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Adoption of the Urban Air Mobility System: Analysis of technical, legal and social aspects from a European perspective

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Abstract: As the demand for mobility and traffic in European urban areas continues to grow, innovative transportation solutions, particularly Urban Air Mobility (UAM), are gaining increasing prominence. UAM takes advantage of the third dimension to reduce ground traffic by integrating low-noise electric vertical take-off and landing vehicles (eVTOLs). Nonetheless, the successful implementation of UAM necessitates not only technological advancements but also the legal framework and social considerations to guarantee effective and safe operations. Holistic investigations of UAM are scarce, especially in the European context. Therefore, this study discusses the developments and challenges of UAM from technical, legal, and social perspectives and derives a set of UAM-tailored design drivers for the effective deployment of UAM in Europe. A comprehensive literature review is conducted on the state of the art of UAM technologies, regulations, and public attitudes. Various eVTOL configurations are compared, taking into account pertinent system factors such as energy efficiency and suitability for short- or long-duration missions. Besides, the cost-effectiveness of eVTOL configurations for a specific mission is evaluated through a cost-optimization analysis: the total cost is calculated to be around 2 € per payload-kilometer, which is approximately tenfold the current price for road transport. The regulatory activities of the European Union Aviation Safety Agency are discussed for the period 2017-2022, during which several systematic improvements to the regulations have been introduced. Typical factors for assessing the public acceptance of UAM are identified, and a survey is conducted across European medium-sized cities to gain insights into public opinion. The survey results indicate that 59% of the respondents are moderately positive toward UAM deployment, representing a more cautious attitude compared to findings from studies conducted in metropolitan cities or countries. Furthermore, 56% of respondents are willing to try out delivery services with aerial vehicles, while, 32% would use air taxis. This is in contrast with studies conducted in metropolitan areas or at the country level. Based on the proposed holistic investigation of UAM, the set of design drivers can be identified to reduce uncertainty in UAM adoption and ensure a flawless deployment.
Keywords: *Urban Air Mobility (UAM);legal framework;eVTOL configurations;public acceptance;Europe*
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1. Introduction

The increase in ground traffic within urban environment coincides with the growth of the population living in cities, which also expands the need for connections and delivery services (Schuh et al. 2022, Berger 2022). Urban Air Mobility (UAM) is the term used to describe the aviation sector that deals with the transportation of people and cargo within urban and suburban regions. The implementation of UAM has the potential to enhance connectivity and alleviate congestion in urban areas, making it a highly promising solution to address the ongoing challenges of urbanization. The development of electric Vertical Take-Off and Landing (eVTOL) vehicles is receiving substantial attention and investment as an integral part of the UAM system. The eVTOLs aim to foster sustainability and are well-suited for urban environments as the capability for VTOL allows them to operate in densely populated areas, where space is limited.

A large number of start-ups and established companies, as well as research organizations, are developing and testing eVTOL vehicles and related technologies, while the UAM sector is still in its early stages (Sun et al. 2021, Cohen et al. 2021*a*). Uber, Airbus, and Boeing, among others, have made significant investments in creating UAM infrastructure and designing vehicles that succeed in all three dimensions of sustainability, namely environmental conservation, economic development, and social sustainability (Bauranov & Rakas 2021). In 2019, the European Commission launched the Green Deal (European Commission and EASA 2019) to call for the implementation of climate-neutral solutions by 2050. This target also applies to the aviation sector and therefore to UAM (Organization for International Economic Relations 2020). On the way to a sustainable UAM sector and the fulfillment of the requirements of operating in an urban environment, the design space is still open. Partly due to a large number of potential missions and partly due to the ongoing research and development in the field, no superior and/or preferred design solution has yet been identified. The exploration of the UAM design space leads in most cases to eVTOLs. Depending on the missions to be flown, different configurations may be considered, such as multicopters, tiltwing or propulsive aircraft, or hybrid configurations (Kraenzler et al. 2019, Sun et al. 2021). The deployment of UAM is relatively rapid, which in turn raises concerns about the early stages of regulation, the technological maturity of eVTOL, and the necessary public acceptance, which are highly correlated with the successful implementation of UAM (Organization for International Economic Relations 2020, Babetto et al. 2022, Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020, Sells 2022). In this context, the UAM - more precisely defined as a whole as a UAM system - has to be analyzed and evaluated on the basis of three main aspects: the *UAM system* is divided into *technical*, *legal* and *social* aspects respectively (Figure 1).

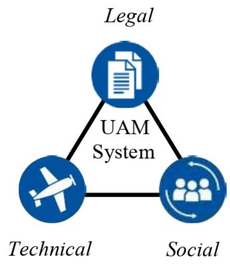


Figure 1: *Description of UAM system aspects.*

Technical aspects encompass performance, safety, cost, and operation. For example, UAM-eVTOLs are designed to be compact and capable of flying along pre-defined routes in semi- or fully autonomous mode with minimal emissions and noise (Berger 2022, Babetto & Stumpf 2021, Cohen et al. 2021*a*). The legal aspect includes the regulatory framework (Mitchell et al. 2022, Bauranov & Rakas 2021, Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020). Authorities such as the European Aviation Safety Agency (EASA) are working to establish standards and rules for the safe operation of UAM vehicles. This is essential, as eVTOLs operating in urban environments are currently not subject to any specific restriction (Schuh et al. 2022). The social aspect is concerned with how eVTOLs operate in urban environments as a novel technology, which will have a direct impact on technology diffusion and the market success of the UAM service as a business (Garrow et al. 2021, Ahmed et al. 2023). This is particularly the case because UAM operation raises concerns for society, including noise, safety, and privacy (NASA 2018, Kellermann et al. 2020, Dannenberger et al. 2020, Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020, Sells 2022, Bauranov & Rakas 2021). In order to study concerns as well as the benefits that UAM can bring, a survey is conducted as it is the most common method to collect public perceptions toward new technology by efficiently gathering data from a large number of participants and providing quantifiable results (Pettke et al. 2021). The survey target is medium-sized cities since it was identified as a research gap in this field. In fact, currently available surveys about UAM are either focused on big cities or worldwide countries (NASA 2018, EASA 2021*b*, Rothfeld et al. 2021, Ahmed et al. 2023, Yedavalli & Mooberry 2019, Fu et al. 2019). Furthermore, medium-sized cities have been identified as a key target group for UAM, as they represent the majority of the European population and are a potential area for economic growth and mobility improvement (Giffinger et al. 2007).

In this paper, the interrelationship among these aspects is addressed, as they are not independent of each other, but rather intertwined (Berger 2022, Garrow et al. 2021, Bauranov & Rakas 2021). As most of the published studies dealing with the topic do not cover it in a holistic way, a holistic analysis of the UAM system will be carried out with regard to the three aspects - with special attention to the European scenario (Clothier et al. 2015, Cyber 2018, Pettke et al. 2021, Slovic et al. 1982). This way, the knowledge base, and understanding will be extended. Based on this, challenges, priorities, and opportunities within the UAM system can be identified and new design drivers can be derived that need to be aligned with stakeholder and public needs as suggested by similar works in (Johnson et al. 2022, Tepylo et al. 2023). In order to achieve a holistic analysis of UAM systems with respect to the three aspects, first each aspect is examined independently and then their interrelationship is discussed. Finally, their overall impact on the UAM system can be outlined and future actions can be proposed. In this work, the research is guided by the following objectives:

- Analyse the main characteristics of the technical, legal, and social aspects of the UAM system.
- Identify the current challenges of each aspect.
- Interrelate the identified characteristics and/or challenges.
- Derive new design drivers resulting from the three aspects' perspective.
- Define a strategy for a flawless deployment of the UAM system.
- Delineate the pathway towards the adoption of a future UAM system in Europe.

Following the introduction in Section 1, a comprehensive literature review is carried out. The results of the literature review are presented - according to the aspects of analysis shown in Figure 1 - in three main sections: Section 2 to Section 4 (see Figure 2). Section 2 presents the background of the UAM service, i.e., provides a detailed description of the current vehicle concepts designed for use in a future UAM scenario and discusses the numerous potential configurations according to individual specifications such as range, speed, and efficiency. This is done in order to determine which design is most promising for the mission purpose. Section 3 presents the historical development of the regulatory framework from 2017 to 2022, elucidating the rulemaking activity that paves the way for the establishment of innovative UAM technology. The UAV-specific safety assessment approach is also briefly covered in this section. Section 4 deals with the public acceptance of UAM. Recent statistical analyses on the social acceptance of UAM are discussed and the results of an own survey on public acceptance in medium-sized European cities are examined. The case study of medium-sized European cities was chosen because the literature review revealed a gap in this research field. In this way, it was possible to obtain a more comprehensive picture of European acceptance with regard to UAM. A comprehensive discussion of the technical characteristics, the legal framework, and the public acceptance as well as their interrelationships is provided in Section 5, giving the basis for a future pathway of UAM from a European standpoint. Conclusions are drawn in Section 6.

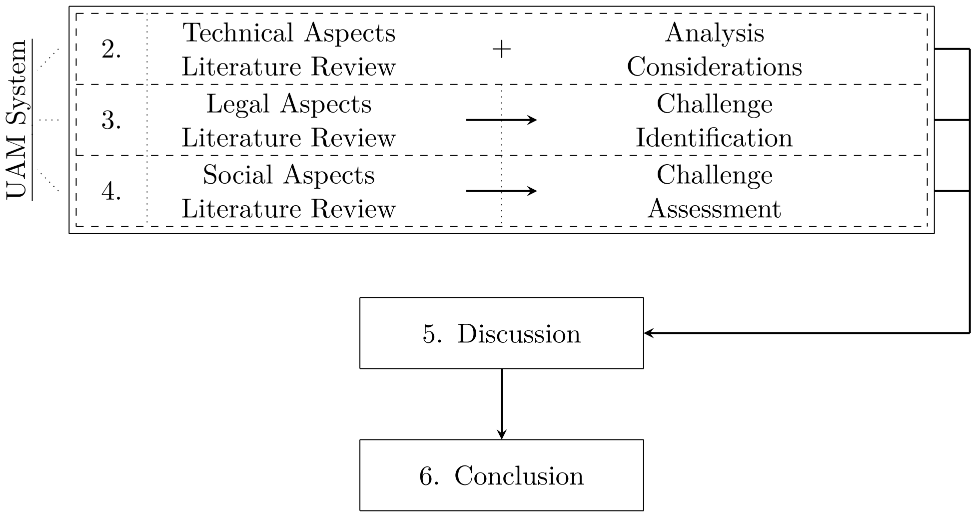


Figure 2: *Structure of the paper.*

2. Technical aspects of the UAM system

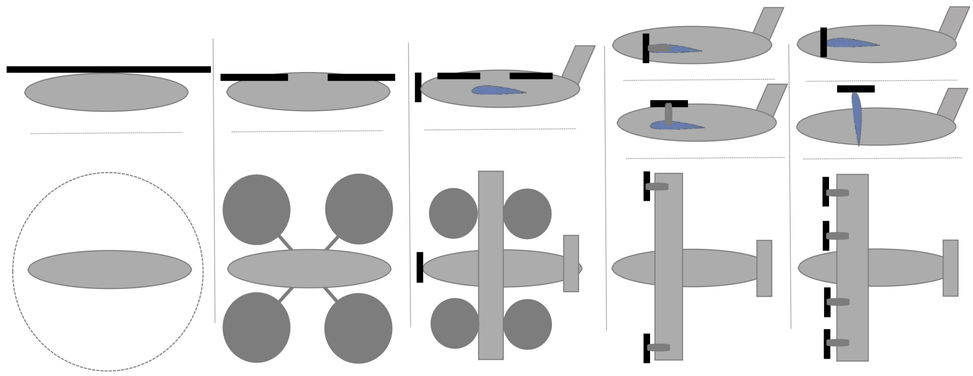
A brief review of the technical aspects of the UAM system allows stakeholders to gain a comprehensive understanding of the capabilities, limitations, and potential impacts of UAM technology. This understanding is fundamental for developing effective legal frameworks and regulations that address, e.g., safety, noise, and integration within the manned space associated with UAM (Bauranov & Rakas 2021, Sun et al. 2021). It also aids in formulating social acceptance strategies by addressing public concerns and ensuring that UAM systems are integrated harmoniously into urban environments. The technological aspect of the UAM service comprises, first, the vehicle concepts and, second, the operating system with built infrastructure (Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020, Garrow et al. 2021, Mitchell et al. 2022, Sun et al. 2021). On the one hand, current vehicle concepts for use in UAM are presented in the following section accompanied by an introduction on comparative methods between UAM concepts based on the type of mission, i.e., inter- or intra-city transportation services. On the other hand, an overall cost evaluation of the operating UAM concepts based on the state-of-the-art of operation management is given in Section 2.2 in order to assess the cost-effectiveness of alternative transportation services.

2.1. UAM vehicle concepts

The enabler of the UAM system is the aerial vehicle concept. Therefore, the design of the vehicle itself and related technologies have to be discussed. Technological developments, such as the VTOL capability and configuration layouts that differ significantly from conventional aircraft, have provided the technical basis for the emergence of UAM. Since approximately 2010, a large number of manufacturers and research institutes have proposed various configurations of UAM vehicle concepts, most of which are eVTOL vehicles (Cohen et al. 2021*a*, Sun et al. 2021, Ahmed et al. 2023). Studies have classified the unconventional layout of eVTOL vehicles into three main classes (see Figure 3) (Bacchini & Cestino 2019, Bauranov & Rakas 2021, Babetto & Stumpf 2021):

1. Lift + Cruise,
2. Vectored thrust,
3. (Multi/Heli)copters,
4. Others.

The *Lift + Cruise* configuration relies on separate engine units to achieve both VTOL capability and conventional cruise. Typically, lift rotors provide vertical thrust for the VTOL phase, while pusher propellers generate thrust for forward flight (Giannini et al. (2018), Silva et al. (2018)). *Vectored thrust* enables an aircraft to change the direction of thrust resp. lift force. These vehicles achieve force vectoring by tilting the ducted fans or rotor units or by tilting the entire wing with installed propulsor units. For tilt-wing aircraft, the propulsor units are generally firmly attached to the wing, and the direction of thrust is changed by rotating the wing around the pitch axis. Whereas, in tilt-rotors, the direction of the propeller's shaft shifts to achieve a change in the direction of thrust. *Multicopters* are mechanically simple VTOL layouts that are suitable for urban operations due to their compact size (Babetto et al. 2022). With no wings and generally having four or more propellers to generate thrust, multicopters allow for simple flight mechanics and superior flight control (Hoffmann et al. 2007). The *Helicopter* configuration is often excluded in UAM research due to its non-electric power and high noise emission. However, with the development of technologies, the helicopter configuration could be improved and should be considered in the research. Other UAM concepts are unconventional configurations, such as tail-sitters among others, but are not further detailed in this study. A comparison of the various eVTOL configurations with respect to each model's capabilities in terms of range, speed, payload capacity, efficiency, affordability, etc. contributes to mapping the explored design space onto existing mission and operation requirements and thus, to down-select promising candidates resp. identify suitable configurations for a specific mission. Comparative studies of UAM configurations fall into two main categories: analyses based on statistical data taken from eVTOL projects beyond the concept phase, and analyses based on the design and simulation of conceptual models.



(a) Helicopter ***(b) Multicopter*** ***(c) Lift + Cruise*** ***(d) Tiltrotor*** ***(e) Tiltwing***

Figure 3: *General conceptual layouts for candidate configurations (Babetto & Stumpf (2021)).*

2.1.1. Statistical and conceptual model analysis

Statistical analyses

Several statistical studies have listed the UAM concepts that have emerged on the market (e.g. Polaczyk et al. (2019), Goyal et al. (2018), McDonald & German (2017), Marzouk (2022), Datta et al. (2018)). It can be seen that the cruise speed of the multicopter configurations ranges from 64-97 km/h. This is generally slower than the typical 177-306 km/h of the winged configurations. Multicopters using conventional fuel have a greater range than those supplied by hybrid-electric power. Purely electrically driven multicopters with 48-80 km have the lowest range of all analyzed eVTOL options. In comparison, the purely electrically driven Lift + Cruise configuration can cover ranges within 80-128 km. Figure 4 schematizes these statistical considerations on eVTOL performance. In addition to speed and range, two principal metrics of eVTOL performance are also typically included in statistical analyses of eVTOL concepts (Datta et al. (2018)):

1. Power loading, i.e., the mass of the aircraft lifted per unit of power while hovering,
2. Aircraft lift-to-drag ratio during cruise.

Low-speed hover-dominant vehicles are designed to operate at low disc loading to achieve high power loading, but cruise-dominant/high-speed vehicles are designed to operate at higher disc loading to provide a superior lift-to-drag ratio. Therefore, a trade-off analysis between the hover and the cruise performance must be carried out based on the required mission (Sun et al. (2021)). Overall, the statistical considerations draw the same conclusions regardless of the metrics considered, i.e., cruise vs. range or power loading vs. lift-to-drag ratio.

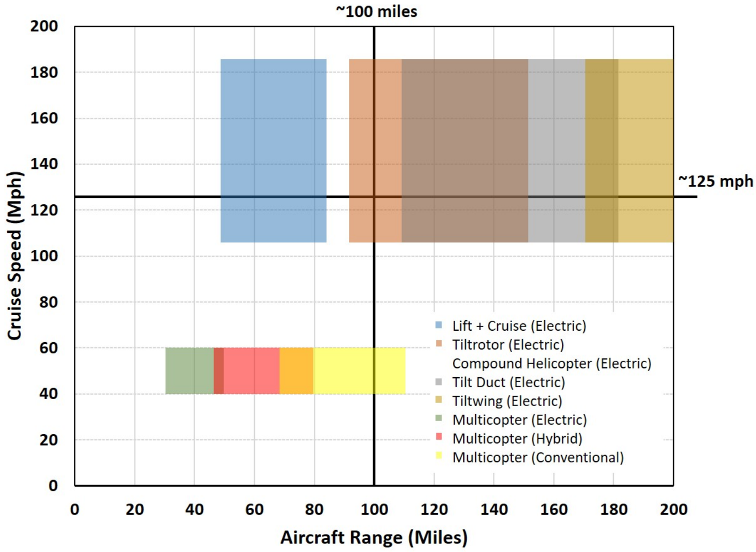


Figure 4: *VTOL vehicle range versus cruise speed graph (Goyal et al. (2018)).*

Analyses through conceptual models

A conceptual design analysis requires the creation of a conceptual design method. Since the conceptual design methods rely on a limited design space of eVTOLs, these studies include sensitivity analyses in order to draw conclusions on the whole design space of UAV design. Several conceptual design analyses are performed, e.g., Kraenzler et al. (2019), Kadhiresan & Duffy (2019), Bacchini & Cestino (2019). These works analyzed the performance of multicopter, tilting configurations, and Lift + Cruise to evaluate the efficiency of eVTOL configurations with respect to range variation. With regard to energy efficiency (i.e., using payload-specific energy metrics) of vehicles with the same size and mission profile, Kraenzler concluded that the tilt-wing layout can achieve a range of 95 km; whereas, the multicopter configuration is ideal for a shorter range of up to 18-20 km. The Lift + Cruise configuration performance is a compromise between the advantages of tilting configurations and multicopters with acceptable flight endurance and payload capacity. Similar to Kraenzler et al. (2019), Kadhiresan & Duffy (2019) analyzed the performance of eVTOL configurations with constrained sizes and different battery energy densities in order to select the optimum configuration with minimum feasible gross weight for identical payload. If assuming a high battery energy density (300 Wh/kg), the multicopter is suitable for low speeds (80-160 km/h) and short ranges (16-64 km), whereas the other considered configurations are suitable for high speeds (up to 240 km/h), respectively, the tilt-wing and Lift + Cruise configurations being most suitable for long range missions (up to 160 km).

The conclusion of the work in Bacchini & Cestino (2019) is that multirotors enable lower energy consumption in hovering condition, tilting configurations are more efficient at high cruise speed with the range depending on the specific mission profile and Lift + Cruise configurations are a compromise between the two mentioned concepts. Overall, although the conditions of the simulations in Kadhiresan & Duffy (2019), Kraenzler et al. (2019), Bacchini & Cestino (2019) are study-tailored, the drawn conclusions agree well (Garrow et al. 2021, Bauranov & Rakas 2021, Mitchell et al. 2022, Cohen et al. 2021*a*).

2.1.2. General VTOL design principles

In summary, by combining the statistical with the conceptual model analyses, the following design principles can be summarized:

- The Lift + Cruise configuration is a compromise of wingless rotorcraft and fixed-wing aircraft. However, as the lift rotor is not used during cruise, this adds extra weight and, thus, drag. In turn, the wings and pusher propellers add weight, which is detrimental during VTOL and hovering stages, i.e., increasing disk loading and reducing hovering efficiency. Hence, the Lift + Cruise configuration could be an optimal choice at medium speeds and ranges but it might not be the best choice for the combination of small ranges and low speeds or large ranges and high speeds.
- The vectored thrust configuration is preferred for long ranges and high speeds due to its high lift-to-drag ratio. And a distributed propulsion system can further improve its cruising efficiency. The disadvantage of vectored thrust configurations is that the mechanism used to vector the thrust increases the weight of the propulsion unit and increases

the complexity of the aircraft system and structure, thus, reducing reliability resp. increasing maintenance efforts. The tilt-wing configuration is generally heavier than a tilt-rotor configuration because of the complex tilting system of the wing. However, in some cases, tilt-rotor's rotor slipstream is negatively affected by the wing compared to the tilt-wing configuration.

- The multirotor configuration is limited to short ranges and low speeds due to relatively low disk loading and low lift-to-drag ratio during cruise. Helicopters can fly faster than multicopters due to their cyclic rotor system. However, because of the increased complexity of the rotor system and higher speeds, helicopters are less efficient than multicopters on very short ranges.

2.2. UAM Operation Analysis

In order to compare different UAM services based on diverse eVTOL configurations and missions, analyses regarding the cost-effectiveness of diverse UAM services are required (Mitchell et al. 2022, Cohen et al. 2021a, Ahmed et al. 2023). Here, a potential UAM service can be considered in two levels, namely the vehicle level and the fleet level (Garrow et al. (2021)).

2.2.1. Vehicle level: performance analysis

For the UAM vehicle level, state-of-the-art vehicle parameters are applied to an equivalent base-case mission profile, and performance analyses are conducted. Hence, the mission profile has to be defined in the first place to derive power requirements, range restrictions, flight efficiency, and energy costs as part of the total operating costs. The energy consumption per flight itself is dependent on the vehicle's performance data and the mission profile (see Table 1). To calculate the required power for the mission, the mission flight segments have to be defined (Melo et al. (2020)). Referring to Lee et al. (2020) and Kasliwal et al. (2019), three flight segments are considered:

- a hovering phase for takeoff,
- a horizontal flight segment for the cruise,
- a hovering phase for landing.

Transition phases depend on the vehicle configurations and on the respective legal basis, and, thus, are considered uniformly at this point. The required hovering power P^{hover} for an eVTOL vehicle is derived from the disc actuator theory with correction factors based on the configuration, such as coaxial or single rotors (Fredericks et al. 2018, Husemann et al. 2023, Lucas 2007). For horizontal cruise, the required power is dependent on the vehicle's gross weight, lift-to-drag ratio, cruise flight efficiency and cruise speed (Melo et al. 2020, Husemann et al. 2023). The eVTOL data are summarized in Table 1 with reference to Brown & Harris (2018), Bacchini & Cestino (2019), Chauhan & Martins (2019), Lee et al. (2020). Additional computed data through OpenVSP simulation for aerodynamic parameters, e.g., c_{D0} and $\kappa = \frac{1}{\pi e \Lambda}$, are included. Furthermore, a hovering time phase of 60 seconds per each takeoff and landing phase is set, a medium battery-specific energy density of 250 Wh/kg is assumed (Brown & Harris 2018, Lückhof 2021), a cruise flight efficiency of 75 % is considered (Kasliwal et al. 2019, Melo et al. 2020) and maximum battery usage of 80 % is included (Kasliwal et al. 2019). Based on these data, a diagram illustrating the trend of efficiency vs range is displayed in Figure 5 a) for the considered eVTOL configurations. Results show that multirotor configurations require more energy per payload-km and have a shorter range. Nevertheless, considering UAM trips of 15–20 km, multirotor and other configurations overlap regarding performance. Therefore, aspects at the fleet level must be investigated for a holistic analysis.

2.2.2. Cost analysis at fleet level

Referring to Garrow et al. (2021), Mitchell et al. (2022), Cohen et al. (2021a), Ahmed et al. (2023), fleet-level analyses provide additional metrics to comprehensively compare UAM services without relying solely on vehicle performance facilitating decision-making on infrastructure planning and economic viability. In order to perform a fleet-level analysis, supplementary input data are required. As a part of a fleet-level analysis, this study focuses on a cost analysis considering recharging requirements of the vehicles, demand fluctuations of UAM trips during an operating day, capacity constraints at vertiports, and optimization potentials regarding network sizing and infrastructure planning Garrow et al. (2021), Ahmed et al. (2023). For cost calculation, an approach by Husemann et al. (2023) is used. Here, the authors combine a *Multi-Agent Transport Simulation* of UAM flights as input data with a mathematical cost optimization model. The emphasis is on the scenario of the Metropolitan Region Ruhr as requested UAM trips are mainly in the range of 15 to 20 kilometers (Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020, Sun et al. 2021). In particular, the cost optimization model includes costs for infrastructure and recharging, costs for the vehicle fleet and related maintenance, costs for batteries, and energy costs as suggested in Garrow et al. (2021), Mitchell et al. (2022). As typical input data, 33 0 days of UAM operations per year are assumed as average, energy costs are set to 0.22 EUR/kWh, a residual value of 30 % of the vehicles after 13 years lifetime is presumed and the vehicle costs are calculated in relation to the empty weight with a factor of 675 EUR/kg (Husemann et al. (2023)).

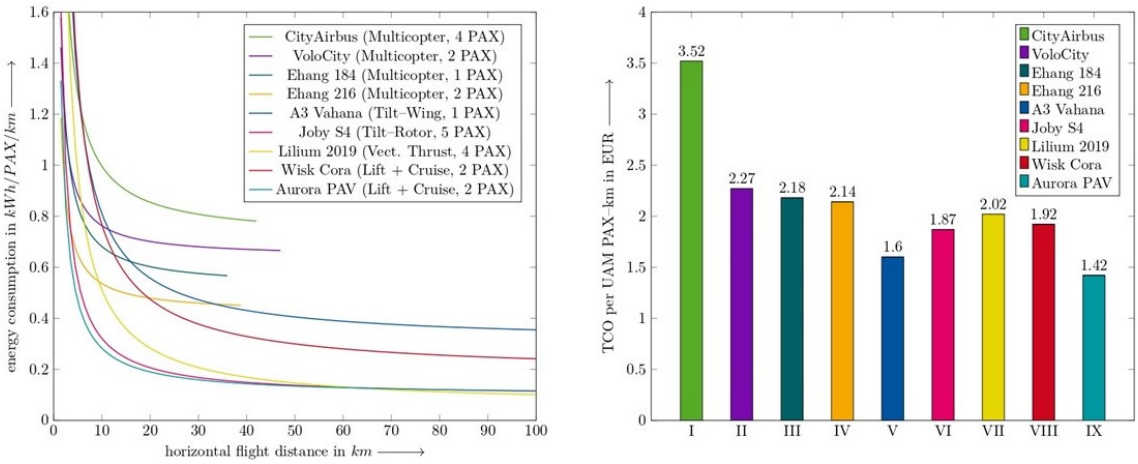
Vehicle	General Data	Hovering Data	Cruise Data	Sources
CityAirbus *Multirotor*	$EW = 1180\ kg + 660\ kg$ $v_{max} = 120\ km/h$ $4\ PAX\ (360\ kg)$	$f = 1.42$ $A_{disk} = 72\ m^2$	$(L/D)_{cr} = 2.8$	computed, Airbus (2023), averaged battery factor
VoloCity *Multirotor*	$EW = 400\ kg + 320\ kg$ $v_{max} = 110\ km/h$ $2\ PAX\ (180\ kg)$	$f = 1.25$ $A_{disk} = 74.8\ m^2$	$(L/D)_{cr} = 2.5$	computed, Volocopter (2023), averaged battery factor
Ehang 184 *Multirotor*	$EW = 168\ kg + 102\ kg$ $v_{max} = 100\ km/h$ $1\ PAX\ (90\ kg)$	$f = 1.42$ $A_{disk} = 16.08\ m^2$	$(L/D)_{cr} = 2.5$	Brown & Harris (2018) , Bacchini & Cestino (2019), Lucas (2007)
Ehang 216 *Multirotor*	$EW = 225\ kg + 175\ kg$ $v_{max} = 130\ km/h$ $2\ PAX\ (180\ kg)$	$f = 1.42$ $A_{disk} = 32\ m^2$	$(L/D)_{cr} = 2.5$	Brown & Harris (2018), Bacchini & Cestino (2019), Lucas (2007)
A3 Vahana *Tilt–Wing*	$EW = 475\ kg + 250\ kg$ $v_{max} = 200\ km/h$ $1\ PAX\ (90\ kg)$	$f = 1.25$ $A_{disk} = 14.14\ m^2$	$S = 9\ m^2$ $c_{D0} = 0.0485$ $\kappa = 0.0544$	Lee et al. (2020), Chauhan & Martins (2019), computed
Joby S4 *Tilt–Rotor*	$EW = 1080\ kg + 650\ kg$ $v_{max} = 322\ km/h$ $5\ PAX\ (450\ kg)$	$f = 1.25$ $A_{disk} = 52.57\ m^2$	$S = 13.75\ m^2$ $c_{D0} = 0.02138$ $\kappa = 0.0390$	computed, Joby (2023), averaged battery factor
Lilium Jet (2019) *Vectored Thrust*	$EW = 250\ kg + 240\ kg$ $v_{max} = 230\ km/h$ $4\ PAX\ (360\ kg)$	$f = 0.9$ $A_{disk} = 0.64\ m^2$	$S = 3.6\ m^2$ $c_{D0} = 0.0163$ $\kappa = 0.0580$	Bacchini & Cestino (2019), old concept
Wisk Cora *Lift + Cruise*	$EW = 824\ kg + 400\ kg$ $v_{max} = 180\ km/h$ $2\ PAX\ (180\ kg)$	$f = 1.25$ $A_{disk} = 13.60\ m^2$	$S = 10\ m^2$ $c_{D0} = 0.0438$ $\kappa = 0.0294$	Bacchini & Cestino (2019), Fredericks et al. (2018)
Aurora PAV *Lift + Cruise*	$EW = 360\ kg + 260\ kg$ $v_{max} = 180\ km/h$ $2\ PAX\ (180\ kg)$	$f = 1.25$ $A_{disk} = 25\ m^2$	$S = 8.8\ m^2$ $c_{D0} = 0.0378$ $\kappa = 0.02972$	computed, Boeing (2023), averaged battery factor
Note: Some weight values are adjusted to fulfill PAX=90 kg. Averaged battery factor is set to 30 % of MTOM.				

Table 1: *Vehicle specifications and data for analyses.*

Minimizing the total cost of ownership (TCO) of one day of UAM operations, the results can be calculated with respect to the different eVTOL configurations. Results show the average costs are around 2 € per payload vs trip-kilometre with an overall market share of up to 1 % of all mobility trips which is in line with recent literature (see Husemann et al. (2023), Rothfeld et al. (2021), Garrow et al. (2021), Ahmed et al. (2023), Mitchell et al. (2022).

Considering the parameter studies by Kirste et al. (2022) and Husemann et al. (2023), the following considerations can be highlighted. For multirotor concepts, the operation of a UAM fleet is inefficient and only economically valuable with a battery-specific energy density of 250 Wh/kg and above. This can be explained by the cost per payload–kilometer since multirotor concepts spend more time on the ground. Moreover, recharging requirements for multirotor concepts are higher, which leads to a worse fulfillment of demand especially at rush hour times, and further increases costs for charging infrastructure. The total cost per UAM flight (payload-kilometer) is higher than for Lift + Cruise or tilt-rotor concepts due to more restrictive recharging constraints at the fleet level and demand cuts resulting from the shorter range. Moreover, for the Lift + Cruise or tilting concepts, a high cruise speed above the optimal lift-to-drag ratio can be considered inferior, as the additional demand due to the reduced travel time cannot compensate for the increased energy consumption and the resulting battery as well as recharging constraints. For these concepts, a hovering time of less than 150 sec is critical to implement fleet operation economically valuable with current battery technology. Besides, the advantages of high payload capacity vehicles can be assessed as detrimental at the fleet level. This is due to higher waiting times when the vehicle operates at full capacity (as this leads to a reduction in the total number of requests) and higher energy costs when the vehicle operates when it is not fully loaded.

A scheduled dispatching approach can be considered an alternative to an on-demand air vehicle service. This is due to the higher operational variability of on-demand systems and the resulting noise emissions, which cannot be precisely controlled as in the case of scheduled approaches. The acceptance of higher demand by users of an on-demand system



a) Efficiency vs Range b) Total Cost

Figure 5: *Efficiency vs range (a) and total costs (b) for different eVTOL vehicle fleet operations.*

is thus contrasted with lower acceptance by non-users. Furthermore, it should be noted that technical calculations and cost estimation depend on the legal framework of UAM operation and on user acceptance. Therefore, the lower costs for autonomous vehicles assumed here could be limited as piloted aircraft are currently more accepted than autonomous vehicles. The further development of technical concepts, based on the legal framework that lays behind allowable operations, has to be considered at the overall system level as significant to specify viable future scenarios.

3. Legal aspects of the UAM system

The emergence of UAM has attracted attention since the mid-2010s (Organization for International Economic Relations 2020, Garrow et al. 2021, Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020, Cohen et al. 2021*a*, Berger 2022). For this reason, numerous initiatives and regulatory frameworks have been put in place in recent years to ensure the *safe* integration of novel types of aerial vehicles into the urban environment in compliance with current and future regulations (Keller et al. 2021, Bauranov & Rakas 2021). In the following part, the regulatory steps from 2017 to 2022 are methodically enumerated with the aim of delineating the European regulatory process and highlighting the impact of stakeholders and the public on it. Figure 6 depicts the principal milestones achieved in Europe.

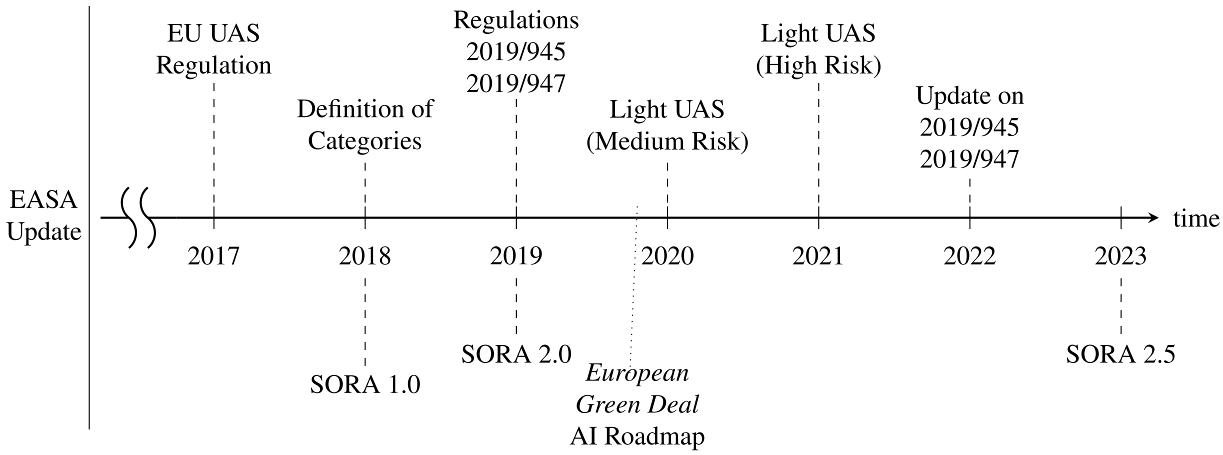


Figure 6: *Timeline of important EASA certification publications.*

3.1. European UAM regulation in 2017-2022

In Europe, the European Union (EU) and the European Union Aviation Safety Agency (EASA) are the institutions responsible for regulating UAM and issuing the necessary UAM certification standards.

Before 2017 - The first release of UAV regulations was at the end of 2016 (EASA 2017). These regulations were guided, especially in the beginning, from the European certification standards CS-23 for small aircraft and the CS-27 for small rotorcraft. Purely implementing the certification standards for either small aircraft or rotorcraft, based on the type of vehicle, and incorporating minor modifications would not ensure an equitable certification procedure.

Nevertheless, the first set of conditions for the certifications of UAVs was based on the aeronautical standards as they were the only certification specifications available: the result was a "prototypical" set of conditions for the certification, applicable in specific circumstances and contexts (Nikodem et al. 2018, Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner 2020).

2017 - To address the lack identified prior to 2017, the EASA took proactive measures by implementing a harmonized regulatory framework for UAM in Europe (see Figure 6). This marked EASA's initial step towards ensuring a common regulatory framework for UAM in Europe. To differentiate aerial vehicles based on weight, speed, size, and the level of risk they pose in the air and on the ground, a categorization of future UAM vehicles into three classes was essential to improving safety, establishing clear regulations, simplifying the certification process, and stimulating innovation in the UAM industry. Furthermore, in order to update and extend the regulatory framework for the certification of UAM vehicles, EASA launched an initiative inviting stakeholders such as industry, academia, and national authorities involved in UAM to collaborate in the development and adoption of UAM by providing feedback on UAV regulations. Public concerns were also collected. The involvement of stakeholders and the public can help ensure that regulatory decisions are based on a thorough understanding of the challenges posed by UAM, while also addressing the needs and concerns of all parties involved (Mitchell et al. 2022).

2018 - Although there were no rulemaking developments, i.e., no new policy release, the definition of the categories was *finalized* in the document "Introduction of a regulatory framework for the operation of unmanned aircraft systems in the 'Open', 'Specific' and 'Certified' categories which was an important cornerstone in the regulatory process (see Figure 6. EASA's commitment to working with stakeholders and the public was successfully demonstrated being a necessary approach for the safe integration of UAM into the airspace.

2019 - In 2019, several important milestones were achieved in the regulatory activity for UAM. The first concrete milestone for the regulation was done as a first step towards implementing a comprehensive framework for UAS operations across Europe. Remarkably, the "Commission Delegated Regulation (EU) 2019/945 on unmanned aircraft systems" and the "Commission Implementing Rules 2019/947" were published (see Figure 6). There are a number of risk factors that must be taken into account when deploying UAVs, including challenges related to airspace management, safety protocols, public acceptance, and regulatory compliance with manned air traffic (Organization for International Economic Relations (2020), Bauranov & Rakas (2021), Sells (2022), Ahmed et al. (2023)). EASA's three categories of UAVs are based on their weight, size, and intended operation (Schuh et al. (2022)). The combination of weight, size, and operation leads to the level of risk. This level of risk is qualitatively calculated through the Specific Operation Risk Assessment (SORA) approach (Nikodem et al. (2018), Babetto et al. (2022)). The development of a risk-based approach SORA was an important milestone, as it considers not only the safety level of the aerial vehicle per se but also the risk posed to the surrounding environment in which it operates (Schuh et al. (2022), Babetto et al. (2022) and Berger (2022)).

The involvement of aviation in the Green Deal initiative further highlights the significance of UAM in promoting sustainability and addressing environmental concerns (European Commission and EASA (2019), Pons-Prats et al. (2022), Organization for International Economic Relations (2020), Ahmed et al. (2023)). The goal is to develop new *sustainable* solutions for transportation, including the innovation represented by the UAM scenario by providing a low-emission mode of transportation with eVTOLs, which can contribute to the transition towards more low-carbon aviation. The concept of Standard Scenario (STS) is also introduced in both Regulations 2019/945 and 2019/947. The STSs are collections of operational and technical requirements for UAV operations that are deemed low-risk and can be carried out without the need for a specific operational authorization are defined. An extension of STSs is planned to be published soon, defining the ability to handle greater MTOMs, the flight above densely-populated areas along with the BVLOS, and automated flight mode as intended in EASA (2022). In fact, the wider the scope of STSs is, the more straightforward it is to certify and conduct UAV operations (Bauranov & Rakas (2021), Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020), Mitchell et al. (2022)). Hence, the evolving definition of the STSs, along with the categorization of UAVs, has been recognized as a step forward for the successful and flawless market entry of UAM vehicles (Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020)).

2020 – In 2020, the EASA released the first version of the Artificial Intelligence (AI) Roadmap 1.0, (see EASA (2020*a*)). The ethical dimension of the AI application in aviation is discussed targeting the challenges presented in the adoption of augmented systems and machine learning for automatic decision-making (Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020), Bauranov & Rakas (2021)). At the time of release in 2020, there was no impact on rulemaking. Despite this, its potential impact on UAM regulations in the future, which target highly-automated systems, could be indirect by providing a framework and new standards for the safe, secure, and effective use of AI in aviation and, in turn, in the UAM system (Sells (2022)). In addition, the EASA released the first edition of the "Special Condition for the Certification of UAVs ", which detailed specific safety requirements for UAM vehicles in the "Specific" category (see EASA (2020*b*)). For instance, performance (MTOM, maximum altitude, and airspeed, type of operation), control and communication as well as navigation and surveillance (e.g., requirements for the detect-and-avoid system) along with environmental and noise emissions levels are covered as fundamental aspects for UAM operations as outlined by Bauranov & Rakas (2021), Sells

(2022), Mitchell et al. (2022).

This calls for an airspace concept specifically designed for the deployment of UAM vehicles, namely the U-Space, which includes establishing air traffic management and, communication and surveillance requirements (Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020), Bauranov & Rakas (2021)).

2021 - A revision of the "Special Condition for the Certification of UAVs " was issued extending the coverage of riskier UAM vehicles (see Figure 6). Moreover, the first proposal for the U-Space was made available. Here, a "high-level framework" was discussed capable of integrating the unmanned traffic into the manned traffic in a harmonized way. The definition of U-Space, such as providers' as well as services' requirements along with responsibilities allocation, interoperability and data exchanges protocols definition, is a necessary aspect for ensuring the safe and efficient integration of low-altitude flights over urban areas (EASA (2021*a*), Bauranov & Rakas (2021), Mitchell et al. (2022), Sells (2022)). Hence, its establishment in 2021 represents one more essential milestone in the development of a robust regulatory framework for the UAM system in Europe (Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020)).

2022 - In 2022, the norm already laid down was regularly updated in terms of safety management and risk containment, national certification and border-related inconsistencies in legal policy. Besides, the noise emissions were also covered (European Union and EASA (2022), Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020), Bauranov & Rakas (2021)). Lastly, in September 2022, a revision of the Regulation 2019 was released and can be read in EASA (2022) (see Figure 6). Inviting the national authorities to conform with the European regulations in terms of UAM vehicles' requirements and certification as well as U-Space-related policies represents a further fundamental step towards a harmonized U-Space framework across Europe (Sells (2022), Ahmed et al. (2023)).

In summary, EASA has adopted a robust approach to addressing necessary aspects of the regulatory framework for UAM since 2017. Today, this framework includes technical design through the class definition, manufacturing, safety levels, and safe operations via the formalization of SORA and, airspace harmonization with ATM by establishing the U-Space. Furthermore, stakeholder and public cooperation have been launched and developed over time, resulting in successful rulemaking acceleration. Through stakeholder involvement, the regulatory technical gaps have been addressed systematically, and public concerns have been targeted to increase acceptance, which has a great impact on the adoption of innovative technologies as detailed in Section 4.

3.2. Legal challenges identification

Considering the actual legal framework presented in Section 3 and similar worldwide studies (e.g., Sells (2022), Bauranov & Rakas (2021)), various challenges have been identified that the UAM has to face to be fully integrated into the airspace and are summarized here:

- The flight in BVLOS is essential for many UAM use cases (e.g. delivery, passenger transportation, and aerial inspection). However, this is currently allowed only if a human ground operator has visual contact with the aerial vehicle and can communicate with the pilot in real-time.
- The flight above densely populated (or congested) areas is not permitted.
- The airspace and correlated traffic controller providers are still vague: for instance, the UAM system might take place either in the uncontrolled airspace, in the controlled airspace or in a merged airspace of the previous two.
- The UAM system is expected to be highly autonomous but today only flights monitored by a licensed operator are authorized. This is accompanied by the use of advanced AI algorithms, which in turn raise cyber-security challenges.
- UAM vehicles must be designed considering the minimization of noise emissions as a design driver.
- Privacy and data protection concerns must be tackled, as there is no common protocol available that complies with the data protection standard.

Overall, the lack of regulations and protocols, service providers, and a transparent harmonization with general aviation as well as strict airworthiness requirements impede any operation carried out in a city. This inevitably compromises the deployment of the UAM system. These challenges, which compromise public acceptance, will be tackled to derive new design drivers to accelerate the safe adoption of the UAM system.

4. Social aspects of the UAM system

Establishing UAM as a future transport option requires on top of technological maturity and a legal framework acceptance by the affected stakeholders, in particular the acceptance of society. Although it is a highly relevant scientific topic to study the acceptance for successfully adopting and establishing new technologies, the UAM acceptance has not yet been fully grasped (Johnson et al. 2022, Tepylo et al. 2023). The purpose of the following literature review is to investigate the factors that encourage or discourage individuals to try UAM and, thus consequently, not only to tolerate it but to accept the new mobility option to enter the market (Al Haddad et al. 2020). UAM, including UAVs, UTM, and the legal framework, is not yet in place resp. in service. As a result, the only way to study acceptance is to assume that behavioral intention and/or willingness to try UAM services corresponds to acceptance per se (Ajzen 1991, Garrow et al. 2021, Lotz et al. 2023). This motivates the dynamics and changeability of UAM acceptance. Moreover, although statistical analysis with a large sample size is a valuable tool for identifying overall trends and patterns in UAM acceptance, it cannot fully capture the individual experiences and perspectives within the population Johnson et al. (2022). Thus, individual opinions are important for comprehending the reasons behind specific statistical trends, identifying potential issues, and developing more "accepted" solutions. Individual opinions play also a significant role in shaping the dynamics and changeability of UAM acceptance, as they may adapt over time in response to changing circumstances, evolving information, or altering social and cultural contexts. Despite this complex interdependence, previous UAM research has been able to assess acceptance and analyze the relevant factors influencing it (Tepylo et al. (2023)).

4.1. Factors for the social acceptance study

The acceptance concerning UAM can be derived by analyzing the studies of UAM acceptance in light of three groups of influencing factors for primary conventional acceptance: subject-related, object-related, and context-related factors. Subject-related factors refer to the characteristics of the individuals who consider UAM as a mode of transportation, whereas object-related factors consist of the individual evaluation of the technology (i.e., the object) in a specific environment. Instead, context-related factors address the conditions under which the individuals (subjects) accept the new technology (object) (Tepylo et al. 2023, Schäfer & Keppler 2013).

The psychological, sociological, and demographic characteristics of people who might use or interact with UAM are referred to as *subject-related factors*. For instance, younger people are more likely to use UAM services and are generally more receptive to new technologies. The importance of gender and income was also noted, as women and those people with lower incomes are less inclined to use UAM due to cost and safety concerns (Yedavalli & Mooberry (2019)). In addition, previous exposure to similar modes of transportation, such as private planes or helicopters, may influence how individuals perceive UAM. Based on the study area of Germany, Dannenberger et al. (2020), Fu et al. (2019) found that age and gender are the main factors influencing the acceptance of air vehicle systems for passenger and freight mobility. Younger and male respondents are more likely to accept UAM vehicle systems. The influence of respondent's age on acceptance is confirmed by Castle et al. (2017) and Bansal et al. (2016). Instead, the research of Al Haddad et al. (2020) and Straubinger, Kluge, Fu, Al Haddad, Ploetner & Antoniou (2020) focused on sociological aspects, showing how employment status, commuting factors, culture and/or education can influence a person's choice of transport mode. People with higher levels of education and people that hold a driver's license are more interested in utilizing UAM services (in Cohen et al. (2021*b*) and Krueger et al. (2016) respectively, accompanied by the work of Fu et al. (2019)). Moreover, Shaheen et al. (2018), Dannenberger et al. (2020) and Johnson et al. (2022) found that familiarity with and accessibility to technology related to UAM had a positive influence on people's perceptions of the UAM vision. In particular, Dannenberger et al. (2020)'s study showed that men were more attracted due to technological accessibility, although the impact of this factor was significantly lower compared to the other (purely demographic) factors. Lastly, individual perception is strongly subjective, i.e., a person's personality may have an effect. An open mind and an individual propensity for innovation, according to studies such as Charness et al. (2018) and Al Haddad et al. (2020) respectively, increase acceptance of UAM.

The *object-related factors* refer to the characteristics of UAM that may affect public acceptance of this mode of transportation. Safety (and reliability) is often cited as the most important factor, as accidents or incidents involving UAM vehicles could have a significant negative impact on public perception. Public acceptance of UAM can also be influenced by other important components such as noise levels and environmental impact. Furthermore, the public should also consider the availability, price and privacy of UAM as object-related factors. Firstly, it can be stated that a low environmental impact exerts an important influence compared to competing mobility concepts. Lotz et al. (2023) showed that, in addition to price, environmental impact is a decisive factor in motivating a switch to another mode of transport. Moreover, the choice of transport mode is mainly determined by cost and travel time (Rothfeld et al. (2021), Al Haddad et al. (2020), Lotz et al. (2023)). In this case, consumers are more likely to pay more for personal air travel than for conventional ground transport, especially if the distance traveled is longer. The work of Fagnant & Kockelman (2018) and NASA (2018) also acknowledge the relationship between price and travel time. While the latter focuses on UAM and autonomous aircraft, the findings of Krueger et al. (2016) and Fagnant & Kockelman (2018) primarily deal with ground transport and commuting. These studies conclude that the higher cost of UAM travel may have a negative impact on acceptance; this is confirmed by Shaheen et al. (2018). Piloted UAM aircraft continue to be preferred by the community compared to remotely piloted and autonomous aerial vehicles, despite the promising improvement of highly autonomous technologies studied by NASA (2018), Johnson et al. (2022). If a pilot is on board and monitors the autonomous flight of the vehicle, the perception is positively changed (Shaheen et al. (2018)). However, the relative emphasis on autonomy and remote control in the underlying surveys might lead to different levels of acceptance among different groups of respondents (Lotz et al. (2023)). Safety is another critical factor that could influence acceptance and has therefore been analysed in recent studies (Kellermann et al. (2020), Lotz et al. (2023)). Safety affects not only the attitude towards the entry into service but also the intention to use UAM (Babetto et al. (2022), Reiche et al. (2018)). In this context, it is important to underline that safety covers different aspects (Dannenberger et al. (2020)): on the one hand, safety is correlated with the perceived risk; on the other hand, the correlation is with the actual risk. In regard to this, it is not only necessary to refine the aerial concepts but also to start a dissemination initiative within the community through experts, the media and politics. One misconception is for instance that piloted vehicles are perceived as safer in any case than autonomous vehicles. This negative safety perception might be due to a lack of familiarity and/or knowledge about autonomous flight (Slovic et al. (1982)). Such perception is not only observed by users but also by uninvolved people, who identified safety as their main concern (NASA (2018), Yedavalli & Mooberry (2019), Al Haddad et al. (2020)). However, it should be pointed out that this concern may be alleviated and confidence regained if regular UAM-certification is fully established, i.e., the certification level must be similar to that of the automotive field or aviation (EASA (2021*b*)). Additionally, the survey by EASA indicated that noise was the second most important concern and environmental friendliness was the third most relevant (EASA (2021*b*)). Firstly, noise, together with visual annoyance, is seen as potentially damaging to the quality of urban life. This could undermine the deployment of UAM (Shaheen et al. (2018), EASA (2021*c*), EASA (2021*b*)). Secondly, people are more favourable to using a sustainable mode of transportation (Dannenberger et al. (2020)); however, the concrete environmental impact of the UAM is still under investigation (Lotz et al. (2023)). Lastly, privacy and cyber-security concerns (e.g., private life and data protection) are also identified as potential issues by, respectively, NASA (2018) and EASA (2021*b*).

The broader social, economic and cultural circumstances, in which UAM will be utilized, are referred to as *context-related factors*. Public acceptance of UAM is strongly influenced by urbanisation, the accessibility of current transport options and the regulatory framework. The acceptance of UAM is also influenced by the ability of general public in considering technological progress and its impact on jobs and the economy. Take-off and landing stations, also known as vertiports, are an important aspect of the UAM scenario evaluation. Acceptance is influenced by access to vertiports, as the time saved by travelling to vertiports could be reduced. Therefore, in future UAM planning, direct and/or seamless access to the vertiports could increase the propensity to use aerial vehicles (Rothfeld et al. (2018), Fu et al. (2019)). However, the optimal location for the vertiport is still being researched, as it depends on the infrastructure and urban design of the city, as well as operational planning and noise annoyance. In order to determine the placement of the vertiports, further assessments of the future demand for such UAM services need to be conducted. In summary, the placement of the vertiports could be a significant challenge for the implementation of UAM as it requires expertise in various disciplines (Rothfeld et al. (2018), Goyal et al. (2018)). Lastly, the regulatory framework has been identified as another important context-related factor. For instance, individuals are more willing to adopt UAM when flying altitude, noise, safety, and privacy are regulated by law (Dannenberger et al. (2020), EASA (2021*b*)).

4.2. Social acceptance study

In order to contribute to the study of public acceptance in Europe towards the adoption of UAM, at the Institute of Aerospace Systems a novel survey was developed and carried out. The survey was designed to contribute to a more comprehensive knowledge of public acceptance with respect to UAM in Europe. In addition to data collected by EASA in EASA (2021*b*), which focused on European metropolises, this work targets European medium-sized cities.

4.2.1. Type of the analysis

In this study, a conjoint model is used. In a conjoint analysis, participants are presented with a series of hypothetical product or service scenarios that differ in terms of their attributes, such as price, quality, design, and features. The participants are asked to evaluate or rank the product or scenario, and the results are analyzed using statistical models to determine the relative importance of each attribute. This study focuses on determining how respondents value various technical and legal characteristics of the UAM system. By better understanding respondents' *"preferences"*, UAM developers (i.e. UAV operators and/or service providers who will offer the UAM technology) will be able to meet people's needs and fulfil their requests. In order to identify these *"preferences"*, the survey is carried out by decomposing an aspect and/or item into its characteristics or specifications. For instance, the potential of the UAM scenario is decomposed into benefits and concerns that UAM can bring, which in turn comprise a spectrum of elements. On the one hand, benefits are related to the reduction of road traffic and faster and more customised transport services Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020), Garrow et al. (2021), Ahmed et al. (2023). On the other hand, concerns include cyber-security issues and aural pollution Straubinger, Rothfeld, Shamiyeh, Büchter, Kaiser & Plötner (2020), Bauranov & Rakas (2021). To determine people's preferences, a variety of combinations of these factors are tested and evaluated. In this way, it is possible to conclude how much each aspect contributed positively and/or negatively to the respondent's opinion with respect to the adoption of UAM.

4.2.2. Survey Structure

Topics and sections The questionnaire was developed with a developer- and user-friendly interface, where data are updated in real-time. Furthermore, the extraction of data in spreadsheets and the direct processing of data in graphs and tables accompanied by the corresponding shares is possible. The authors only process the data collected and the questionnaire is anonymous to protect the privacy of the respondents.

Questions structure The questionnaire contains various types of question-wording and answering options. *Questions* The questions are grouped into thematic sections and are briefly stated as single or multiple-choice questions to convey the purpose and facilitate understanding. Only at the end of the survey, there is an optional free text question to gather spontaneous feedback and/or insights. *Answers* All responses can be multiple or single answers by selecting from a suggested list.

Sample size At the national and metropolitan levels, results are already available in the literature (see Section 4.2.2). For this reason, the present work focuses on the identified knowledge gap with respect to medium-sized cities. A medium-sized city is defined as a city with 100,000 to 500,000 inhabitants. An ideal city benchmark of around 200,000 inhabitants is chosen for this study. The opinion of such a large population can be represented by accurately considering a *proper* sample size. When calculating the sample size to obtain the most accurate picture of the population, the *margin of error* and the *confidence level* are accounted for: the standard margin of error is set at 95 %, while the confidence level is set at 5 %. The definition of *margin of error* and *confidence level* can be, e.g., found in Qualtrics (2023), Yedavalli & Mooberry (2019). Given the benchmark of 200,000 people, the calculated result suggests that the ideal sample size is 370 respondents.

Sample type The sample was obtained by collecting a random sample, where everyone has an equal likelihood of being selected. The survey was shared on multiple types of social media in order to target diverse age groups and types of people. In addition, a QR of the survey was generated and distributed in paper form by hanging it on the streets of the city rather than handing it directly to people. The combination of 'paper form and online approach' was preferred to the traditional approach of email or phone calls. Although the latter approach allows for faster data collection, it was considered more time-consuming due to the preparatory work and implementation. Instead, the strategy used requires a considerable amount of time to be devoted to the dissemination activity, as the survey needs to be "*popped up*" regularly.

Target sample The target cities were selected using the following systematic methodology to collect responses from people living in similar European medium-sized cities.

Initially, nine European countries were selected: United Kingdom, France, Germany, Spain, Italy, Belgium, Netherlands, Denmark, and Portugal [1]. Secondly, cities with a population of approximately 200,000 were identified. The selection process was guided by an essential factor: the accessibility of the authors to the city. The possibility to physically access the city enables the distribution of the survey in paper form in addition to the online format. Although the selection of predetermined cities may lead to bias, the number of responses collected through the different distribution approaches (online and in paper form) balanced this out. This would not have been possible without access to the city. Additionally, one city per country was selected based on similarities within the technical factors listed below:

- Population (number of inhabitants in 2019 [2]),
- Market value: Gross Domestic Product (GDP) in billions of € in 2019[5],
- Airfield nearby (in a radius of 15-20 km)
- Presence of a technical university,
- Similar addressable market and services offered.

The cities and technical factors are summarised in Table 2.

CITY	POPULATION	GDP	AIRFIELD	UNIVERSITY	SIMILAR MARKET	GENDER SHARE (male & female)	AGE SHARE (20-39)	SOURCE
MILTON KEYNES	229941	17.8	✓	✓	✓	49.8%, 50.2%	29.6%	ONS
LILLE	234475	17.6	✓	✓	✓	49.8%, 50.2%	27.7%	INSEE
AACHEN	249070	11.7	✓	✓	✓	49.2%, 50.8%	23.9%	Federal Statistical Office
PADUA	203725	18.7	✓	✓	✓	47.4%, 52.6%	22.8%	ISTAT
CADIZ	204783	12.7	✓	✓	✓	48.5%, 51.5%	22.3%	INE
LIEGE	197217	25.4	✓	✓	✓	48.6%, 51.4%	22.3%	Statbel
EINDHOVEN	233620	22.1	✓	✓	✓	50.6%, 49.4%	22.5%	Statistics Netherlands
ODENSE	207762	11.2	✓	✓	✓	50.1%, 49.9%	22.1%	Statistics Denmark
PORTO	237591	20.9	✓	✓	✓	45.2%, 54.8%	22.3%	Statistics Portugal (INE)

Table 2: *Selected cities and gender as well as age share.*

In Table 2, the age group 20-39 is reported as it is the largest individual group within the selected age range 20-70. However, while the age share reported in Table 2 is based on the total population, including people under 20 and over 70 years old, the age groups "< 20" and "> 70" are not included in this survey. For this reason, the age share data in Table 2 should be adjusted when verifying the representability of the sample. This adjustment leads to excluding the "youngest" and "oldest" people, i.e., approx. 35 % of the population.

4.2.3. Study Results

The survey was first distributed in December 2022. At the time of writing, 358 have been collected. Although the number of respondents does not meet the calculated ideal sample size, it is sufficient to delineate a preliminary trend regarding

[1]The survey was translated into different languages in order to obtain more responses per country. Given the high level of confidence in speaking English in Denmark and the Netherlands, the questionnaire was distributed in English in both countries.

[2]2019 was chosen to exclude the impact of the COVID-19 pandemics

public acceptance of UAM in European mid-sized cities.

The geographical distribution of the sample is shown in Figure 7 a). South-western European countries such as Spain and Portugal are currently being addressed, for this reason, their share is at this point in time lower compared to the other European countries and geographical uniformity has not been achieved yet.

The sample includes 50.2 % of women and 47.5 % of men (see Figure 7 b), which corresponds to the gender distribution of the selected cities summarized in Table 2. A share of 97 % of the respondents are between 20 and 70 years old. Seven respondents were discarded as they were out of range. Figure 7 c) shows only the age share within the 20-70 age group. Emphasizing the 20-39 age group, it can be noted that the sum of the age groups, respectively 20-29 and 30-39, results in 48 % of the population. Comparing this number with the “adjusted” and more consistent 38 % (derived excluding the 35 % of the population as aforementioned with a preliminary calculation), a gap of 10 % is shown, which is reasonable given the potential statistical errors and the provisional correction used.

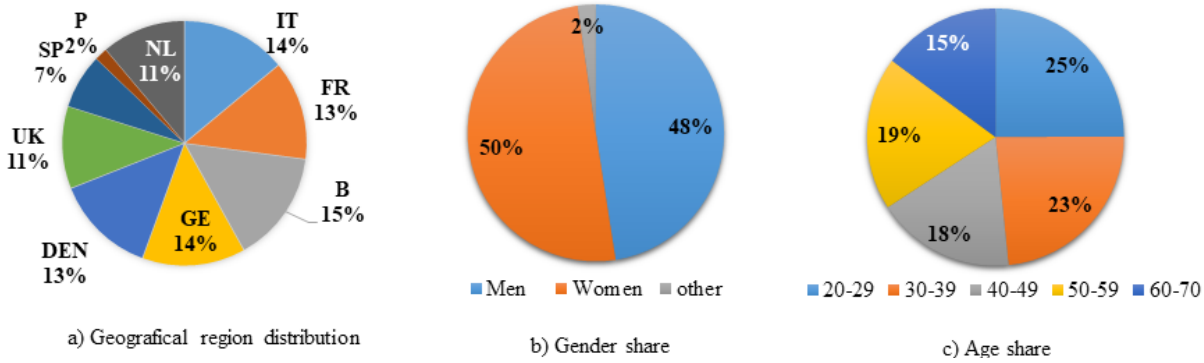


Figure 7: *Distribution of the sample.*

A share of 59 % of the respondents have a positive attitude towards the future adoption of UAM as can be seen in Figure 8 e). In particular, 95 % of the sample confirmed comprehending the term ”smart device” and stated to own at least one ”smart device” (97 %) (see Figure 8 a) and b)). In addition, a relevant number of respondents indicated that they often use mobile phone applications for delivery services, booking, renting, ride-sharing, etc., namely, 16 % specified “at least once per week”, 21 % “once in two weeks”, 27 % “once per month”. The ability to use such services is described by 41 % as “very good” and 33 % chose “good” (see Figure 8 c) and d)). This indicates a promisingly open-minded attitude towards new technologies, which presumably justifies the share of favourable willingness concerning the UAM scenario depicted in Figure 8 e).

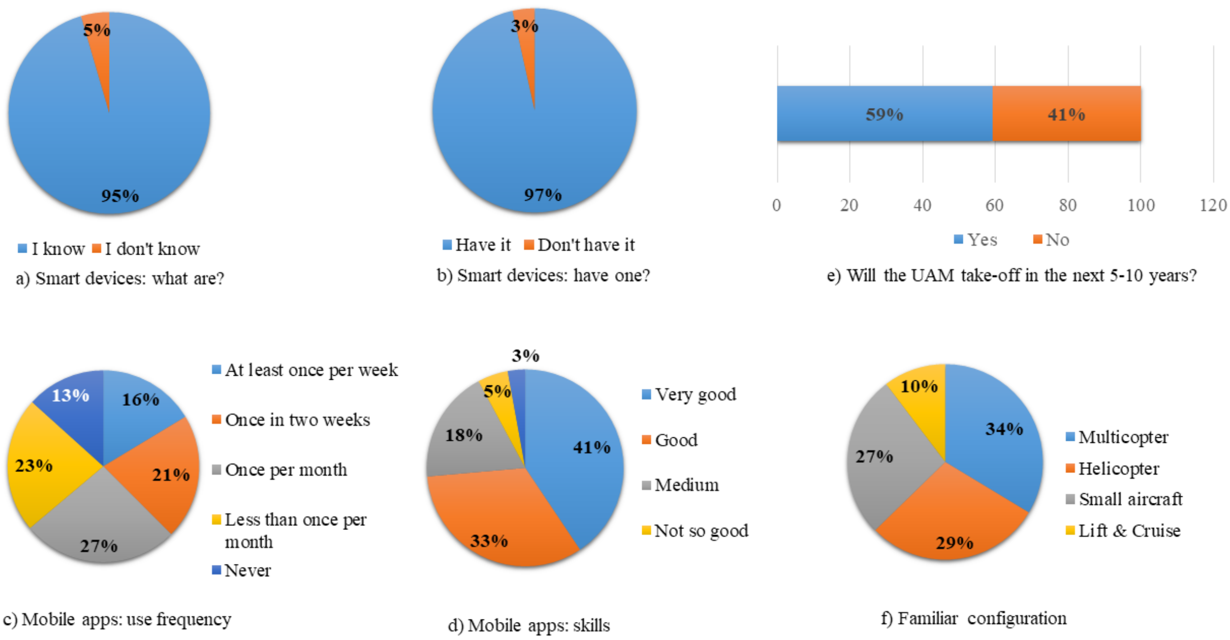


Figure 8: *Social abilities.*

On the one hand, when asked to rank people’s opinions on trying *air taxis*, 29 % of the respondents are prone and 26

% are indifferent regardless of whether the price is higher than traditional ground-based services. A share of 21 % of the replies shows the opposite tendency. When requested the opinion on potentially higher airfares, 36 % of the respondents opted for the "indifferent" option, 25 % were enthusiastic while 17 % were reluctant to pay more (see Figure 9 a) and b)). Furthermore, in the specific use case of air taxis, the opinion on being a passenger has also been investigated: 24 % of the respondents expressed comfort (13 % stated high comfortability) and 26 % showed indifference. However, a share of 28 % would feel uncomfortable (see Figure 9 c)). The majority of people who are indifferent to air taxis (36 % in Figure 9 b)) corresponds to the share of respondents who expressed discomfort as being a passenger. This might underline a lack of confidence in air taxis per se.

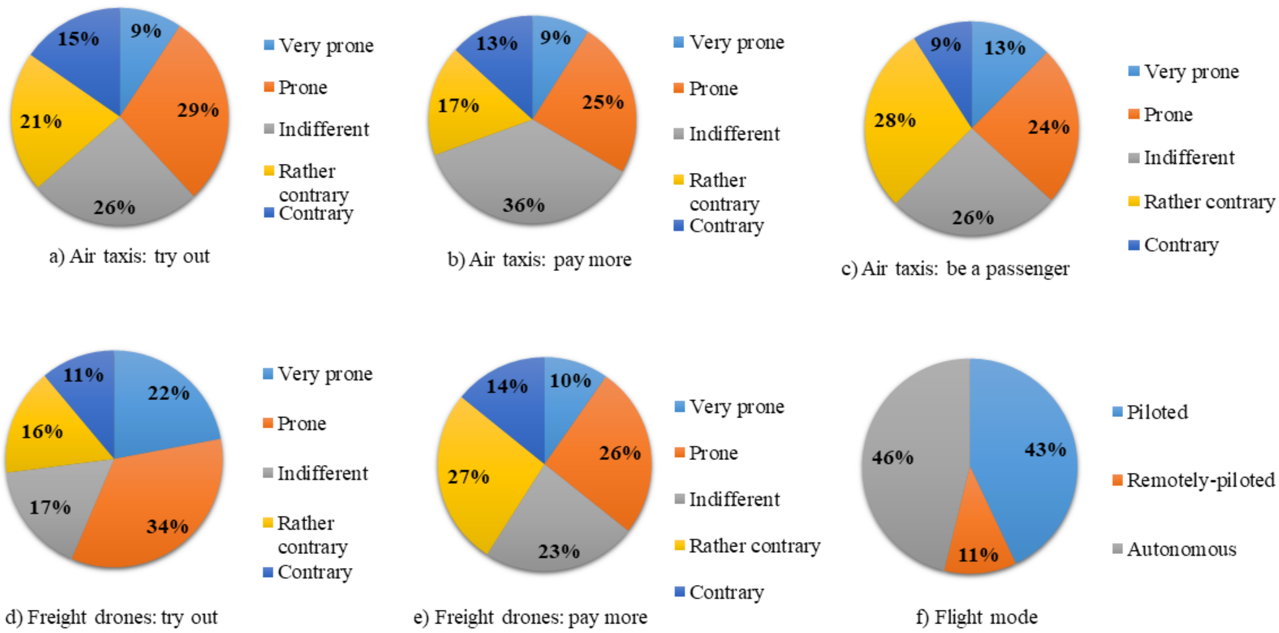


Figure 9: *Willingness on UAM adoption.*

On the other hand, with regard to drone delivery services, 34 % of the respondents were enthusiastic about trying the service, 22 % were very prone and 17 % expressed indifference. All this describes a positive attitude towards drone delivery services (see Figure 9 c)). In addition, the opinion on paying more for delivery services varies between enthusiastic and indifferent (26 % and 23 %, respectively), while, 27 % expressed rejection (see Figure 9 d)). This rejection, combined with a similar response on accepting higher airfares, outlines a potential concern related to the affordability of such UAM services. This hypothesis is confirmed in the following section on UAM concerns.

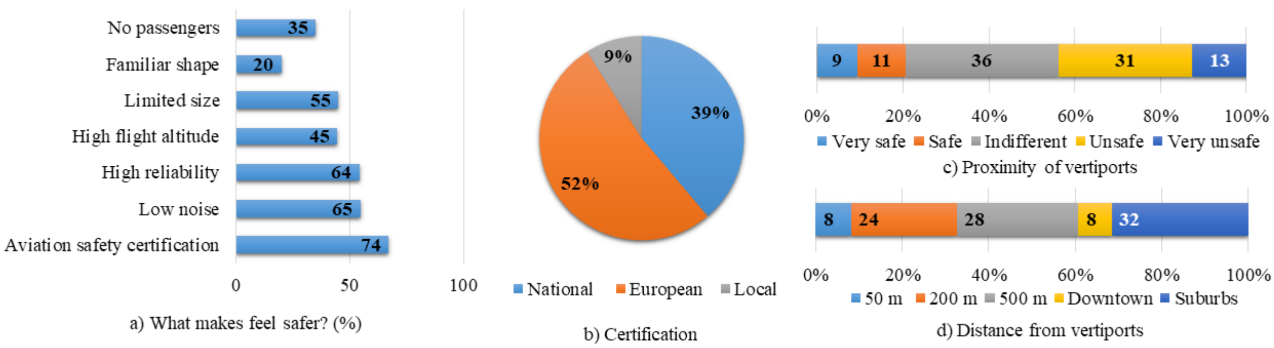


Figure 10: *Comfortability factors.*

The subsequent section of the survey was meant to clarify how safety is perceived. Respondents were asked which configuration they were most familiar with among small aircraft, helicopters, multicopters, and a combination of fixed-wing and wingless layouts (see Section 2). A share of 34 % of the respondents placed the multicopter in the first place. The multicopter may be the most familiar configuration, as this layout is already well-known for operating close to people, e.g., leisure and filming drones, police and inspection multicopter, and small package delivery vehicles. The helicopter follows with 29 % of preferences. The lift + cruise is the less familiar (10 %) (see Figure 8 f)).

After focusing on safety in the previous section of the survey, people were asked which aspect could ”make them feel safer”. This was a multiple-choice question. The results show that 74 % of respondents voted for certification at the aviation level, 65 % believed that low noise levels improve comfort and 64 % thought that a reliable control system induces a safer perception (see Figure 10 a)). In particular, 52 % of the surveyed people preferred the European authorities to grant permission to fly, while 39 % supported the national authorities (see Figure 10b)). This high level of national support is explained by the fact that the United Kingdom has downgraded the role of the European Union in recent years: in fact, a share approx. of 80 % of the English respondents supported national authorities. Moreover, two English respondents selected the preference of "local authorities" to grant the certification, which strengthens in turn the national support.

The UAM infrastructure was also mentioned as a relevant factor for UAM acceptance. The opinion on the acceptance of UAM can be improved by investigating the urban planning and the location of the vertiports. As Figure 10 c) shows, a share of 36 % of the respondents is indifferent concerning the situation of such vehicles taking off and landing in proximity to their residences. However, 31 % are concerned and 13 % are very concerned. Although 11 % of respondents ranked UAM vertiports generally as ”safe”, the tendency is towards a negative attitude concerning the allocation of vertiports near residential areas. Consequently, the questionnaire asked how far vertiports should be located to increase comfort. A share of 28 % of respondents stated that they would prefer vertiports to be located in suburban areas or at least 500 m from their place of residence (32 % and 28 % respectively) (see Figure 10 d)).

Lastly, people were questioned about the benefits and concerns related to the adoption of UAM. *Benefits* The potential to relieve ground traffic is the most valued benefit. This is followed by dealing with urgent situations with the help of aerial vehicles, such as a pre-arrival overview of the situation for a firefighting squad or inspection in case of environmental disaster. A value of 35 % of respondents considers air taxis to be an effective solution for intercity connections. This is the third-ranked option for this use case, after reducing ground traffic and emergency management, with 68 % and 61 % of responses respectively (see Figure 12 a)). On the other hand, the potential for faster delivery in cities is the third most supported option for the freight use case (51 %), behind reducing ground traffic and emergency management (68 % and 54 % respectively). Other benefits mentioned, which were rated less than the aforementioned ones, are intra-city connections, customized transport/delivery (inter-city and intra-city delivery in suburbs), and pollution reduction (see Figure 12 b)).

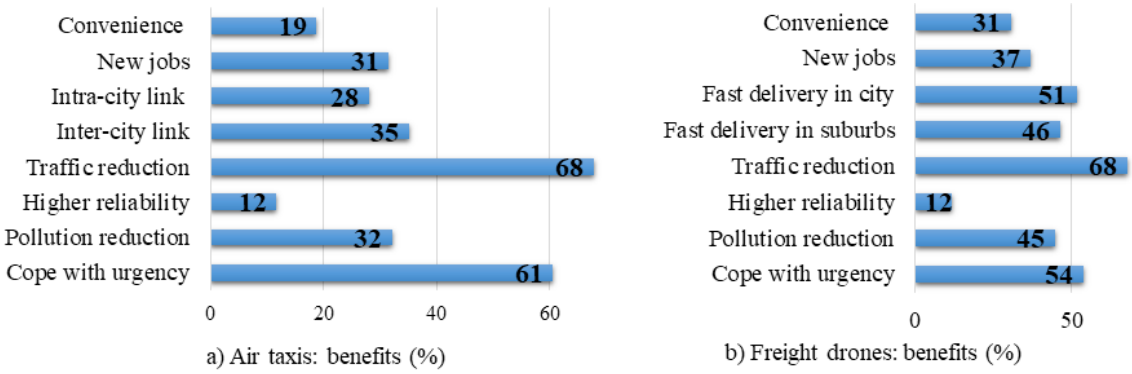


Figure 11: *Benefits of UAM.*

Concerns Inadequate safety, noise annoyance, privacy, and environmental concerns are considered "macro-level" concerns and are recognized as important challenges in the development and implementation of UAM. Instead, visual annoyance, low altitude, and high flight frequency are "sub-concerns" that are associated with "macro-level" concerns. The "sub-concerns" have impacts on multiple "macro-level" concerns. For instance, the high flight frequency of UAM vehicles can contribute to noise annoyance, safety hazards, privacy invasion, and environmental disturbance. Such disruptions, respectively, increase the likelihood of accidents and hazards, reduce comfort levels due to privacy violations, and disturb wildlife and ecosystems. Therefore, addressing these "sub-concerns" is essential to identify the root causes of "macro-level" concerns and mitigate them effectively through targeted strategies. Noise disturbance and insufficient safety are the most voted concerns for both use cases (see Figure 11 a) and b)). The third concern is related to the environmental impact on wildlife. Concerns about affordability, visual pollution, privacy and cyber-security, high flight frequency, and low altitude follow with a minor percentage gap.

4.2.4. Survey assessment

The survey results show a moderately positive attitude toward the adoption of UAM. This resulting trend is moderately in accordance with the outcome of the EASA analysis done for the category of metropolitan cities (EASA (2021*b*)). However, the proportion of positive attitudes is lower: a share of 59 % of the respondents is described as positive in the authors' survey compared to 81 % stated by the EASA in EASA (2021*b*). This might be explained by the more open-minded attitude of inhabitants of metropolitan cities. The prospect of reducing traffic, of using an innovative and alternative transport system,

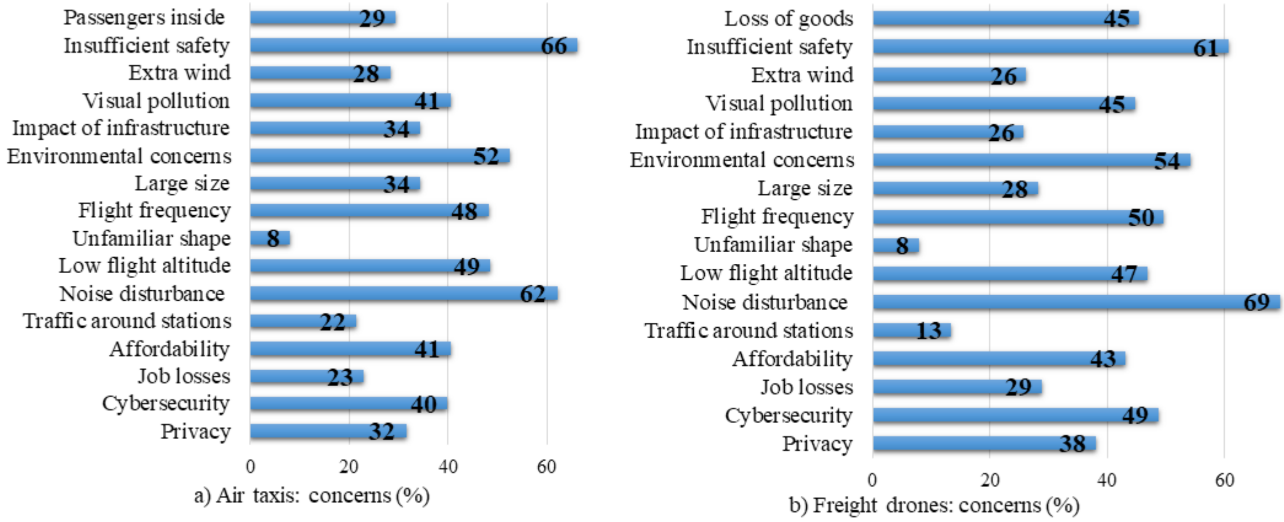


Figure 12: *Concerns of UAM.*

or of receiving an ordered package quickly, could present a relieving scenario that encourages people to give it a trial. The trend demonstrated in our own survey also shows accordance with the factors outlined in Section 4.1. Safety levels, noise emissions, environmental protection, affordability, privacy, and vehicle configuration are the main concerns that will affect public acceptance of the UAM system (Bauranov & Rakas (2021), Sells (2022)).

5. Discussion

In this section, the legal and social challenges outlined respectively in the analysis of the current European legal framework (Section 3) and the assessment of social acceptance (Section 4) are considered as starting point to derive UAM design drivers. The comprehensive technical information presented (Section 2) serves as an enabler of potential technical solutions, guided by new design drivers, to cope with the introduced challenges.

Legal challenges can be summarized as an incomplete set of rules, protocols, and a lack of service providers regarding operations in the urban environment in order to offer a safe and efficient aerial transportation service.

Aerial vehicles considered in this work will accommodate presumably at least one passenger or an equivalent cargo mass and volume.

Operations in the urban environment involve the flight of large and heavy VTOL configurations over assemblies of people, at lower altitudes and potentially in BVLOS mode, which requires progressive algorithms. The proximity to people of such UAM vehicles causes social challenges. People are mostly concerned about the risk level posed on the ground and in the air, the noise disturbance and flight frequency, the vehicle layout, and the type of vehicle control. All these concerns can be translated into design drivers that often differ from the known set valid for conventional aviation.

The identified design drivers are examined in the following:

- UAM vehicle concepts should assure a high level of system reliability, generate low noise emissions, be as compact as possible and carry out safely semi- or fully-autonomous operations.
    1. Configurations, such as multicopter and lift+cruise, have the potential to be more reliable due to their propulsion architectures that intrinsically provide a higher level of redundancy. Additional systems, e.g., advanced and AI-supported communication, navigation, and detect-and-avoid systems can be installed, accompanied by operational contingency measures, for instance, automatic emergency landing in order to enhance the overall safety level.
       If certification is done and airworthiness approval is granted by dedicated authorities only, people's concern related to safety and reliability is further mitigated. Furthermore, addressing one single certification authority centralizes the rulemaking activities. In this way, the rulemaking process is accelerated and improved.
    2. Optimization of rotor design or installation of ducted rotors can reduce noise emissions. Moreover, by scheduling flights only during the day and in specific timeslots, the noise annoyance might be time-wise concentrated. Society might tolerate this as a daily nuisance. Hence, innovative rotor solutions and smart scheduling can be utilized to cope with noise disturbance in the UAM system.
    3. Compact and, at the same time, efficient UAM vehicles are hard to realize. However, preferring the multicopter configuration might balance this concern. First, a multicopter is deemed to be the most familiar UAM configu-

ration for the public, which might potentially relieve the visual pollution challenge. Second, if this configuration type is enhanced such that the flight with multicopters is more comfortable for passengers, providing easy access for disabled individuals or being able to contribute in emergency situations (e.g., for transport or surveillance) on a regular basis, multicopters might become an accepted aerial mobility and service option.

- A safe flight operation is essential for the adoption of the UAM system. Autonomy is, however, identified as a demanding social challenge accompanied by privacy and cyber-security concerns. This is presumably due to a low level of knowledge and/or confidence from the public regarding the technological status quo. In this case, technological development might only partially help to increase acceptance. Even if aerial vehicles show to fulfill the required safety level for autonomous flight and protect personal data as well as prove not to be vulnerable to hacking, jamming, and spoofing attacks, public acceptance might not be taken for granted but will probably remain low for some time. At this point, the potential individual benefits that the UAM service can offer must be highlighted to target the negative public attitude. The UAM service may help avoid road and rail congestion and reduce ground traffic noise and facilitate intra-city transportation as well as inter-city transfers, e.g., for travelers and commuters, and/or fast deliveries. All of this can become a profitable business. In order to achieve this perception of safety and security, public involvement can help to change the prevailing public opinion by promoting UAM capabilities and achievements through education and information campaigns targeting especially potential misconceptions.

- An additional concern is related to affordability. People are negatively predisposed to paying substantially more for UAM services. Route-optimized design, trip scheduling, and the selection of the most efficient configuration for a specific trip range can help limit ticket price premiums resulting in a more affordable service, increasing, in turn, the willingness of experiencing UAM. Scheduled UAM trips will probably be the first service type implemented, paving the way for on-demand UAM transportation at a later stage. Route optimization and trip scheduling have also an impact on urban planning and infrastructure design.
- People are not inclined to allocate vertiports in the city centre or in the proximity of residential areas. However, in order to ensure an efficient and effective UAM service, vertiports must be quickly user-accessible, otherwise, time-saving can be compromised due to travel time expenditure to head to the nearest vertiport. In addition, a dense network of vertiports increases safety, as additional near locations for a controlled emergency landing are available.

The combined impact of the technical, legal, and social aspects on each other is shown to act as additional design drivers that could support the deployment of UAM by addressing current major UAM challenges from different stakeholder perspectives, respectively that of regulators, technical experts and the public and calling for mutual action.
Hence, a massive engagement among these three stakeholder groups is suggested. The prerequisite of this engagement is regulators that advance the current state of rules and derive comprehensive future certification standards for Europe. Within this cooperation, the technical experts can bring in their technological expertise and may guide the rulemaking process in order to reach a final set of rules that is neither too restrictive nor permissive. Furthermore, public involvement is necessary, first, to reduce the lack of knowledge concerning UAM, second, to include public feedback and, third, to drive forward a user-centric and society-balanced UAM development respecting public concerns. Thus, technical and social inputs conduct retroactively the rulemaking process. Such a rulemaking process in close collaboration within the three stakeholder groups has been already initiated for noise regulation. EASA has recently published a guidance document on noise measurement and invited VTOL operators to submit their individual methods and results. Gradually, EASA will derive a formal guideline based on a repository of received input from the operators and will issue standards to be applied across Europe by the end of 2023. Similarly, EASA's SORA was updated in 2023 to version 2.5, which includes a quantitative safety level that can help VTOL operators to evaluate the overall safety level of their VTOL. In addition, the transition to a highly automated framework for UAM services, consisting of autonomous eVTOL and semi-automated infrastructure, is underway and should be completed by the end of 2024.
By applying a similar collaborative process, addressing firstly the use of advanced algorithms according to European data protection regulations, and secondly, the urban planning of vertiports in European cities, the acceptance of these two UAM challenges can be managed and improved. In summary, UAM systems will be better understood and handled in the coming years, enabling real-world testing of open UAM systems by 2025.

6. Conclusion

The aim of this paper was to investigate the adoption of Urban Air Mobility (UAM) from a European perspective, first, by carrying out a literature review of the state-of-the-art of technical, legal, and social aspects concerning UAM, and second, by discussing the mutual influence of these three aspects on the UAM system. The examined UAM vehicle concepts have been mainly developed since 2010, with several eVTOL configurations being tested in the meantime. At the conceptual design stage, comparative analyses can guide the selection of an optimal configuration as wingless, fixed-wing configurations and hybrid layouts possess diverse advantages and disadvantages based on the mission purpose. In terms of energy efficiency, rotorcraft are efficient for short-range missions, while winged and hybrid configurations are more suitable for long-range missions. Nevertheless, other aspects such as reliability, noise emissions, and compactness have to be evaluated when choosing the ideal configuration. For instance, all configurations (with the exception of the helicopter layout) are equipped with several rotors, since this ensures greater redundancy and thus, a lower risk of hazards. Multiple rotors may, however, generate more noise annoyance. At the vehicle-level, performance analyses are still under investigation, e.g., with regard to noise emissions, numerous rotors can be a quieter sound source than a single or few rotor configurations if they are properly designed and synchronized or ducted. The fleet-level cost analysis shows that the Lift + Cruise or tilting concepts allow lower costs per UAM trip-km. Recharging requirements and requests for longer UAM flights are contraries to a multirotor design concept. In addition, ticket prices have been calculated approximately at 2 € per payload vs trip-kilometer, which conforms to current literature. While the technical side is progressing rapidly, the legal framework is far from complete. The European rulemaking activity started in 2017 by EASA and is ongoing. Despite the remarkable progress achieved so far, especially for recreational drones, EASA is actively focusing on current UAM concepts, which are characterized by greater MTOM and size, BVLOS flight mode, high level of autonomy, and operations over densely populated areas. These factors represent rulemaking key obstacles that must be tackled in the coming years in order to accelerate the reliable and safe deployment of UAM. Social aspects are highly relevant. As an emerging technology, UAM has not yet entered the market and is therefore not part of the daily life of the community. Therefore, studies on social aspects rely on perspectives that may be biased, as respondents have to base their opinion on an envisaged future UAM scenario. In reviewing the current state of the art on social acceptance of UAM, the opinion of mid-sized cities was identified as a research gap to be further explored. For this reason, the Institute of Aerospace Systems developed a survey to be distributed in European medium-sized cities and assess the public opinion on UAM. This survey, combined with EASA's survey of European metropolitan areas, allows for a more comprehensive overview of social acceptance from a European perspective. The overall trend of our survey on the attitude towards the adoption of UAM complies to a moderate extent with the trend of EASA's survey. Specifically, EASA's survey showed 81 % of positive opinions compared to 59 % in the own survey. This inferior percentage is attributed to a potentially more "cautious" attitude of medium-sized city inhabitants with respect to technology leaps, despite the fact that the selected cities have a technical university nearby. The presence of a technical university was deemed to be a balancing factor with a relevant impact on the final results. However, this requires further investigation to be confirmed. The main concerns are acknowledged to be an expected low level of safety and large noise annoyance, followed by environmental concerns (e.g., wildlife), privacy, and cyber-security. The cargo delivery scenario seems to be more accepted (56 %) than the air taxi scenario (32 %). This is in contrast with EASA's survey, whose results outline that air taxis are more accepted than delivery with aerial vehicles, respectively, 51 % and 36 %. However, for both scenarios, the trend is negatively reduced if people were asked to pay a premium for such services. The challenge of higher prices can be met, for instance, by offering scheduled UAM trips with route optimization. The benefits of UAM are recognized to be the reduction of ground traffic congestion and pollution, faster urban deliveries and connections, and a contribution to coping with urgency/emergency situations, which is consistent with the main purpose of UAM development.

Although the moderately positive attitude towards UAM and the associated benefits that UAM could provide to cities are highly promising, its deployment is still problematic as the set up of a legal framework is ongoing and public acceptance needs to be enhanced across Europe. The proposed holistic analysis combined technical, legal, and social aspects in order to address the developments and challenges of UAM from three stakeholder perspectives. By conducting an extensive literature review of UAM enriched with a cost analysis of UAM services and a survey on UAM public acceptance, an in-depth understanding of the UAM system was achieved and UAM-tailored design drivers to tackle the uncertainty in the adoption of the UAM system were derived. Most notably, the holistic analysis suggested establishing effective cooperation among stakeholders. Regulators should advance rules and certification standards, while technical experts contribute expertise and guide the rulemaking process. Public involvement is necessary to cope with concerns and address user-centric UAM development. In Europe, stakeholder collaboration is already underway with actions for a UAM framework that ensures low noise disturbance and a high level of safety, respectively, by 2023 and 2024. By applying a similar collaborative process with the public for knowledge dissemination on highly automated vehicles and urban planning of vertiports in European cities, the acceptance of UAM can be managed and improved. These actions will lead to an adequate understanding of UAM paving the way to real-world testing of UAM systems by 2025. This collaborative approach among European stakeholders can be considered a success for achieving a faster and flawless UAM deployment in Europe, setting a global benchmark for other regions to follow.

Future research work will include:

- a comprehensive analysis of UAM vehicle efficiency including new technologies, such as batteries with enhanced energy capacity, hybrid propulsion systems and, advanced autonomous control systems,
- the identification of disturbing noise for humans through a study of psychoacoustics,
- the assessment of the reliability level of UAM vehicles through a risk analysis and verification of compliance with the standards,
- strategic decision-making with regard to network and vehicle configuration assessment,
- the optimization of total costs for reduction of ticket prices and enhancement of market shares and revenues in the

life-cycle assessment,
- a more in-depth presentation of the survey design and data usage,
- a discussion of collected data with regard to the geographic distribution and individual perceptions,
- a correlation between macro-level and sub-concerns through the conjoint analysis.

Authorship Contribution Statement

Laura Babetto: Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing. **Ansgar Kirste:** Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft, Writing. **Jingshu Deng:** Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing. **Michael Husemann:** Supervision. **Eike Stumpf:** Conceptualization, Writing – Review & Editing, Supervision.

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