, one of the addressed topics is power supply. Some initiatives developed charging infrastructure (docking stations) as a part of a comprehensive system of drones for a specific application, e.g. AIRCARRUS (SME-1, autonomous drone delivery system) or SKYSAVER (SME-2, transport of medical supplies). However, it should be highlighted that charging was not the main point of interest in any of the cases.

Several projects investigated the topic of landing infrastructure. The RAPID (IA) project, within its broader scope of maritime infrastructure surveillance, developed a take-off and landing system, able to operate within 5 cm accuracy. Two projects addressed landing infrastructure in an indirect manner, by proposing solutions enabling drones to land under any circumstances and independently of any special infrastructure. One of them is REALISE GROLAS (SME-1), which investigated a mobile ground-based landing gear system. Apart from decoupling landing from infrastructure, the technology removes the need for an undercarriage, allowing thereby for extra payload and reduction in fuel consumption. LOLAS (SME-1) tackled the problem of landing in difficult conditions, such as severe weather, poor visibility or on a moving platform. The project developed a local landing system, a novel solution consisting of the on-board and ground equipment that communicate with each other during approach across different channels. The system is resistant to jamming or absence of satellite navigation and allows for centimetre-grade precision.

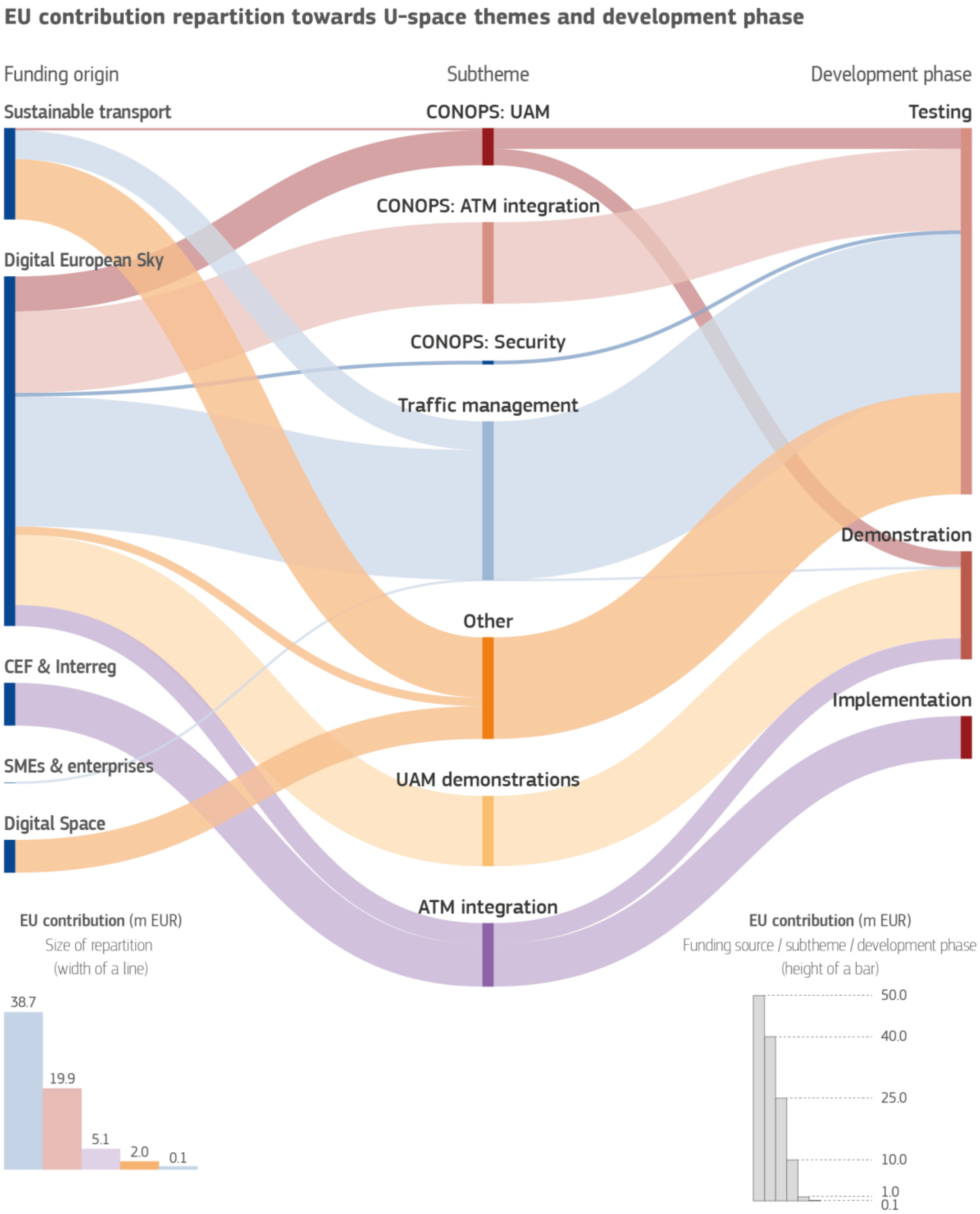
Substantial attention was devoted to digital infrastructure, particularly to telecommunications and satellite services. The 5G!DRONES (RIA) project carried out large-scale trials to prove that 5G infrastructure can support the simultaneous running of several types of drone services, using network slicing. The project tested several use cases covering a variety of 5G services. PRIMO-5G (RIA) demonstrated an end-to-end 5G system providing immersive video services for moving objects focused on vehicular and aerial drone settings. Some of the developments include millimetre wave radio technologies, interoperable 5G core networks, and AI-assisted communications. Some projects investigated cellular technologies applications for drones. The objective of DROC2OM (RIA) was the definition of an integrated cellular-satellite data link specification for UAs. The project delivered a system architecture concept for the proposed solution, and evaluated the data link based on experimental radio investigations and system simulations. The EMPHASIS (SESAR-RIA) project investigated cellular signals in the context of rotorcrafts and general aviation. Among others, the project explored the possible use of 4G/5G network for aerial communications, and positioning using a combination of cellular network with satellite-based and inertial navigation. FACT (SESAR-RIA) inquired innovative use of existing infrastructure and technology bricks to update the communications, navigation and surveillance for the future air traffic management. SAPIENT (SESAR-RIA) explored the possible synergies of CNS technologies and the 4D trajectory management concept. The developed innovation is based on the integration of accurate estimations of the flights 4D trajectories with data from air traffic management air/ground datalinks carried out by aircraft transceivers linked to the new navigation infrastructure. Several projects focused on GNSS application to UAs traffic management. GAINS (SESAR-IA) validated, through live demonstrations, some innovative navigation and surveillance concepts enabled by GNSS and EGNOS services. DELOREAN (IA) investigated the case of urban air mobility, evaluating feasibility and readiness of EGNSS as an enabler for navigation and positioning of drones in the future city sky. The GAUSS (IA) project developed a drone positioning system focusing on very low-level (VLL) operations, based on combination of multi-constellation GNSS and internal sensors data fusion. The project tested feasibility of some exceptional features of Galileo and EGNOS for U-space services, such as UTM simulators and tactical deconfliction. Similar work was carried out within the SKYOPENER (IA) project, which developed a drone navigation system integrating technologies such as GNSS, satellite communication and security tools. REVOSDR (SME-1) addressed the technological limitations of wireless communications systems connecting the drone and its operator. The project developed a wireless modem for drone communications employing software-defined radio technology, where radio operations are programmed in software. The system continuously monitors the data link quality and adjusts radio parameters accordingly (including frequency, link speed and transmission power). Finally, the TRANSDAT (SME-1) project also investigated long-range drone communication, proposing a satellite-based communication system to monitor drone position and orders through a base station, tablet, or a mobile phone.

## 4.4 U-space

### 4.4.1 Overview

U-space, the European unmanned aircraft system traffic management system, has received significant attention, as it is a prerequisite for the safe increase of drone traffic and for achieving urban air mobility. 26 of the 38 reviewed projects are part of the SESAR work programme. The RIA actions cover the definition of the U-space concept of operations (CONOPS), a set of operational requirements for an unmanned traffic management system, as well as development of necessary functions and services of the U-space, with a strong focus on drone separation and deconfliction. The large-scale demonstrators undertaken under IA and CEF aim to put to test the developed concepts and services in real conditions and also generate data for their refinement. The following paragraphs examine the aspects of U-space developed in each project.

**Figure 15.** Repartition of EU funds on U-space technology themes and their development phase




*Source: TRIMIS, JRC, 2024 based on TRIMIS and CORDIS data*

### 4.4.2 Project analysis

The research efforts regarding U-space can be classified into several subdomains. One of the prominent themes is development of a concept of operations for drones. A concept of operations describes the characteristics for a proposed system from the user's perspective, providing qualitative and quantitative information on its utilisation and behaviour. In the U-space context the concept of operations aims at answering the basic question 'how the U-space should work' and providing a common ground for further definition of details. In this sense the drone concept of operations outlines definitions and operating principles for the operating environment (e.g. phases of flight, rules for airspace management, ground infrastructure, system architecture etc.) and for specific

U-space services (e.g. drone registration and monitoring, traffic information, weather monitoring, management of conflicting flight paths, etc.). These efforts can be further assigned into two broader categories: concept of operations for urban air mobility and for U-space and air traffic management integration.

The METROPOLIS (CP-FP7[10]) project was one of the early attempts at concept of operations definition for urban air mobility. By the means of simulation, it explored the potential future urban scenarios with high air traffic densities and derived the initial requirements for the future airspace. Building on these results, METROPOLIS 2 (RIA) developed concepts for U3/U4 level services, such as strategic and tactical deconfliction, and dynamic capacity management. Various services were validated by means of simulation, and the most promising ones were further tested in real-world demonstrations. CORUS (SESAR-RIA) developed a concept of operations for safe drone operations in very low-level airspace, further extended within the follow-up project CORUS-XUAM (SESAR-IA) by aspects specific to urban air mobility. The USEPE (RIA) project delivered a concept of operations for safe drone separation in crowded urban airspace, also contributing to the development of machine learning algorithms for deconfliction automation.

A significant group of projects focused on developing concept of operations for safe integration of drones into the existing air traffic management ecosystem. X-TEAM D2D (RIA) aimed at developing concept of integrating air traffic management into overall intermodal network at urban and extended urban levels, to enable door-to-door connectivity, in up to 4 hours, between any location in Europe. The developed concepts were validated by a simulation platform created within the project. INVIRCAT (SESAR-RIA) investigated ways of incorporating remotely piloted aircrafts into the existing air traffic control procedures and infrastructures, including automatic take-off and landing procedures. The PJ01-W2 EAD (SESAR-RIA) project engaged in a similar activity, developing concept of operations to enhance the use of the controlled airspace within the airport and enable greater use of optimised climb and descent operations. TERRA (SESAR-RIA) identified new operational and functional requirements for U-space and air traffic management integration and analysed the possible applications of existing air traffic management technologies to unmanned aircrafts traffic management. Two projects focused on data handling. DREAMS (SESAR-RIA) developed a concept of operations for aeronautical information management, putting together the knowledge of mission needs and operational requirements of drone operators with the operating modes and procedures currently adopted in commercial and general aviation. On the other hand, PJ34-W3 AURA (SESAR-RIA) proposed a concept of operations for U-space information exchange with ATM systems. It identified the requirements for information exchange through system-wide information management and conducted some validation exercises to test the developed concepts.

Finally, the SECOPS (SESAR-RIA) project investigated a unique aspect compared to the other concept of operations -related initiatives. The activity focused on the security of drone operations, developing an integrated security concept. The proposed concept of operations covers resistance of drones against unlawful interference and integration of geo-fencing technology. It focuses on technological options (navigation, surveillance, in-flight updates, etc.) for both airborne and ground elements, considering legal, regulatory, and social aspects.

A broad category of projects within the U-space domain are the initiatives aiming at development of specific tools and services. Several projects worked on traffic management systems, with strong emphasis on drone separation. BUBBLES (SESAR-RIA) worked on minimum separation distance between drones and deconfliction methods for very low-level operations. The delivered algorithms compute the collision probability between UAs using the developed separation minima to keep it under acceptable levels. AI was applied to dynamically manage these minima using different separation methods and agents. The CLASS (RIA) project was one of the early attempts at developing a UTM. The project combined a variety of cooperative and non-cooperative UAs technologies into a preoperational prototype of U-space. The delivered platform provides an overall view of both the planned and the current real-time airspace situation. LABYRINTH (RIA) further advanced the U-space system concept, with a system design capable of communication with the drones in a certain area, processing their desired origin and destination points and computing paths to avoid collisions. One of the key deliverables of the project are path-planning algorithms for implementation in ground control stations to support auto-guidance of drone swarms. ONESKYCONNECT (SME-1) developed an in-house UTM system employing data from

[10] The METROPOLIS project is part of Framework Programme 7 and is the only project from this funding scheme featured in the report. It was included as the predecessor of the METROPOLIS 2 project to demonstrate the continuity between the two initiatives.

ground-based receivers, allowing drones to safely share the sky with manned aviation thanks to automatic collision avoidance tools. On the other hand, the MONIFLY (RIA) project based its UTM concept on the existing mobile network infrastructure. Such approach allows for geofencing applications that use static databases and high-dynamic update rates, greatly reducing the risk of potential collisions. DACUS (SESAR-RIA) developed a demand and capacity balancing process for drone traffic management. The developed algorithms and technologies allow to find the optimal balance between on-board separation intelligence and U-space separation service intelligence. The objective of PJ10 PROSA (SESAR-RIA) was to develop tools for air traffic management automation, to delegate some of the tasks away from human operators, thus freeing their capacity for situations where human intervention is crucial. In particular, the project addressed separation management, including management of drones deconfliction. AIRPASS (SESAR-RIA) analysed the enabling technologies for U-space on the vehicle side. It covered detect-and-avoid systems for cooperative and non-cooperative traffic, autopilot components, and communication, navigation, and surveillance systems. The project identified the available infrastructure and on-board technologies and formulated an implementation approach for successful integration of unmanned aircraft systems and U-space. The on-board detect-and-avoid systems were also addressed within the AEROBITS (SME-1) project, which developed an Automatic Dependent Surveillance–Broadcast (ADS-B) technology. The device can be used in small-scale modules and combined with secondary radar technology ensures safe separation between drones and other aircrafts.

Another large subdomain of U-space projects covers large-scale demonstrations. The goal of such campaigns is deepening the initial concepts and bridging the gap between development and deployment of U-space services. Again, also in this case the initiatives can be approximately categorised into those oriented on urban air mobility and the ones testing the U-space and air traffic management integration. The PODIUM (SESAR-IA) project was one of the early large-scale demonstration campaigns, with the objective of demonstrating state-of-the-art U-space concepts in operational environments, assessing their maturity, and making recommendations for the future developments. In total, more than 185 flights were carried out in a variety of conditions, bringing together drone manufacturers and users, air traffic management actors, infrastructure providers and local authorities. The USIS (SESAR-IA) was another of the early-stage initiatives, demonstrating the feasibility of short-time deployment of essential U-space services, such as drone registration service, flight notification, authorisation, and basic traffic monitoring. AMU-LED (IA) and USPACE4UAM (IA) projects tested operations in U-space for several types of UAs in different urban scenarios, use cases and applications, e.g. air taxis, emergency services, delivery of goods, and surveys. Also SAFIR-MED (IA) conducted demonstrations in the urban context, but in contrast to the other initiatives, it focused particularly on medical transport applications. The TINDAIR (IA) project demonstrated safe integration of drones into crowded urban airspace of the future, focusing on tactical deconfliction (U3 level service). The service tested within the project detects possible conflicts and sends instructions to change aircraft speed and trajectory to avoid the conflict, and subsequently to guide the rerouted aircraft back on course. The VUTURA (SESAR grant) addressed the problem of sharing the same urban airspace by multiple U-space services providers. The demonstrations contributed to improving interoperability of various drone types and service providers, proving feasibility of airspace sharing and highlighting the need for further development of flight planning, monitoring and procedures, for example for cross-border flights.

A number of large-scale demonstration projects tested the U-space and air traffic management integration. SAFEDRONE (SESAR-IA) tested very low-level operations where general aviation, state aviation, piloted aircrafts and drones will share the same airspace. The project accumulated evidence and experience about the required services and procedures for implementation of some of the foreseen U-space services, e.g. electronic registration and identification, flight planning and control, geofencing and flight tracking. The GOF2.0 (IA) project addressed integration of drone operations into ATM airspace in the urban context. Demonstrations validated U-space architecture for highly automated real-time separation assurance in dense air space including precision weather and telecom networks for air-ground communication. EALU-AER (SESAR-CEF) demonstrated integration with air traffic management by testing some U1 and U2 level functionalities. The tested scenarios focused on BVLOS operations, including use cases such as local inspection, light-freight, long-distance logistics, and air-taxi operations. U-ELCOME (SESAR-CEF) is a related project, testing similar U-space architecture operations (U1 and U2), focusing especially on information exchange and coordination between U-space service providers and air traffic management. The project developed and carried out testing campaigns in 15 locations distributed in Spain, Italy, and France.

Several projects developed specific U-space related products, which do not easily fall into any of the broader categories. ICARUS (SESAR-RIA) tackled the problem of altitude measurement for UASs. Since, unlike in the case of manned aviation, drones can take off and land almost anywhere, the conventional way of using a common altitude reference for determining altitude of an aircraft is challenging. The project developed an U3 level service based on the actual positioning of the drone along its trajectory, computed by a GNSS receiver. The output of the system provides information on distance from the ground and obstacles in combination with the common altitude reference. The IMPETUS (SESAR-RIA) project explored a smart UTM concept based on the Function-as-a-Service paradigm. The solution utilizes a cloud-based, serverless environment to respond to multiple users with diverse business models and assures the data quality and integrity necessary for UTM-ATM integration. REFMAP (RIA) investigates the environmental aspect of air traffic management. The core theme of the initiative is green planning – it develops a digital service aimed at quantifying the environmental footprints of air mobility for airliners and unmanned aircraft systems at a multi-scale level, where single-trajectories (micro) and the flow traffic of multiple vehicles (macro) are optimised to minimise their environmental impact. In addition, the project explores the impact of the availability of environmental data on aviation business models. The ORCHESTRA (RIA) project tackled the challenge of seamless integration of drones in the existing multimodal transport network. The main deliverable is the Multimodal Traffic Management Ecosystem in which traffic managements in different modes and areas (rural and urban) are coordinated to produce a more balanced and resilient transport system. The project delivered a Polycentric Multimodal Architecture (PMA) specifying how diverse system components interact, considering smart infrastructures, technical and organisational aspects and polycentric governance. AURORA (RIA) is a large multi-faceted project focused on safe urban air mobility. The project developed and integrated safety-critical technologies to support autonomous drone operations in urban environments, ranging from autonomous UASs architecture and path planning algorithms to fast obstacle detection systems and radar for wire strike avoidance. COMP4DRONES (RIA) delivered a framework of key enabling technologies for safe and autonomous drone applications. The initiative focused on five applications: transport, construction, surveillance and inspection, logistics and agriculture. The project offered an embedded platform featuring reusable, qualified components, as well as an agile engineering environment to support development of drone industry.

# 5 Research on environmental and socio-economic impacts of drones

## 5.1 Main trends in research on impacts of drones

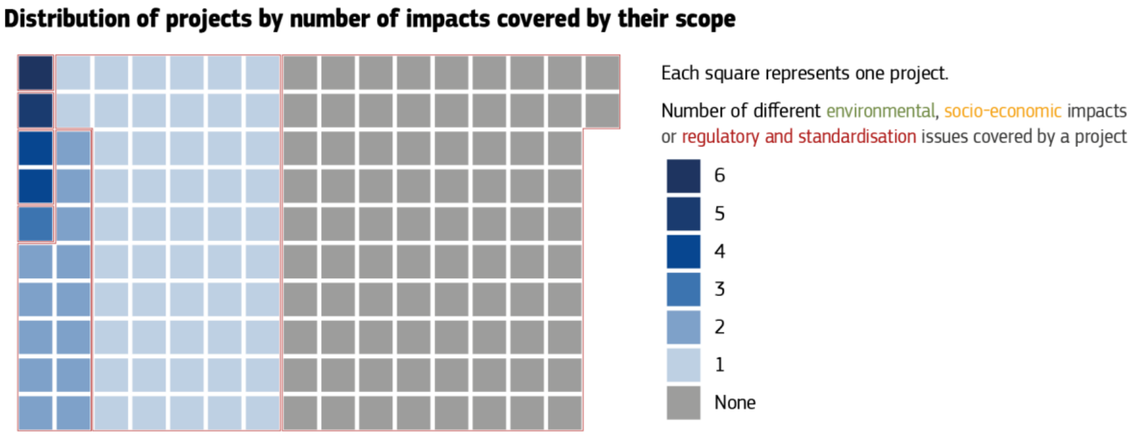
This section of the report explores the research conducted on the environmental and socio-economic impacts of drones. Figure 16 presents a comprehensive list of presented topics, and the review provides examples how these topics are addressed within identified European research and innovation projects.

**Figure 16.** Main impacts of drones in European research and innovation activities


*Source: TRIMIS, JRC, 2024*

In total, fewer than 50% of the reviewed projects explored environmental or socio-economic impacts of drones, or regulation and standardisation topics (Figure 17). Of these projects, the majority provided insights into one of these areas, while a small number of individual projects investigated three or more.

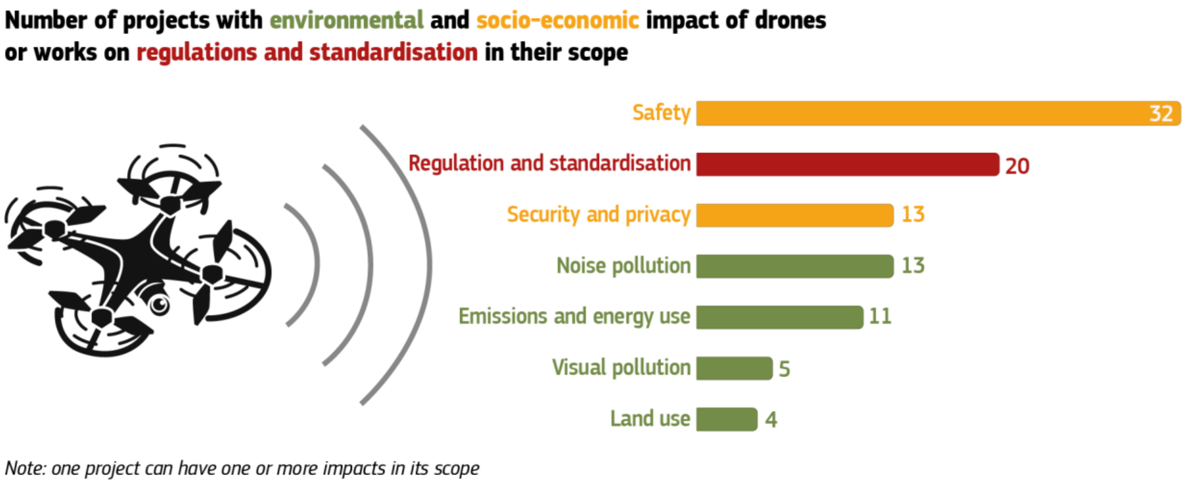
**Figure 17.** Number of different impacts of drones investigated by reviewed projects




*Source: TRIMIS, JRC, 2024*

Safety is the most frequently studied topic among the reviewed projects, encompassing all environmental and socio-economic impacts of drones (Figure 18). Additionally, other projects often address safety-related subjects or have been implemented with safety considerations in mind. There was also a considerable focus on regulations and standardisation, with several projects dedicated to this area. Furthermore, security and privacy concerns were addressed by a noteworthy number of projects, indicating a significant level of attention in this area. In terms of environmental impacts, several projects focused on emission and energy use, while others addressed noise pollution. Additionally, a smaller number of projects were dedicated to assessing land use and visual pollution impacts. Overall, the distribution of project focus across these different impact areas provides valuable insights into the priorities and areas of emphasis within the field of drone research and innovation.

**Figure 18.** Number of projects covering particular types of impacts of drones in European research and innovation activities

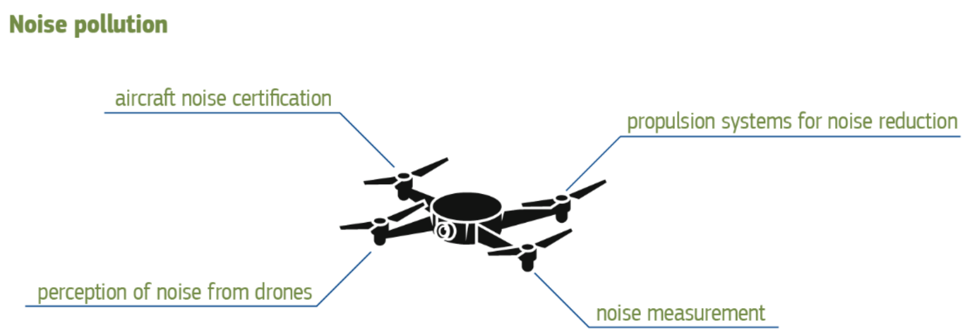



*Source: TRIMIS, JRC, 2024*

## 5.2 Noise pollution

A few projects have specifically addressed the impact of drones on noise pollution. The FP7 METROPOLIS project made progress in the field of **noise measurement**, applicable metrics, prediction, and noise pollution assessment for future urban air traffic systems. AIRMOUR developed a noise mapping tool that enables the assessment and visualisation of noise levels generated by drones. DACUS focused on summarizing noise influence factors and examining the impact of drones on citizens, while ASSURED-UAM assessed noise constraints for the social acceptance of urban air mobility. Similarly, SAFIR-MED examined the hindrance caused by noise generated by urban air transport and proposed methods for **aircraft noise certification**. Lastly, HARMONY conducted noise tests to gain an understanding of how noise generated by drones is **perceived** by people. The results of the latter study indicated that high noise levels significantly impact the decision-making behaviour of bystanders, particularly women.

**Figure 19.** Main topics in European research on impacts of drones on noise pollution




*Source: TRIMIS, JRC, 2024*

AUDAX AERO and SILENPROP projects focused on enhancing **propulsion systems** for drones with the aim of reducing noise pollution. AUDAX AERO designed a VTOL aircraft with a hybrid propulsion system that effectively reduces noise levels while improving flight distance. SILENPROP, on the other hand, concentrated on understanding the primary noise aspects associated with Distributed Electric Propulsion (DEP) configurations. They conducted simulations and experimental studies to explore potential solutions for noise reduction, evaluating technologies such as noise suppression and shielding.

## 5.3 Visual pollution

Visual pollution has received limited attention in drone-related research and innovation projects. ASSURED-UAM project includes an analysis of visual pollution as part of its broader review of potential environmental impacts of urban air mobility. The DACUS project has assessed that visual pollution is among the most important negative **influence factors** resulted from drone operations. The recently finished AIRMOUR project proposed a perception-based quantitative indicator to express visual pollution. The indicator was developed using an image-based questionnaire. The results confirm that visual and noise pollution decreases with distance and increases with the number of drones. However, the study shows that indicators have a non-linear character and a change in disturbance from additional drones decreases when more aircraft are already in the air. Based on these results, the project also prepared a **mapping tool** which can be used for path planning and airspace management system. Apart from noise and visual pollution, the tool takes under consideration collision risk while optimising total length of flights. The results show also that path planning for drones should be coordinated and the consortium propose a hypothesis that future drone flight paths should be organised within a pre-defined UA-corridors. The recently started HE IMAFUSA project includes on **perception** of visual pollution in their study on societal acceptance of urban air mobility.

**Figure 20.** Main topics in European research on impacts of drones on visual pollution


*Source: TRIMIS, JRC, 2024*

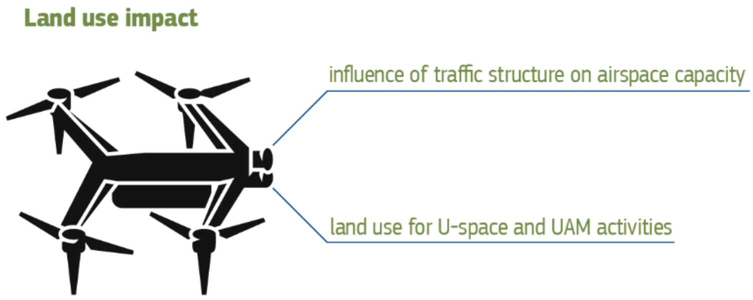
## 5.4 Land use impact

The assessment of transport impact on land use is typically addressed in general transport projects, with only a few specifically focusing on the impact of drones. The FP7 METROPOLIS project examined the **influence of traffic structure on airspace capacity**. The findings suggest that traffic structuring should consider the anticipated traffic demand pattern to optimise capacity. Additionally, for the heterogeneous, or uniformly distributed traffic demand patterns a decentralized layered airspace concept was most effective. This approach involves restricting horizontal travel within a specified heading range for each altitude band, resulting in the most balanced performance across all metrics.

Building on these results, the H2020 METROPOLIS 2 project developed and compared different dynamic capacity and separation management concepts for drones: the centralized, hybrid and decentralized approach. The centralized approach ensures optimal flight coordination and efficiency through centralized management. The hybrid concept integrates centrally optimized strategic planning with decentralized tactical separation management, where individual drones are responsible for their own separation during operations. In the decentralized approach, drones handle separation management without any central coordination. The results show that the hybrid concept improved safety and airspace alignment compared to the other approaches. However, it also revealed a trade-off between efficiency and safety in urban air operations, as it requires more flight distance and time compared to the other approaches.

The results of SAFIR-MED project highlight the importance of considering **land use for U-space and urban air mobility activities**. This involves the establishment of ground infrastructure, such as vertiports and landing areas, along with the vertical space occupied by UAs. The recently initiated CITYAM project aims to assist cities in adapting their planning practices in relation to landing sites and airspace management. The project also seeks to scale city-owned drone operations and integrate them into a cohesive multimodal transport system.

**Figure 21.** Main topics in European research on impacts of drones on land use

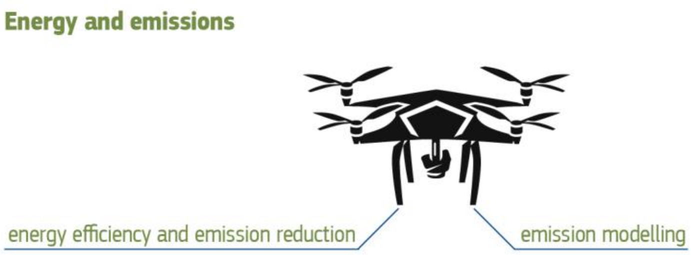



*Source: TRIMIS, JRC, 2024*

## 5.5 Energy and emissions

There are two main subthemes within drone-related projects which covered impact of drones on energy usage and emissions. The first one focused on increase of **drone energy efficiency and emission reduction**. HUUVER aims to surpass current drone capabilities by increasing payload capacity to 3 kilograms and extending active flight time to 20 minutes without generating environmental pollution. Additionally, HUUVER's drone can function as a ground vehicle for up to 40 minutes, contributing to energy savings. The SKYSAVER project conducted analysis of the air quality impact of UAs in cities, emphasizing the positive impact of electrically powered drones on reducing air pollution. It presented the solution which uses a network of zero-emission drones, capable of autonomously navigating the shortest routes with a payload of 1.5 kg, specifically designed for emergency healthcare delivery. Finally, the ongoing RAPID project is working on smart energy management systems to increase the reliability and efficiency of power systems on unmanned aircraft systems.

**Figure 22.** Main topics in European research on impacts of drones on energy and emissions




*Source: TRIMIS, JRC, 2024*

The second group of projects concentrates on **emissions modelling**. The AIRMOUR project developed a $CO_2$ emissions dashboard tool for visualizing and modelling end-to-end emissions in the urban air mobility ecosystem. The system encompasses airborne, ground, and other transport mode emissions. The OASYS project quantified the environmental and emissions outcomes of future advanced air transport systems, including urban air mobility. The SAFIR-MED conducted the air quality impact of UAs in cities as deployment of drones will have implications for air quality, both during operation and from a life cycle perspective. Moreover, the infrastructure required for urban air mobility, such as vertiports, will also impact air quality. The study concludes that most drones are expected to have a positive impact on air quality in cities, as they are designed to be electrically powered or use hydrogen fuel cells, which produce minimal air pollution.

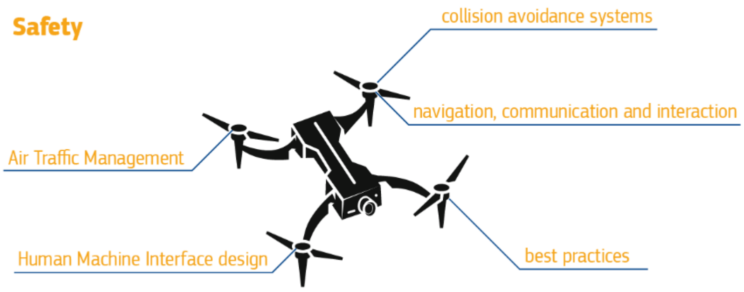
## 5.6 Safety

Several projects worked on developing **collision avoidance systems** and determining the necessary **separation minima** for safe operations in shared air space. The ODESSA project developed a light anti-collision system compatible with VTOL aircraft, while ADACORSA focused on sensor development and demonstrated automatic take-off and landing capabilities to enhance drone avionics with collision detection and avoidance capabilities. The RAPID project worked on minimizing the risks of drone collisions using a mixed reality digital twin that models airborne hazards. It also developed LiDAR simulations to evaluate hazard identification. One of the successful outcomes of this project was the validation of a 2-km range for the detect and avoid system. Finally, the recently started SPATIO HE project is going to work on relationship between separation and capacity in U-space airspaces.

The PERCEVITE project utilized mature communication systems to enable the exchange of position and velocity information between drones, facilitating collision avoidance with other drones and ground-based obstacles. TINDAIR addressed collision avoidance by implementing individual air corridors and conducted demonstrations of mixed traffic operations involving eVTOL aircraft, drones, and helicopters, including scenarios such as merchandise delivery, person transport, and emergency situations. The ICARUS project developed the Vertical Alert Service, an algorithm capable of performing multiple complex calculations simultaneously. Vertical Alert Service alerts drone pilots to the presence of ground obstacles or other drone traffic in close proximity. The BUBBLES project focused on developing algorithms for determining separation distances based on a risk-based, operation-centric collision model. They utilized AI decision-making and Machine Learning techniques to automate computations. Similarly, the USEPE project developed a novel separation method known as the dynamic density corridor concept. This concept involves dynamic traffic density segments, high-speed corridors with reduced conflict risk, and a general syntax for guiding aircraft trajectories.

Another significant topic in drone research and innovation is related to **navigation, communication, and interaction** between airspace users. The EMPHASIS project aimed to enhance safety by improving the reliability of satellite-based navigation systems (GNSS) for drones operating at low altitudes (below 500 feet). To achieve this, the project integrated the GNSS system with supplementary position methods, including 4G positioning reference signals and an Inertial Navigation System that utilizes measurements from accelerometers and gyroscopes. The LABYRINTH project focused on developing an algorithm for centralized planning of multiple UAs to avoid collisions and manage interactions with other drones. The AMU-LED project specifically addressed the safe interaction of urban air mobility with other airspace users in complex urban environments. It identified key points of interaction between U-space users and defined a data model for the exchange of information between them. Finally, the INCEPTION project aims to develop a robust flight control system that can adapt to unforeseen failures and configuration changes. The project focuses on predicting and adapting to safe flight regimes, contributing to the future development of flight control systems.

**Figure 23.** Main topics in European research on impacts of drones on safety




*Source: TRIMIS, JRC, 2024*

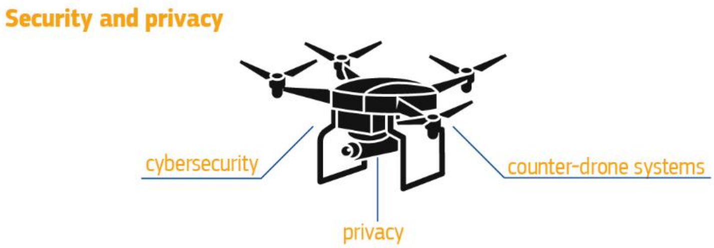
The SKYOPENER project focuses on mitigating human error and reducing safety threats through the development of safety systems and the implementation of a **Human Machine Interface** (HMI) design. The CO2TEAM project also works on improving pilot interfaces and communication with the ground.

The DREAMS project has developed the Specific Operations Risk Assessment (SORA) methodology for drone operations. This methodology helps assess and mitigate risks associated with specific drone operations. The CORUS-XUAM project aims to improve safety through the development of aerial operating procedures in urban areas and the enhancement of governance in U-space. The CORUS project concentrates on **air traffic management** in very low-level airspace (below 150 m). It has developed contingency plans, incident/accident investigation requirements, and methods for quantifying safety, security, and risks in this airspace. Lastly, the ASSURED-UAM project collects and promotes **best practices** in urban air mobility, ensuring the adoption of safety standards and protocols.

## 5.7 Security and privacy

The identified projects have contributed to research and innovation in the field of drones across three main areas: counter-drone systems, cybersecurity, and privacy. In the area of **counter-drone systems**, the KNOX project proposed an early warning system for drone detection. Other projects focused on protecting specific areas, such as airports and maritime areas.

**Figure 24.** Main topics in European research on impacts of drones on security and privacy




*Source: TRIMIS, JRC, 2024*

The COMPASS2020 project introduced a range of new services, including anomaly detection, classification, risk assessment, predictive analysis, and optimized operations using unmanned platforms. The ASPRID project explored innovative concepts and technologies for safeguarding airports from drone threats. The proposed solution extends counter-drone systems as it assesses the threat caused by the incursion, monitors drone data, produces zone trespassing alerts and supports communication with the concerned actors. Moreover, provides a coordinated mitigation procedure and supports neutralization actions. The CLASS project specifically focuses on developing surveillance technologies for unmanned aircraft systems traffic, with a particular emphasis on counter-drone systems for protecting sensitive sites like airports. The project involves the implementation of real-time tracking capabilities and deconfliction algorithms to determine if a drone is authorized or not. Finally, the SKYFALL project developed a European matrix outlining strategies for protecting and responding to various types of UA incidents. This matrix takes into consideration the location and nature of the event. Moreover, the project evaluated and ranked all currently available systems suitable for physical drone interception, considering factors such as the ability to detect different types of UAs, ease of transport and deployment of a device, as well as its effectiveness and efficiency.

SAFIR-MED project highlighted a need of a new indicator to evaluate the level of **cybersecurity** of urban air mobility technologies, however it has not proposed any practical solution. The AIRMOUR project presented a report on cybersecurity threats specific to emergency medical scenarios. The review threats include an unauthorised access, ransomware and malware, GPS spoofing (providing a drone a falsified GPS data), Wi-Fi jamming or interception of communication between a drone and urban air mobility infrastructure, DoS (overloading coordination system), or risks of technical and operational issues, among others. The SECOPS project conducted a comprehensive assessment of potential security risks in Unmanned Traffic Management and summarized its findings in a report that identifies discovered security gaps. Building upon this analysis, Security Concept of Operations prioritized these risks and developed an integrated security concept to address them. Lastly, the GAUSS project focused on the security of the GNSS system, specifically addressing anti-jamming and anti-spoofing capabilities of the Galileo EGNOS systems.

The AIRMOUR project has developed privacy guidelines to address concerns related to urban air mobility applications, particularly in emergency medical service scenarios. The guidelines start with the presentation how the privacy may be defined and how a definition may vary in different context followed by definition of main stakeholders of a system and allocation of roles and responsibilities. Then, the guidebook highlights a need of definition of what type of data needs to be collected, by whom, for whom and for what purpose. Next point shows an importance of a proper risk assessment in order to develop necessary mitigation procedures. These guidelines aim to ensure the protection of **privacy** in the use of drones for medical purposes. The DRONERULES PRO project focuses on creating a privacy culture within the commercial drone industry. It achieves this through an online course that trains professionals to recognize and mitigate privacy and data protection risks associated with drone operations. This initiative provides valuable resources and training to promote privacy compliance within the European drone industry. These initiatives contribute to establishing clear guidelines and promoting awareness of privacy considerations in the use of drones, ensuring the protection of individuals' privacy rights.

## 5.8 Regulation and standardisation

The identified projects have conducted comprehensive **reviews of regulations and standards** related to the use of drones. The 5G!DRONES project focused on reviewing regulations and legislation in the drone market, examining the existing legal framework surrounding drone operations. The 5D-AEROSAFE project synthesized legal texts and procedures for the use of UAs in various airspace environments. This project aimed to provide a comprehensive understanding of the legal requirements and procedures governing drone operations. The CORUS-XUAM project developed recommendations for urban air mobility safety regulation and standardisation. It aimed to address the regulatory challenges and establish standardized safety frameworks for the integration of urban air mobility into existing airspace systems. The ASPRID project reviewed drone operation regulations and identified obstacles specific to the deployment of drone protection systems at airports. This review aimed to address regulatory barriers and facilitate the implementation of drone protection measures at airports. The AW-DRONES project provided specific recommendations to the European Union Aviation Safety Agency on regulatory aspects and referenced standards. This project aimed to contribute to the development of regulatory frameworks that ensure the safe and efficient operation of drones, focusing on the harmonisation of the EU drone regulations and standards.

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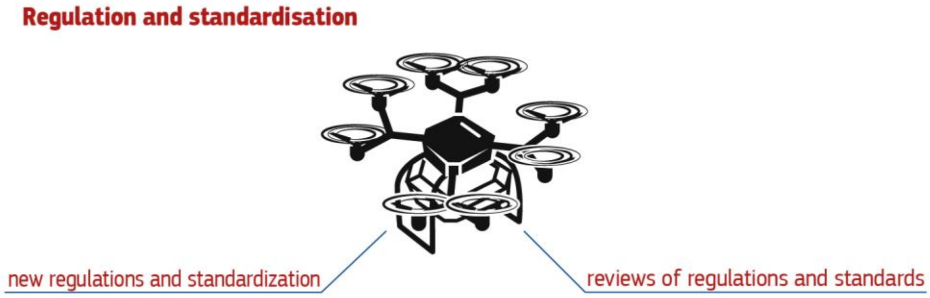
**Figure 25.** Main topics in European research on regulation and standardisation




*Source: TRIMIS, JRC, 2024*

The IMPETUS project presented recommendations for the standardisation of information data related to drones and reviewed European national regulatory procedures for U-space information management. This project aimed to establish standardized processes and procedures for U-space information management. Another project that contributed to the **new regulations and standardisation** in the drone industries was AIRMOUR which provided recommendations for standardisation and regulation development in urban air mobility emergency medical service operations. ASPRID has proposed adaptations and modifications of existing regulations to address potential obstacles in protecting airports from drones. ASSURED-UAM has proposed standards and recommendations for urban air mobility system components and regulatory requirements, considering their impact on the urban air mobility industry. DELOREAN has provided inputs to standardisation groups, incorporating EGNSS measured requirements and performance within the minimum operational performance standards applicable to urban air mobility and urban air delivery categories.

# 6 Research and innovation support for policy initiatives

This chapter provides a summary of projects' contributions to policy initiatives, as outlined in the Drone Strategy 2.0. The chapter is organized into three sections to present results for each of the defined policy areas, which in turn group identified flagship actions (see chapter 2.2.2 for details). The scope of each project was revised to align it with one or more policy areas, defining them through the aims of included flagship actions. Moreover, whenever possible, we also aligned project scopes with the aims of particular flagship action or actions. However, not all projects could be matched, nor do all project scopes have policy relevance.

## 6.1 Safety rules and requirements for airspace and aircrafts

Over half of reviewed projects contributed to policy initiatives directed towards development of safety rules and specification of requirements for airspace and aircrafts. Most of them have been working towards the achievement of the Flagship action 1 **on the safe integration of drones and piloted eVTOL operations**, exploring options for a shared use of the airspace and the rollout of U-space solutions and regulatory framework. In particular, different projects deal with the development of **U-space and its integration with air traffic management**, as well as the advancement of innovative air mobility. This involves revising existing aviation safety rules and certifications, as well as creating new ones specifically tailored to the needs of Urban Air Mobility.

The development of more advanced **U-space services** is at the heart of several research and innovation initiatives, developing concept of operations and relevant enabling technologies. The use of U-space solutions and operational concepts for a **more automated air traffic management** has also been tackled. Examples of investigated topics include U-space services for drone operations management including monitoring of **flight trajectory, flight planning (including cross-border), scheduling, approval and tracking**. Other research topics are automated ground processing stations and technologies that enable drones to make safe autonomous decisions. R&I projects are focused on **anti-collision systems**, **detect-and-avoid systems**, **models for separation minima**, determination of **precise and secure positioning and altitude**, **traffic monitoring and management technology** solutions and **surveillance interface** between aircraft and air traffic control. Research and innovation activities covered also a topic related to **deconfliction** management between two drones on similar trajectories, as well as artificial intelligence detection and recognition techniques. Robustness against **jamming and interference** was also tackled by R&I projects.

Moreover, identified projects provide assessment of existing **standards and regulations** to identify **best practices** and remaining obstacles. Gathered information is then disseminated through developed information portals which aim to facilitate to identify standards and recommendations. Finally, several large **demonstrations** have been performed to gain experience about services and procedures to operate drones in a safe, efficient and secure way within U-space.

The adoption of new European **standard scenarios for low to medium risk aerial operations** (Flagship action 3) is also at the heart of several R&I projects. Some of them focus on transport of medicines or goods, emergency medical services, status of infrastructure and maritime surveillance operations, navigation in GPS-denied and cluttered environments or rescuing operations following accidents or natural disasters. Guidance, navigation and control systems in emergency-related applications have also been investigated. In fields like delivery and inspection, research has focused on global self-positioning, beyond line-of-sight and without the use of GPS. Ultra-high resolution multi-sensor for search and rescue applications was also investigated. Specific Operations Risk Assessment methodologies have been developed. Swarm operations are also studied, including common information-sharing and synchronisation.

R&I projects also focused on **rules for the "certified" category of drone operations and operational requirements for manned VTOL-capable aircraft** (Flagship action 4). Examples are developments of emergency medical services operations in the specific and certified categories.

In addition, a few projects contribute to adoption of **rules for the design and operations of vertiports** (Flaghship action 5). This includes interfaces with aerodromes, interoperability and open access of equipment. Research projects include coordination of ground, take-off and landing operations with unmanned aircraft systems, air-taxis and demonstration of vertiports procedures, separation and data services. Optimisation of the vertiports traffic flow has also been developed.

**Training and competences requirements for remote pilots and pilots of VTOL aircrafts** (Flagship action 8) also appears in the scope of reviewed R&I projects. For example, they developed urban air mobility training programmes including on data protection risks and solutions for crew reduction based on cognitive computing technologies.

The necessity to amend the aviation security rules to ensure that aviation authorities and airports **increase their resilience when faced with the risks posed by drones** (Flagship action 18) is also among conclusions from reviewed projects. The research and innovation activities involve studies on cybersecurity, secured communication and identification. Research projects deal with airport protection systems from intruding drones, including recommendations for future regulation and procedures. Examples are **counter-drone solutions** able to early detect the presence of any drone, jam their activity without interfering with other mobile signals and force them to a safe landing.

## 6.2 Research and innovation strategies

Most projects evaluated as relevant for this policy area work on development of **Integrated Communication, Navigation and Surveillance** technologies, progressing towards the aims of the Flagship Action 2. They cover a broad spectrum of topics relevant for Integrated Communication, Navigation and Surveillance technologies. They mostly have a strong technology focus and their work on development of new sensors, telecommunication services as well as innovative approaches to data fusion and processing.

The autonomy of drones is also a major technological challenge, which includes aspects such as automatic take-off and landing, autopilot systems, and reliable functioning, particularly when operating beyond visual line of sight. These challenges are closely linked to the high quality and precise communication with drones, relying on satellite-based navigation systems (GNSS), mobile radio technology (4G and 5G), and air-ground communication, which are also being investigated within this group of projects.

Finally, simulation and demonstration activities at different scales and locations were also part of the identified drone-related research and innovation activities within this group of projects. They aimed at the safe integration of urban air mobility and the reduction of risks. this included the validation of drone prototypes and related technologies and solutions. The demonstration activities carried out were also useful in the process of developing new standards and formulating recommendations for improving regulations in line with Flagship Action 2, such as Minimum Operational Performance Standards.

Definitely R&I projects have directed less attention towards the remaining issues included in this section. Only very few projects worked on the **creation of an online platform to support sustainable IAM implementation** (Flagship Action 7). These R&I projects have contributed to the realisation of the flagship policy action by development of training tools, such as guidebooks and online courses, for authorities, communities, municipalities, industry, and stakeholders. These resources cover important aspects of drone integration, existing regulations, air traffic management and urban air mobility rules, privacy, data protection, and best practices. the projects have also provided recommendations for improving standards and regulations.

Another small pile of R&I projects have been working towards the **development of a strategic technology roadmap for drones** and the identification of priority areas to stimulate research and innovation, reduce existing strategic dependencies and avoid the emergence of new ones (Flagship Action 12). Regulatory analysis and the identification of potential gaps in technology and legislation, as well as the development of new applications for drones are examples of activities that have been carried out.

## 6.3 Civil, security and defence industry capabilities and synergies

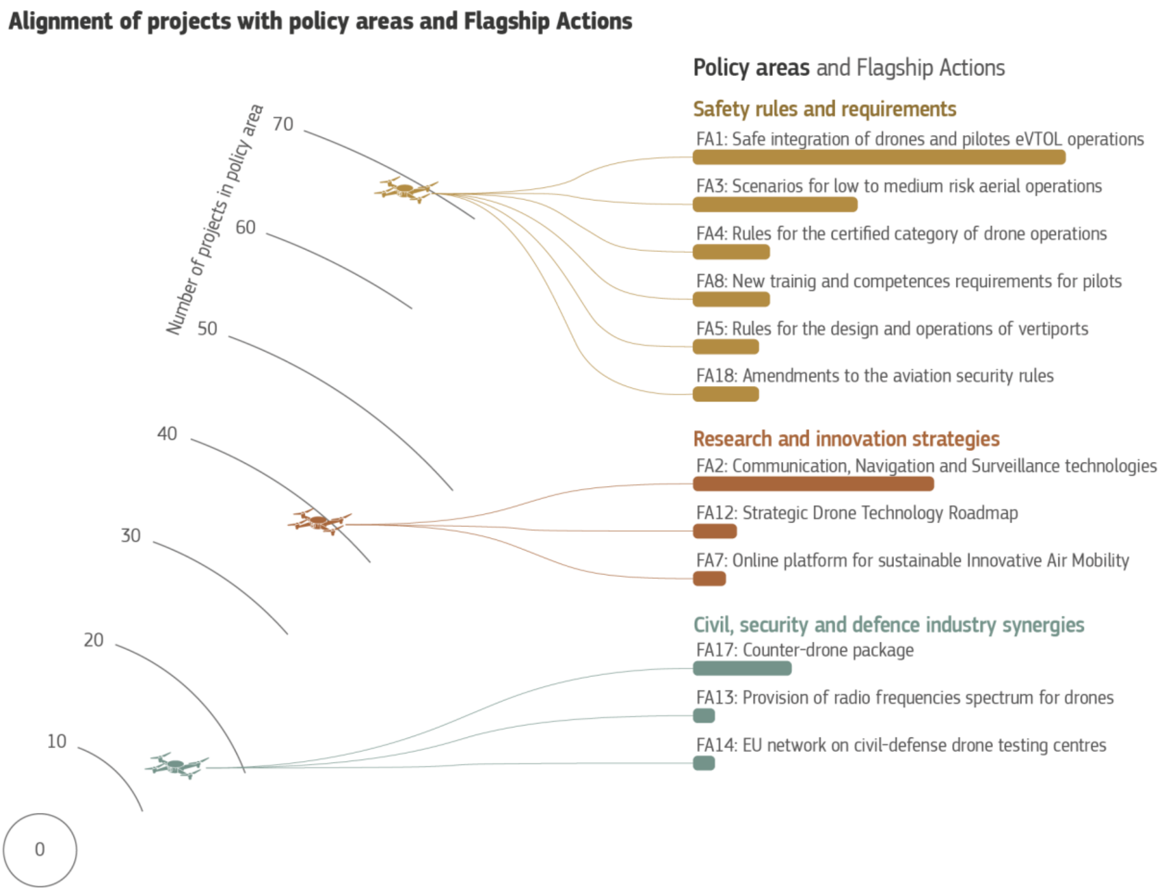
The scope of the synergies between civil, security and defence sectors are mostly out of the scope this report and R&I projects identified for the review. This is reflected by limited number of projects that contribute towards realisation of aims of relevant flagship actions. Nevertheless, a few R&I projects worked on a development of **counter-drone systems** (Flagship Action 17). Some of them focused on the development of tools for the detection of unmanned aircrafts. Such systems have been developed based on different technologies and for different purposes and stakeholders, e.g. public and private sector, coastal and border surveillance, protection of critical infrastructures, etc. Work on standardisation and future regulations as well as education/training elements also remain visible among the research activities. It should be noted that the amount of information available on these projects remains limited due to the focus on sensitive, defence-related issues.

A specific research topic of development of a common approach to providing sufficient radio spectrum for the operation of drones (Flagship Action 13) is of a marginal interest of European R&I projects reviewed for this report. Similarly, works related to the establishment of an EU network of civil and defence drone test centres to facilitate exchanges between the civil and defence sectors (Flagship Action 14) have also been supported by a relatively small number of projects from our portfolio. Examples of activities carried out include the development of affordable drone reconnaissance systems and increasing awareness and understanding of countering unmanned aircraft systems among Member State authorities. Finally, we have not identified projects related to the remaining topics covered in this section of policy action (Flagships 15 and 16).

## 6.4 Main trends in research and innovation support for policy initiatives

Over 72% projects revised for the presented report have relevance for policy areas, as outlined based on the Drone Strategy 2.0, including 21.5% which were aligned simultaneously with two policy areas. Most projects, 68 out of 130 reviewed, are related to safety rules and requirements (Figure 26). Within this policy area, the highest number of projects have in scope aims of Flagship Action 1, which refers to the adopting of amendment to the Standardised European Rules of the Air (SERA) and the Air Traffic Management / Air Navigation Services Regulation to safely integrate drone and piloted eVTOL operations, is in the scope. It is followed by Flagship Action 3 (adopting new European standard scenarios for low to medium risk aerial operations).

**Figure 26.** Main impacts of drones in European research and innovation activities




*Source: TRIMIS, JRC, 2024*

Research and innovation strategies fall into scope of interest to nearly 40 projects. Out of the three Flagship Actions, the highest number of projects contributed to supporting the aims of Flagship Action 2. This action focuses on research on integrated communication, navigation and surveillance technologies to ensure the convergence between air traffic management and U-space environments. The two remaining Flagship Actions have attracted less interest.

The lowest number of projects – 15 – aligned with the policy area dedicated to synergies between civilian, security and defence industries. Only two out of other four Flagship Actions covered by the umbrella of this policy area garnered any attention from R&I projects, and this attention was very limited.

# 7 Conclusions

The rapid growth of research and innovation in drone technologies has brought about significant changes in the transport landscape, shaping the future of aerial mobility and logistics. As a result, there are various challenges and opportunities in the European research and innovation landscape related to drones. From a technological perspective, key challenges include advancements in drone aircraft, infrastructure, and operational capabilities, including air traffic management. Additionally, there is a need for further research to address the environmental and socio-economic impact of drones and the integration of new technologies such as artificial intelligence, robotics, and semiconductors. From a policy perspective, the challenges in the European research and innovation landscape related to drones are aligned with the policy aims outlined in the European Drone Strategy 2.0. The policy aims cover fostering research and innovation in drone technologies to maintain Europe's competitive edge, driving economic growth, job creation, and technological leadership. Moreover, they align with technological challenges as their main target is to ensure the safe and secure integration of drones into European airspace, minimize operational risks, address concerns related to privacy and security, and encourage the development and implementation of environmentally friendly drone technologies. Finally, the progress needs to be in line with the EU's sustainability and climate goals.

In the area of **vehicles and their subsystems**, the main achievements have been related to advancements in technologies leading towards a development of holistic drone concept as well as further progress in propulsion systems, energy efficiency, increased range and payload. Several projects worked on improvements of propulsion systems and reduction of energy and fuel consumption to increase flight range and time and manageable payload. For example, it included a development of a cargo drone with up to 2500 km range and 350 kg payload. Moreover, projects have achieved increases in resilience for drones operating in challenging environmental conditions, e.g. strong wind, high temperatures, fire, nuclear radiation or strong electromagnetic fields. Drone operation safety has been tackled by development of a hybrid drones with emergency propulsion systems as well as prototype of a ballistic parachute for very low altitudes. Finally, R&I projects noted advancements in collision avoidance systems, autonomous navigation in GPS-denied environments, and the development of adaptive control systems and self-tuning flight control systems. These developments align with policy initiatives directed towards the development of safety rules and the specification of requirements for airspace and aircraft, particularly in the context of the safe integration of drones and piloted eVTOL operations, exploring options for shared use of the airspace.

The projects focused on the development of **infrastructure** for drones, including power supply, charging infrastructure, and landing systems. Initiatives developed docking stations as part of comprehensive drone systems for specific applications, such as autonomous drone delivery systems and medical supply transport. Landing infrastructure was addressed, with projects focusing on take-off and landing systems, mobile ground-based landing gear, and local landing systems for challenging conditions. In case of digital infrastructure, projects investigated innovative use of existing infrastructure and technology bricks to improve the communications, navigation, and surveillance for future air traffic management, as well as the application of GNSS and EGNOS services for navigation and positioning of drones in urban air mobility settings. Research and innovation activities also focused cellular technology applications for drones, including interoperable 5G core networks and AI-assisted communications, leading to improved quality and reliability of communication systems.

The **U-space** development projects have addressed several key challenges, including air traffic management in urban airspace, increased density of flight operations, communication between pilots and air traffic controllers, trajectory optimization, and the need for legal regulations. Efforts have been focused on the development of concepts of operations for drones, particularly in urban air mobility and U-space/air traffic management integration. Projects have explored the integration of air traffic management into intermodal networks, incorporating remotely piloted aircraft into air traffic control procedures, and enhancing the use of controlled airspace, in particular within airports. Furthermore, a significant emphasis has been placed on developing traffic management systems, including minimum separation distance and collision avoidance methods, as well as tools for air traffic management automation and unmanned traffic management systems. Large-scale demonstrations have been undertaken to test U-space concepts in operational environments, assess their maturity, and bridge the gap between development and deployment of U-space services. Finally, specific U-space related products have been developed, addressing challenges such as altitude measurement for unmanned aircraft systems, U-space concepts based on the Function-as-a-Service paradigm, environmental aspects of air traffic management, seamless integration of drones in existing multimodal transport networks, and key enabling technologies for safe and autonomous drone applications.

Several observations accompany this summary of technological developments. The literature suggests that numerous companies, from established aviation firms to start-ups, are currently focusing on the development and prototyping of aerial vehicles to enhance the maturity of drone and urban air mobility technologies. Meanwhile, research communities, in collaboration with regulatory bodies, are concentrating on realising traffic management and airspace integration. This observation from the literature is confirmed in the current analysis, which examines EU-funded research and innovation, with most of the Research and Innovation Actions and Innovation Actions projects focusing on the development of U-space. Conversely, SME-1 and SME-2, as well as actions funded by European Investment Bank, are directed towards vehicle development by companies and their partners and suppliers. Furthermore, except for the recent European Defence Fund projects on drone onboard energy and propulsion systems, the funding effort is largely concentrated on U-space and digital infrastructure projects. Although there is a clear vision for U-space realisation through the U-space roadmap by SESAR and stakeholders, the same cannot be said for unmanned aircraft and urban air mobility vehicle technology. It is worth considering such a strategic vision for vehicle technologies, and this analysis supports the identified need for a Strategic Drone Technology Roadmap in the Drone Strategy and accompanying Staff Working Document (EC 2022b). Critical drone technologies, such as robotics, semiconductors, and the dependence on third-country suppliers and know-how, are not addressed in the identified projects. Further synergy between the transport and digital EU partnerships is desirable, as is a concerted approach to programming. Similarly, additional collaborative efforts can be directed towards energy storage and propulsion systems, in collaboration with the BATT4EU and Clean Hydrogen partnerships.

The relative lack of physical infrastructure projects can be attributed to the need to first develop vehicles and U-space sufficiently. However, this issue will eventually need to be addressed from both an urban planning and land use perspective, as well as to meet charging requirements and grid integration.

Several projects have considered an impact of drones on **noise pollution**, contributing to noise measurement, noise mapping and studies on perception of noise produced by drones. Recent guidelines on noise measurement of certain unmanned aircraft systems are also available from the European Union Aviation Safety Agency. Additionally, studies have concentrated on enhancing propulsion systems for drones to reduce noise pollution through innovative VTOL aircraft design and Distributed Electric Propulsion (DEP) configurations. These efforts align with the need to develop appropriate noise modelling methodologies for drones and eVTOL aircrafts, examine noise perception and annoyance. However, there still some topics which needs further research, such as the impact of noise from drones on local fauna and research on cabin noise affecting passengers.

Few projects provide research on **visual pollution** related to drone operations. The reviewed R&I projects have explored path planning algorithms that consider trade-offs between visual pollution, noise pollution, risk, efficiency, and other relevant factors. They also covered the influence of traffic structure on airspace capacity, the development and comparison of different dynamic capacity and separation management concepts for drones, and the importance of considering land use for U-space and urban air mobility activities. However, there is a need for further research to define the methodology on quantification of visual impact and to explore the impact of movement on visual pollution.

Even less projects covered **land use impact** of drone operations. They examined the influence of traffic structure on airspace capacity and compared different dynamic capacity and separation management concepts for drones. The results highlighted the importance of considering land use for U-space and urban air mobility activities, emphasizing the establishment of ground infrastructure, such as vertiports and landing areas, and the need for cities to adapt their planning practices in relation to landing sites and airspace management. However, reviewed R&I projects did not specifically address the systematic analysis of suitable locations for new enabling infrastructure or the indirect influence of drones on land use patterns.

Several projects have addressed the impact of drones on **energy use and emissions**, particularly focusing on increasing drone energy efficiency, emission reduction, and emissions modelling. They notice a progress in an increase of payload capacity, extending flight time, and development of smart energy management systems to reduce environmental pollution. Additionally, they developed tools for visualizing and modelling emissions in the urban air mobility ecosystem, quantifying the environmental and emissions outcomes of innovative air transport systems, and assessing the air quality impact of unmanned aircrafts in cities. Further research should aim to address remaining topics, such as life-cycle assessment of drones under different operational scenarios, the recycling or reuse of batteries from drones or the evaluation of new propulsion systems and drone design from a life-cycle impact perspective on emissions and energy use.

**Safety** emerged as the most prevalent and extensively addressed topic among all the environmental and socio-economic impacts of drones in the reviewed R&I projects. They extensively addressed various safety aspects of drone operations, including efficient air traffic management, collision avoidance systems, separation minima, navigation, communication, and interaction between airspace users. The projects have also improved safety through the development of specific safety systems, human machine interface design, and defining aerial operating procedures in urban areas. Despite the progress made in addressing safety concerns, the need for further research and innovation in this critical area remains evident. Additionally, future studies should include certification procedures and market surveillance, ensuring that safety standards and protocols are rigorously adhered to.

In the area of **security and privacy**, research and innovation initiatives have made considerable progress with projects focusing on surveillance technologies, early warning systems, and safeguarding airports from drone threats. However, further investigation is required in the areas of evaluating the level of cybersecurity for urban air mobility technologies, proposing practical solutions for cybersecurity threats, and developing measures to address identified security gaps in air traffic management. Additionally, future research should focus on enhancing counter-drone systems, further addressing privacy concerns in the use of drones, and promoting a privacy culture within the commercial drone industry.

In the domain of **regulatory measures and standardization**, the reviewed R&I projects contributed to development of recommendations for urban air mobility safety, providing specific suggestions to the European Union Aviation Safety Agency on regulatory aspects and referenced standards, and establishing standardized processes and procedures for U-space information management. Additionally, initiatives have proposed adaptations and modifications of existing regulations to address potential obstacles in protecting airports from drones. However, further research and innovation efforts are needed to define global standards for cybersecurity and to develop specific and user-friendly guidelines or checklists that explain to drone operators how to comply with data protection and privacy requirements. Attention should also be paid on identification or definition of relevant standards and harmonisation with the EU drone regulations.

There is a visible alignment of the scope of R&I projects with the policy areas. It shows a substantial level of relevance and support for **policy initiatives**, in particular in the area of safety rules and requirements. Most projects have focused on safety rules and requirements for airspace and aircraft, followed by research and innovation strategies and civil, security, and defence industry capabilities and synergies. Projects have contributed to various flagship actions, such as integrating U-space with air traffic management, developing advanced U-space services, and addressing specific operations risk assessment for drone applications. Policy areas related to synergies between civil, security, and defence industries have garnered comparatively less interest, however this might be partly related to the civilian character of the analysed projects with primary focus on research and innovation.

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## List of abbreviations and definitions

| | |
|---|---|
| AAM | Advanced Air Mobility |
| ADS-B | Automatic Dependent Surveillance–Broadcast |
| AI | Artificial Intelligence |
| ATM | Air Traffic Management |
| BVLOS | Beyond Visual Line of Sight |
| CARS | common altitude reference system |
| CEF | Connecting Europe Facility |
| CINEA | European Climate, Infrastructure, and Environment Executive Agency |
| CNS | Communication, Navigation and Surveillance |
| COSME | Internal Market, Industry, Entrepreneurship and Small and Medium Enterprises programme |
| CPS | cyber-physical systems |
| CSA | Coordination and Support Actions |
| D2D | device to device |
| DEP | Distributed Electric Propulsion |
| EASA | European Union Aviation Safety Association |
| EC | European Commission |
| EDA | European Defence Agency |
| EDF | European Defence Fund |
| EGNOS | European Geostationary Navigation Overlay Service |
| EIB | European Investment Bank |
| EIC | European Innovation Council |
| EIT | European Institute of Innovation and Technology |
| ERC | European Research Council |
| EU | European Union |
| eVTOL | electric vertical take-off and landing |
| FAA | Federal Aviation Administration |
| GHG | Greenhouse gas |
| GNSS | Global Navigation Satellite System |
| HERC | Hercules III grant programme |
| HMI | Human Machine Interface |
| IA | Innovative Actions |
| IAM | Innovative Air Mobility |
| ICNS | Integrated Communication, Navigation and Surveillance |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| JRC | Joint Research Centre |
| MSCA | Marie Skłodowska-Curie Actions |
| NASA | National Aeronautics and Space Administration |

| | |
|---|---|
| PMA | Polycentric Multimodal Architecture |
| R&I | research and innovation |
| RIA | Research and Innovation Actions |
| SERA | Standardised European Rules of the Air |
| SME | small and medium enterprises |
| SORA | Specific Operations Risk Assessment |
| SRIA | Strategic Research and Innovation Agenda |
| TRIMIS | Transport Research and Innovation Monitoring and Information System |
| UA | Unmanned Aircraft |
| UAM | Urban Air Mobility |
| UAS | Unmanned Aircraft System |
| UGV-UAV | unmanned ground vehicle – unmanned aerial vehicle |
| USM | U-space Service Manager |
| UTM | Unmanned aerial system Traffic Management |
| UTM | Unmanned Aircraft System Traffic Management |
| VLL | Very low-level |
| VTOL | Vertical take-off and landing |

## List of figures

## List of tables

## Annexes

### Annex 1. Description of funding sources

Marie Skłodowska-Curie Actions (MSCA) invest in the careers of excellent researchers and promote researcher collaboration and mobility in the EU. Thematically, the doctoral fellowships often engage in the development of algorithms, methodologies, and frameworks. They should not be associated with a target TRL level, yet for the sake of providing an indication to the relation to the other types of actions, a TRL range from 0 to 1 is adopted.

The ERC Consolidator grant fosters researchers that would like to establish independent research teams. Applications can be made in any field of research and up to € 2 million can be awarded in Consolidator Grants, which may be awarded for a period of 5 years. ERC Consolidator corresponds to basic high-risk research therefore a theoretical target TRL would be up to 1.

Research and Innovation Actions (RIA) and Innovation Actions (IA) are the main funding actions in the EU multiannual framework programmes. RIAs aim to establish new knowledge or explore new or improved technologies and processes, towards their proof of concept. RIA actions aim for a Technology Readiness Level (TRL) between 2 to 6. The EU funding covers up to 100% of the project costs for RIA actions.

Research and Innovation Actions (RIA) and Innovation Actions (IA) are the main funding actions in the EU multiannual framework programmes. RIAs aim to establish new knowledge or explore new or improved technologies and processes, towards their proof of concept. RIA actions aim for a Technology Readiness Level (TRL) between 2 to 6. The EU funding covers up to 100% of the project costs for RIA actions.

IAs focus on more mature innovation that produces designs for new or improved products, processes, or services. IAs aim to achieve higher TRLs, between 6 and 8. Projects funded under IAs are expected to prototype and demonstrate the developed solutions towards validation and market deployment. The EU funding covers up to 70% of the project costs.

It is possible that a research project outcome brought to a TRL 5-6 during an RIA pursues towards higher TRL level within an IA action in a subsequent call for proposals.

SME Phase 1 and 2 instruments, and their successor EIC Accelerator, support innovative Small Medium Enterprises1 (SME) that have an innovative product, service or business model to scale up. The SME Phase-1 (SME-1) instrument provided lump sum funding of €50 000. The funding aimed to allow SMEs to conduct concept feasibility and commercial studies for their innovations, including risk assessment, market study, intellectual property management, or business plan development. SME Phase 1 was discontinued in 2019. The SME Phase-2 (SME-2) supported SMEs to develop their innovations towards market ready solutions, with a grant funding between €0.5 million and €2.5 million, and different funding schemes to accommodate different targeted TRLs and support arrangements.

The SME-2 instrument was succeeded by the EIC Accelerator, which is the European Innovation Council 's (EIC) flagship programme for SMEs. The funding mechanisms adapt to the target TRL and can be in the form of grants (up to €2.5 million) or direct investments (up to €15 million). EIC Accelerator Challenges receives proposals in predefined topics, while EIC Accelerator Open allows any innovation to be proposed.

The EIT Accelerator, also known as the European Institute of Innovation and Technology (EIT) Accelerator, is a funding and support program for innovative start-ups and scale-ups in Europe. It is part of the broader EIT ecosystem, which aims to promote innovation and entrepreneurship. The EIT Accelerator offers different funding mechanisms, including grants and direct investments, to support the growth and development of selected companies.

Coordination and support actions (CSA) that improve cooperation among EU and associated countries to strengthen the European Research Area including, for example, standardisation, dissemination, awareness-raising, communication and networking activities, policy dialogues, mutual learning or studies. Studies can include infrastructure design and policy and regulatory guidelines for the implementation and wide adoption of innovations. The EU funding covers up to 100% of the project costs.

The Connecting Europe Facility (CEF) for Transport is the funding instrument to realise European transport infrastructure policy. It aims at supporting investments in building new transport infrastructure in Europe or rehabilitating and upgrading the existing one. While its main objective is the realisation of the Trans-European Network for Transport (TEN-T), CEF Transport also supports innovation in the transport system to improve the use of infrastructure, reduce the environmental impact of transport, enhance energy efficiency and increase safety.

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