Addressing the emergence of drones – A policy development framework for regional drone transportation systems

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ARTICLE INFO

Original content: Addressing the emergence of drones – A policy development framework for drone transportation systems (Reference data)

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Keywords:
- Drone transport
- Advanced Air Mobility (AAM)
- Urban Air Mobility (UAM)
- Sustainable transportation
- Policy development

ABSTRACT

The climate crisis demands an energy transition away from fossil fuels, and for the transport sector, this implies finding more electric or hydrogen-fuelled solutions. An emerging disruptive solution with high potential for improved sustainability is using drones as a mode of transport, i.e., Advanced Air Mobility for passenger and freight transport in urban and rural areas, fuelled by electricity or green hydrogen. As drones are being rapidly commercialized, there is a need for a policy framework for local and regional actors to address this in decision-making. This paper aims to develop a policy framework through a systematic literature review where findings have been validated by experts from industry and appropriate governance bodies. The results reveal three conceptual elements in the Advanced Air Mobility system where policy actions are needed: 1) primary technology, including vehicle-related aspects; 2) functionality, including infrastructure and operations; and 3) adoption, including the environment, market, and society. The overall lack of a multi-level governance model for Advanced Air Mobility and the scarcity of knowledge of the topic within vital fields such as energy systems and regional planning are also addressed. The findings are discussed in light of regulatory frameworks for drone transportation in Europe. The paper concludes with a policy development framework for regional Advanced Air Mobility deployment and provides policy implications.

Introduction

The transportation sector is among the highest emitters of carbon emissions due to dependence on fossil fuels (92% in 2015 (Khalili et al., 2019) and 93% in 2017 (International, 2019)) and factors such as globalization and urban sprawl1. Increased attention to converting fossil-fuel dependency toward electricity and hydrogen is needed. Apart from direct greenhouse gas (GHG) emissions, indirect GHG emissions from transportation are large due to increased land and resource use, e.g., road and railway construction and maintenance. Other indirect negative impacts from road transport include emissions of volatile organic compounds (VOCs), and safety issues (e.g., IDA, 2020). Taking these indirect negative impacts into account, for example using carbon budgeting2, and creating mitigation actions, opens opportunities for novel fossil-free drones3 with the potential to create a flexible, resource-efficient multimodal transportation system in the built environment.

Until now the use of drones has mainly been for military purposes (Nex & Remondino, 2014). Now, drones are being used in the transport and aeronautics industries (e.g. Lilium, 2020; Ehang, 2020; Aerospace, 2021) to complement conventional freight and passenger mobility. The term for this concept initially emerged as Urban Air Mobility (UAM), to address urban mobility issues in dense urban environments (Hasan, 2019; Holden & Goel, 2016; Reiche et al., 2019). Today the term has evolved to Advanced Air Mobility (AAM) to include the potential of

1 Urban sprawl is used here as urban encroachment that follows unplanned suburbanization over large expanses of land with little concern for urban planning.
3 Drones in this paper also refer to Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAV), or Vertical Take-off and Landing Vehicles (VTOLs).

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https://doi.org/10.1016/j.trip.2023.100795
Received 7 November 2022; Received in revised form 27 February 2023; Accepted 7 March 2023
Available online 13 March 2023
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using drones in rural regions, with potentially greater environmental benefits. A study in Thailand shows drones have one-twelfth of the environmental impact compared to electric motorcycles for delivery scenarios, and that drones in rural areas had 13 times greater environmental benefits than in urban areas (Park et al., 2018).

Some studies suggest that drone deliveries have clear benefits over electric vehicles where the number of customers per route does not exceed 10 (Figliozzi, 2017) and that drones are most effective if deliveries are within a range of 3.5 to 4.2 km (Stolaroff et al., 2018). While electric drones are said to have more benefits than fuel-celled drones (Yamate et al., 2018), in some cases the benefits are unclear (Koivaniit, 2018). However, studies show the potential of drones and technological evolution is faster than the studies. Many companies such as Amazon, DHL, and Federal Express have begun investigating the viability of incorporating UAV-based delivery into their commercial services (Thibbotuwawa et al., 2020). For passenger drones, the vision could be a gradual deployment scenario beginning first with adoption by specialty vehicles for first responders, then ridesharing companies, and eventually by civilians (Ahmed et al., 2020). Within the next 15 years, SESAR envisions the drone sector employing 100,000 workers with an economic impact exceeding €10 billion per year, which would culminate in a benefit of €140 billion up to 2035 (SESAR, 2016).

However, Colding and Barthel (2017) note that new markets that develop rapidly often overwhelm the capacity of social institutions to respond. In this transition, policies for implementation are urgently needed, as research shows that large infrastructure investments with immature regulation and policy greatly increase the risk of accidents and environmental impact. Currently, test flights and implementation plans are already being conducted for AAM, but regulations for AAM transition to scale-up are still being developed. Many studies show a lack of regulatory framework as a major barrier to implementing AAM (e.g., Vasic and Hansman (2017) Rao et al. (2016) that could “discourage” the use of AAM (NASA, 2018). This could be due to 1) existing regulations hindering activities and outcomes of AAM, or 2) missing regulations for many of the complex operations that AAM will entail. In addition, the authors assert that regulations must also be established for the changes in societal, environmental, and economic systems produced by AAM. A social acceptance study conducted by EASA in 2021 showed that EU citizens already want active and pre-emptive regulations from competent authorities to mitigate risks regarding safety, security, noise, and environmental impact, and ensure affordable, integrated, and complementary services for AAM (EASA, 2021). Filipone and Barakos (2020) indicate that the number of unforeseen circumstances that could arise from flying vehicles would be much larger than with regular civil aviation.

The safe adoption of AAM vehicles will require local and national policies and regulations (Ahmed et al., 2020) to ensure the safety of both users and people and property on the ground. Therefore, establishing well-balanced regulatory involvement on multiple levels (national, regional, and local) is a primary step, and to achieve this research is needed to understand the impact it will have on the system. A document released by the European Commission calls for drone regulatory frameworks to contribute to European Green New Deal and Sustainable and Smart Mobility Strategy (SSMS), and emphasizes the need for a drone implementation system for multi-level authorities within member states (EU, 2022b). To prepare for such situations there is a need for new strategies and policies (Rothfeld et al., 2021) to develop balanced regulatory frameworks, with supportive regulations to promote technologies and innovation in certain ways, and with restrictive regulations to limit undesirable consequences (Kunze & Frommer, 2021). However, there are few scientific studies that comprehensively explore all areas where policies are necessary for AAM deployment, although Alwateer and Loke (2020) address this to a limited degree.

The aim of this paper is to develop a policy framework for regional AAM deployment through a systematic review of publications and interviews with key stakeholders. Three research questions are used to respond to the aim:

RQ 1: What is the existing evidence base regarding policy requirements for Advanced Air Mobility?

RQ 2: What conceptual elements and detailed activities need to be considered in developing policies for Advanced Air Mobility systems?

RQ 3: Based on the above research questions, how can the policy requirements, conceptual elements, and detailed activities be synthesized into a policy framework for regional Advanced Air Mobility deployment?

To the authors’ knowledge, no previous literature review has been made regarding policy development for AAM. The paper may therefore provide an important contribution in addition to the systems view of AAM, which has typically been steered towards market actors (e.g., Cohen et al. (2021)).

The rest of this paper is structured as follows: Section “Method” provides the methods used for conducting systematic literature review, interviews, and development of policy framework. Section “Results” shows results, including a brief overview of the bibliographic analysis on the topic which identifies existing scientific evidence base for AAM policy requirements, in response to RQ 1. Detailed activities necessary for developing policies for AAM system as identified from interviews and literature review are then presented in response to RQ 2. In Section “Policy framework for regional AAM deployment”, the results are discussed as policy actions identified from both interviews and literature review to provide a policy framework for regional RQ 2 deployment. Finally, the significance of this paper and future research implications are presented.

Method

Literature review

A comprehensive literature review was conducted to identify necessary regulations for AAM, systematically outline existing empirical evidence, identify gaps within a research area, and provide a framework for new research (Kitchenham, 2004). A robust method inspired by Denyer and Tranfield (2009) and Durach et al. (2017) was used.

The search strategy consisted of locating relevant studies on two databases: Web of Science (WoS) and Science Direct (SD) through August 2021. Key search terms were “urban air mobility,” “urban aerial mobility” and “advanced air mobility.” Overall, 199 hits from WoS and 158 hits from SD were found, with the earliest papers dating to 2018. The inclusion/exclusion criteria were that at least one of these terms was found in the title or abstract. Applying these criteria, 135 papers from WoS and 36 papers from SD were found relevant. Duplicates, magazine articles, non-English articles, and irrelevant articles to the scope of AAM were manually checked and eliminated bringing the baseline sample to 125 papers. Papers were deemed irrelevant if terms such as drones, eVTOLs, and flying cars are used, but not in the context of UAM or AAM or for transportation of people or goods. A secondary manual search was conducted using the terms “regulations,” “rules,” “policy,” “‘policy makers,’” “government,” “legislation,” and “‘legislative.’” The papers were then shortlisted to 67 papers. This process is outlined in Fig. 1.

A bibliometric analysis was conducted to answer RQ 1 and is presented in Section “Descriptive analysis”. Further, content analysis strategy involved reading the articles, coding the content inductively, and synthesizing information that could answer RQ 2. The content of the studies was broken down, coded, compared and categorized (Corbin &
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Fig. 1. Outlining literature search process.

Fig. 2. Outlining literature search process.

The synthesis of these categories indicated aggregated themes (primary technology, functionality, and adoption), forming a conceptual framework for the AAM system, as shown in Fig. 2. These results are presented in Section “Policy requirements to establish AAM system”. For validation, the analysis was conducted through qualitative synthesis, where the reviewer explores evidence from the study sample and triangulates data findings via interviews.

The structure as presented in Fig. 2 forms the basis for the following Results section.

Conducting interviews

The method used in this paper applies a regulatory lens to a technological system in its early phases. Procurement issues (e.g. batteries), impacts on endangered species, the role of institutions, etc. are thus delimited. The conceptual framework was validated for the accuracy, realistic representation, and generalization of the framework for AAM from a policy and practice perspective. Inspired by (Yin, 1994) the proposed framework was triangulated using semi-structured interviews with 17 respondents who were AAM/UAM research and development experts from private and public organizations and academia, and relevant policy development authorities. The were mainly from Sweden, and further efforts were made to include experts from the United Kingdom, United States and India, see Table 1. Therefore, this study is dominantly from a Swedish perspective. The questions were formulated to explore the topic and verify the results from the review without revealing the framework itself. This enabled the authors to compare the results from interviews to the results from the review. The risk of social desirability bias which was slight as the actual framework was not directly revealed. The results from the interviews were in accordance with the review results. The interviews further contributed to answering RQ 2 and are presented in Section “Policy requirements to establish AAM system”.

Developing the policy framework for regional AAM deployment

The literature review provided theoretical data, while interview results provided empirical data regarding policy gaps. We compared and analyzed the theoretical and empirical data. We found that the empirical results revealed central issues concerning structures, pathways, actors, and knowledge for AAM policy development, as presented in Section “Policy requirements to establish AAM system”. The themes derived from the theoretical results had specific policy concerns in accordance with the empirical results. Evidence of a lack of overall multi-level governance that would dictate policy development and implementation for specific themes of the AAM system in the interest of key stakeholders from the national to local level was also identified. We then analyzed these results in relation to existing regulatory frameworks from EASA, i.e., comission delegated regulation (EU) 2020/1058 (EU, 2020), commission implementing regulations (EU) 2021/664 (EU, 2021a), 2021/665 (EU, 2021b), 2021/666 (EU, 2021c), and 2022/425 (EU, 2022a), as well as EU Drone strategy 2.0 (EU, 2022b). By doing so we were able to discuss our findings in light of the policy regime in Europe. This analysis led to constructing a logical framework of actions required to then be able to address specific regulatory concerns for the various themes of the AAM system (see Fig. 2) on a local/regional level. One part of the analysis uses absorptive capacity (Cohen & Levinthal, 1990) as a means to enhance understanding of prior knowledge of AAM in regional and local actors. An integrative framework was developed, which is presented and discussed in Section “Policy framework for regional AAM deployment” of this paper.
Fig. 2. Structuring the content of the reviewed literature.
and Battipede (2021). Such studies either explored and developed the technologies involved or discussed the concept generically through revelations or conference discussions. Global interest was found for four major conferences: IEEE/AIAA Digital Avionics Systems Conference (DASC), Integrated Communications, Navigation, and Surveillance Conference (ICNS), ACM Transactions on Intelligent Systems and Technology, Aeronautical Journal, Aerospace Science and Technology, Aeroscience, and Atmosphere.

### Year of publication

Literature in the field of AAM starts in 2018, with five articles published that year. Since then, there is a continuous rise of literature in the field with 52 articles published in 2021. Out of the 96 studies analyzed 19 were conference papers and five were review articles. The main journals from which more than five articles were found are Aerospace, Sustainability, Journal of Air Transport Management, Transportation Research Part A: Policy and Practice, Transportation Research Part C: Emerging Technologies, and Applied Sciences-Basel. The other journals are shown in Table 2. The key conferences were IEEE/AIAA Digital Avionics Systems Conference (DASC) and Integrated Communications, Navigation, and Surveillance conference (ICNS).

### Geographical focus

The geographic distribution for identified literature is illustrated in Fig. 3. Of the 96 studies, a majority (50 studies) were from the United States (25 studies) and Germany (9 studies).

### Research areas

The distribution of research themes in the identified literature is illustrated in Fig. 4. Previously developed aggregated themes are hereby applied to categorize the studies. The major fraction of reviewed studies addressed policy aspects related to “Functionality” concerning...
engineering, operations, and computer science (63 studies). Studies that mentioned policy aspects related to "Primary technology" are relatively fewer (32 studies), with aspects related to engineering and technology development. "Adoption" however witnesses the least number of studies (24 studies) with only 12 studies specifically addressing topics related to adoption. A lack of studies in fields such as energy systems, regional planning, public administration, environmental studies, and sociology was revealed. No study was identified that specifically addressed policy requirements, thus underlining the need for this paper.

**Policy requirements to establish AAM system**

The lack of regulations for AAM is a general topic of discussion in these studies (Desai et al., 2021; Maxa et al., 2019; Otte et al., 2018) while scaling up some applicable existing regulations could enable some of the AAM operations to function (Ahmed et al., 2020). However, the lack of regulations in most areas demands specific regulations for each area of the AAM system concerning the risks involved and expected traffic (Filippone & Barakos, 2020; Shao et al., 2021) as well as fostering its immense potential (Merkert et al., 2020). While FAA and EASA (for the United States and European Union respectively) (Otte et al., 2018) and transport agencies on a national level are responsible authorities, a lack of clarity of which local governing bodies should be involved is highlighted in interviews. Interviewees expressed a lack of understanding of roles and responsibilities within various organizations that will be relevant in the AAM governance context. The use cases for AAM (Smith et al., 2022). The experts also saw that the different use cases have different policy development, and thus local policymakers need to analyze the suitability of use cases for AAM. The specific policy requirements for the three conceptual elements of AAM are as follows.

**Primary technology**

Although AAM discourse mainly revolves around drones, flying cars and helicopters are also mentioned (Ahmed et al., 2021a,b; Cohen et al., 2021), policy requirements for which are discussed under vehicles. **Vehicles.** Vehicles cannot be integrated into urban airspace unless accompanying risks and hazards can be predicted, controlled, and regulated (Bauranov & Rakas, 2019). Any vehicles require attention to critical design aspects such as mass, energy, and other design elements and technologies, e.g., battery, propulsion systems and noise reduction technology (Kapoor et al., 2021; Rendon et al., 2021). Requirements relate to airworthiness, aerodynamics, safety, security, and structural integrity (Rendon et al., 2021). Regulatory requirements will involve vehicle-level and system-level safety and security considering features such as reliable data exchange and elimination of failure points (Maxa et al., 2019). Vehicle safety challenges include the need to supervise the activities of recreational vehicles and how they interact with commercial vehicles or manned aviation (Alwateer & Loke, 2020). Increasing the in-vehicle safety and trust aspect for people might also require enforcing regulatory requirements such as having surveillance cameras (Al Haddad et al., 2020). Even with a malfunction in the propulsion system (mid-air), the vehicle design should ensure that it can make a safe landing, with the help of redundancy systems such as parachutes, thus increasing overall technical requirements (Straubinger et al., 2020).

Accordingly, there should be certifications for vehicles in place that varied greatly from one opinion to another. While some experts believed that in the short run AAM will only serve emergency purposes, others believed that first and last-mile deliveries and air taxis will become a reality. The governance of AAM demands the involvement of transportation and city planners (Ahmed et al., 2021a,b; Sziroczák & Rohacs, 2021), but interviews show a lack of awareness and knowledge of AAM within local governance bodies. Interviews also showed that existing regulations are stringent and hindering for drones, although with technology maturity policies could be relaxed. Thus, focus was on policy attention needed to allow technology and infrastructure development. Public-private cooperation was required to explore uncertainties, risks, and contingencies regarding technology and infrastructure, and to develop business models for economic growth and societal benefit. Public acceptance and involvement were key for decision-making.
account for all expected design, safety, and operational goals. All vehicles should be expected to undergo inspection and demonstrate safety levels equivalent to or higher than existing aircraft and helicopters to claim certification for commercial operation (Vieira et al., 2019). Having a single criterion for certification for AAM vehicles would be hard due to the evolution in aircraft design and the multiple designs that arise (Vieira et al., 2019), but is more likely as design features become standardized⁶. The most radical feature of these vehicles is autonomy which would require redundancy systems and on-the-fly decision-making capabilities (Ahmed et al., 2020; Cohen et al., 2021; Schweiger et al., 2021). Initially, this also necessitates regulating the transition and hand-off period between manual and autonomous vehicle control until they are fully reliable (Ahmed et al., 2020). These new control systems and degree of autonomy would be a new consideration for certification authorities, and a gradual transition to being fully autonomous is expected. Until then human pilots are necessary (Garrow et al., 2021; Straubinger et al., 2020), while restricting full vehicle autonomy also requires a change in regulations (Brown & Harris, 2020).

**Functionality**

Infrastructure and operations are discussed under functionality, both of which create the functional environment for the AAM system.

**Infrastructure.** Policy requirements for physical and digital infrastructure required for AAM vehicles to function and provide services, i.e., airspace, vertiports, datalinks, etc. are discussed below.

**Airspace**

A primary consideration for airspace is whether regulations will enable segregated airspace or mandate integrated airspace, where the sky is equally shared (Ahmed et al., 2021a,b). AAM vehicles will fly at much lower altitudes than conventional aircraft. (Doole et al., 2021) suggest that the exact boundaries of the lower airspace remain undefined by policymakers, which also requires considerations of energy usage (which increases with altitude) (Luo et al., 2021) and safety concerns with closer proximity to the built infrastructure (Filippone & Barakos, 2020). Within this airspace, authorities must explore issues with airborne navigation safety, such as mandating landing and take-off patterns and restricting AAM vehicle operators to specified air corridors (Ahmed et al., 2020). Regulations establish no-fly zones above certain types of public buildings due to safety considerations, which could limit the available airspace (Ellsfeldt, 2020). According to (Ahmed et al., 2021a,b) some people are willing to pay higher costs if that means establishing regulations in airspace that could enforce no-fly zones near sensitive locations and establish air-road police. Merkert et al. (2021) suggests that people prefer regulations that would allow them to fly their drones beyond visual line of sight at maximum altitudes, above congested public areas, and on private property, preferably with no tracking of the drones. Another regulatory consideration could be to establish prioritized flight paths for first responders (Alwateer & Loke, 2020). Overall, the development of AAM requires system-of-systems integration of airspace with an urban support network, and regulatory intervention is needed in deciding where drones can be operated (Filippone & Barakos, 2020).

**Vertiports**

The major land infrastructure needed would be landing and take-off sites or vertiports. Regulatory interventions are required in two major areas. First, standards and certifications are needed for the technical features (Postorino & Sarné, 2020). Design specifications would require advanced simulation and optimization techniques to attain maximum operational effectiveness and guarantee safety (Ahmed et al., 2020). Second, standards and specifications are needed for the location of vertiports, as studies suggest multiple solutions such as installations atop large public buildings, as part of mobility hubs, or large designated areas, close to or even within cities, and at existing airports, etc. (Ahmed et al., 2020; Rimjha et al., 2021; Straubinger et al., 2020). Although constraints for vertiports might differ from airports, the overall issues are similar (e.g., land acquisition, noise considerations) (Rimjha et al., 2021). With other novel vehicles like flying cars, the question is if they will adapt to existing road driving regulations or if new management (Ahmed et al., 2020; Rimjha et al., 2021; Straubinger et al., 2020), and organizational features will be required (Postorino & Sarné, 2020).

**Data links**

Operating drones beyond visual line of sight requires new rules and adequate data connectivity to mandate the flight paths, provide traffic management, share information such as weather conditions (e.g., wind speeds, temperature), information and updates on obstacles and terrain, fuel requirements, alternative landing sites, take-off and landing specifications, vehicle information, command and control link, passenger information, operator information, navigation, population over which the flight is flying, flying control systems, etc. (Ahmed et al., 2020; Alwateer & Loke, 2020; Otte et al., 2018; Postorino & Sarné, 2020; Straubinger et al., 2020; Tuchen, 2018). The two major concerns to be addressed are (1) system malfunction, and (2) safety issues related to terrorists and cyber criminals (Ahmed et al., 2020). For the first point, planning, managing, and real-time routing of the trips of drones require a minimum set of data elements for which Tuchen (2018) states that “there is a need to establish a regulatory framework, development of operating rules and performance requirements, and data exchange and architecture” (Tuchen, 2018). Cyber security policies and air traffic management protocols for reliable data exchange standards, liability, security, and data privacy should be established based on policies for autonomous vehicles and involving cyber specialists (Ahmed et al., 2020; Al Haddad et al., 2020). Data sharing and protection, as well as possible privacy infringements when AAM vehicles are deployed close to private spaces (say for home deliveries), are also considerations (Al Haddad et al., 2020; Kellermann & Fischer, 2020). Taking the communication of sensitive data offline while leaving time-critical data online might be an option (Stewart et al., 2019).

**Other**

Studies rarely discuss policy requirements regarding infrastructure related to energy systems and regional planning. Energy infrastructure needs to be included as a part of designing vertiports (Niklás et al., 2020) and requires certification and authorization of network charging or refuelling infrastructure, energy storage technologies along with standardizing battery swapping (Cohen et al., 2021). Policies to support zoning, defining land use, regional airspace management, planning the positioning of AAM infrastructure, goals of regional transportation, and integration with an efficient shift in transportation are vital (Ahmed et al., 2021a,b; Kim & Yoon, 2021; Pant et al., 2021).

**Traffic management**

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⁶ Dominant design is when an innovation becomes mature and more standardized (Utterback, J. M. (1994). *Mastering the dynamics of innovation: how companies can seize opportunities in the face of technological change*. Harvard Business School Press.
There is a need to develop rules and guidelines for safe, scalable, and efficient operations and infrastructure (Ahmed et al., 2020; Fu et al., 2019; Pongsakornsathien et al., 2020; Tuchen, 2018) which includes performance required consistent with operational demand, and data communication architecture that provides situational awareness for all airspace users with different capabilities to support the integration of AAM into existing ATM (Straubinger et al., 2020; Tuchen, 2018) if the airspace will be unsegregated. So far AAM vehicles have been segregated from manned aircraft systems and operated procedurally through approval-seeking processes with relevant authorities (Pongsakornsathien et al., 2020). NASA and EASA have concepts called “Unmanned aircraft/aerial systems traffic management” (UTM) system and “U-space” respectively, which provide frameworks to integrate AAM operations with manned aviation into existing ATM systems and air navigation service (ANS) providers and authorities (Pongsakornsathien et al., 2020; Straubinger et al., 2020). Current regulations only allow the operation of AAM vehicles within visual line of sight after risk assessment, and there are no regulations in place for large-scale operations within visual line of sight and autonomous beyond visual line of sight operations (Pongsakornsathien et al., 2020), both of which concern AAM.

Requirements and certification processes for different operating organizations need to be defined (Straubinger et al., 2020). The safe spacing between AAM vehicles needs to be identified and mandated (Glaab et al., 2019). There are no regulations for “alert limits” and “time to alert” to navigate AAM vehicles, but guidelines for this can be extracted from ICAO (Isik et al., 2020). Electric AAM vehicles also need a battery exchange system to minimize waiting times (Fleischer et al., 2019). Policymakers will also need to prepare guidelines and standards related to technologies (e.g., appropriate robust human-machine interfaces and display systems) to avoid issues with integration from take-off and landing areas and within airspace during operations (Ahmed et al., 2020). Regulations should be set up to ensure operational safety during adverse weather conditions through simulations and live demonstrations to establish the thresholds for factors such as visibility, wind speed, precipitation, etc., of a safe operational environment (Ahmed et al., 2020). Policies for operational efficiency also include ensuring that the system is error-free and guarantees minimum delay (Rimjha et al., 2021). Operations and related personnel also require the setting up of maintenance regulations (Straubinger et al., 2020).

**AAM vehicle operator and pilot**

Both operators and pilots must be trained, licensed, and/or certified, with pre-defined requirements for performance (Straubinger et al., 2020). To date there are no regulations that indicate the required type of license or a procedure to attain it (Vieira et al., 2019). Pilot training by itself plays a significant role in ensuring system safety (Rajendran & Srinivas, 2020). Although AAM vehicles are mostly considered autonomous, getting to the stage of trusting fully autonomous systems will take time and further technological advancements. Until the systems move toward a higher level of autonomy, there will still be some manned operations (Bauranov & Rakas, 2019). Stringent regulations for autonomous systems are suggested to ensure that there is an operator on the ground who can take control in case of a malfunction or emergency (Al Haddad et al., 2020). Barring full-vehicle autonomy could lead to a massive shortage of pilots which will impact AAM adoption (Brown & Haddad, 2020). Having pilots brings considerations such as shift duration, briefing and debriefing times, effective scheduling, etc. (Rajendran & Srinivas, 2020). The relevant national authority will mandate effective risk controls for operators (Ahmed et al., 2020), and near-term operations can be expected to leverage existing ATC procedures (Bauranov & Rakas, 2019; Tuchen, 2018). Present procedures such as pilots keeping open communication with the passengers onboard regarding the vehicle’s status (Rajendran & Pagel, 2020) will apply.

**Adoption**

Adopting AAM into transportation will disrupt the environment, market, and society, categories for which policy requirements are discussed under the respective topics.

**Environment.** The five main environmental concerns that studies indicate should be regulated are noise, visual impact, energy, emissions, and land impacts, which are discussed below.

**Noise**

Ahmed et al. (2020) speculates AAM adds to an already noisy environment in densely populated cities, which could lead to complaints and stringent regulations for noise limits, as was the case for helicopter tours. Even assuming that AAM vehicles will be quiet, these vehicles require upward propulsion which is impossible to achieve without disturbing the air and generating some level of noise (Afonso et al., 2021). The noise from vehicles however depends on the design of the vehicle and its vertical proximity to the ground infrastructure (Filippone & Barakos, 2020). Vehicles with wing designs are much quieter than those with propellers, and smaller drones are said to make more noise (Filippone & Barakos, 2020).

Existing noise limits provided by European Commission are in contradiction with recent WHO guidelines for social acceptance limits (Eiβfeldt, 2020). There is also a lack of understanding of the effects of this mode of mobility for various species (Kellermann & Fischer, 2020). People already fear that with AAM there could be an increased level of stress or fewer places to retreat (Kellermann & Fischer, 2020). It is not yet known how the indoor noise of the vehicles will affect passengers (Filippone & Barakos, 2020). Therefore, it is necessary to mandate permissible noise limits and flying altitudes of vehicles to address acceptance by both users and non-users (Al Haddad et al., 2020; Glaab et al., 2019).

**Energy use and emissions**

Even with electric vehicles emissions arise from the energy used during operation (Afonso et al., 2021). AAM vehicles are predicted to use substantial energy resources and possibly increase overall transportation in terms of distance and frequency due to increased convenience, further increasing energy demand (Ahmed et al., 2020). The vehicles rely highly on the energy grid, therefore the cleanliness of the vehicle in use will depend upon whether the electricity sources contributing to the energy mix in the grid are renewable or not (Afonso et al., 2021; Ahmed et al., 2020; Filippone & Barakos, 2020). The type of energy source will also significantly vary the energy usage rate of the vehicle which impacts performance efficiency, design, noise, emissions, and user acceptance (Lewis et al., 2021). The common issue with batteries is that manufacturing, servicing, and end-of-life consume large amounts of energy and critical materials that may not make them sustainable, and may be as polluting as fossil fuels (Filippone & Barakos, 2020) from a life-cycle perspective.

Another possible situation is that an AAM vehicle may transport goods/passengers in one direction and return with no goods/passengers. This can significantly impact emissions and may require regulations to ensure efficiency and lower impact (Rimjha et al., 2021). The impacts in different operational scenarios such as personal ownership, shared service, or a combination of both vary (Ahmed et al., 2020). Therefore, environmental regulations for emissions from AAM will require proper...
accounting of environmental impacts (Filippone & Barakos, 2020) for the range of potential energy sources (Lewis et al., 2021), use cases and impact on the entire transportation system (Ahmed et al., 2020), and logistics design (Rimjha et al., 2021). It can be expected that AAM will have to comply with emissions and fuel economy standards (Ahmed et al., 2020).

Visual impact

Some studies show that people want regulations to allow them to fly beyond visual line of sight, over densely populated areas (Merkert et al., 2021). However, studies also show people’s concerns related to the aesthetics of the sky which will change with the introduction of AAM. Interviewees in Kellermann and Fischer (2020) express this concern through statements like “It’s not enough that our cities are full of trash, soon everything above will also be full of trash and then we really live on a trash planet” (Kellermann & Fischer, 2020). The impact on visibility in the sky is expected to be greater than existing traffic (Straubinger, 2019).

Land impacts

The need for dedicated land infrastructure such as charging stations, controlling stations, and warehouses can lead to massive consumption (Kellermann & Fischer, 2020; Straubinger, 2019) if unregulated. One other major externality that should be regulated is urban sprawl (Straubinger, 2019). This is due to the possibility of AAM allowing people to relocate away from cities and reduce travel time but in turn cause increased travel miles and massive inefficiencies in pre-existing urban infrastructure (Rendón et al., 2021).

Market

Multiple studies suggest air corridors have pricing strategies like road infrastructure. Congestion pricing (such as peak-load pricing (Straubinger, 2019)) is recommended (Rimjha et al., 2021). Pricing regulations must be like highway toll charges, where large commercial users such as trucks pay a higher fee (Merkert et al., 2021). Variable pricing is suggested to ensure fairness (Merkert et al., 2021). Pricing strategies must also explore options such as maintaining a balanced demand across network locations or having origin-based pricing to compensate for unbalanced demand across network locations (Rajendran & Shulman, 2020). Customers must be served with policies such as free or discounted rescheduling, partial or complete refunds, or alternative transport options to enhance trust in the service (Rajendran & Pagel, 2020).

Regulations in the airspace will also contribute to costs. People were willing to pay more if that means establishing regulations in airspace that could enforce no-fly zones near sensitive locations and establishing air-road police (Ahmed et al., 2021a,b), and also allowing flying their drones beyond visual line of sight at maximum altitudes, above congested public areas, and private property, with preferably no tracking of the drones (Merkert et al., 2021). The overall costs for AAM vehicles are still unknown but include a range of costs relating to direct operation, manufacturing, acquisition, pilot training requirements, certification, and depreciation of AAM vehicles (Filippone & Barakos, 2020). Safety costs are mandatory since the system and architecture will be profitable only if the incident rate is minimized (Lewis et al., 2021). Due to limited airspace, ownership of drones might be another area where regulations in the form of taxes or paid certificates for operation might be introduced to discourage personal drones and promote community-based and commercial-based drones (Alwateer & Loke, 2020). Pricing schemes to ensure that the services are reasonably priced, compete with existing ground vehicles and transport patterns, and are widely accessible must be defined and mandated (Ahmed et al., 2020; Al Haddad et al., 2020).

Alwateer and Loke (2020) states that “no one party should be allowed to own the sky” (Alwateer & Loke, 2020). Natural monopolies however predominant in market structures (Straubinger et al., 2020). Regulations will therefore play a role in assisting communities to resist privatization of the airspace (Sauranov & Rakas, 2021) and land infrastructure can be managed by public authorities or by establishing strong regulations for private infrastructure providers to ensure equal access to all (Straubinger et al., 2020). Additionally, ownership of the data that will be generated in the system is unclear (Filippone & Barakos, 2020) and could lead to information asymmetry where regulation will need to intervene (Straubinger et al., 2020). There is also concern about liability if incidents occur with autonomous systems (Fleischer et al., 2019) exhibiting the need to have insurance for AAM vehicles to cover, as Alwateer and Loke (2020) state, “physical loss, third party damage, product liability, and failure to provide service” (Alwateer & Loke, 2020). A policy scenario to support AAM adoption could also be infrastructure subsidies (Straubinger, 2019).

Society- prospected quality of life critique on AAM

Non-users concerns that revolve around safety, privacy, and legitimacy may lead to conflicts with concerns of those offering drone services (Merkert et al., 2021). It is prospected that the early adopters include those from the high-income market segment (Lewis et al., 2021; Rimjha et al., 2021), and user demographic may primarily include young people and males (Fu et al., 2019). AAM could hence potentially be perceived to result in an elite transport mode that would allow the rich to build and use infrastructure with exclusive property rights and subtle privatization of the lower airspace (Kellermann & Fischer, 2020). AAM may enable e-commerce giants to establish labor-reduced automated services that can provide cost savings that may impact on urban retail market places as well as loss of local retail companies (Kellermann & Fischer, 2020). One may speculate whether AAM could lead to a “systematic and machine-like organization of life” (Kellermann and Fischer (2020), where important and much-needed social interaction with drivers, deliverers, and personal relationships with retailers are eroded (Kellermann & Fischer, 2020). Job losses are a concern for the public (Al Haddad et al., 2020), whose perception is that even if new jobs are created, those who lost the jobs will not get them since the new jobs will require higher qualifications (Kellermann & Fischer, 2020). In combination with previously mentioned impacts such as noise and visual pollution, the role of AAM for issues related to quality of life of non-users therefore is in need of further societal pondering (Postorino & Sarné, 2020).

Policy framework for regional AAM deployment

The findings of this paper show that the regulations and standards for technical aspects such as vehicles, infrastructure, and operational requirements can be more generalizable. However, to address the specific policy requirements that are highly contextual, an overall framework is needed at the national, regional and local levels. EASA’s Implementing Regulation (EU) 2021/664 framework also recognizes the importance of coordination with relevant local bodies (EU, 2021a). This primary need for an overall governance model established for relevant multi-level authorities responsible for AAM is also advocated by Filippone and Barakos (2020). An initial effort from an international level in Europe in the form of a framework for U-space coordinators to clarify the responsibilities of dedicated bodies in establishing a top-down governance framework is found in EASA’s Implementing Regulation (EU) 2021/664. From the results, we see that policy concerns which dictate the materialization of AAM deployment vary on applications, governance, topography, local public–private partnerships, local communities, and ambitions for sustainability and transportation. This calls for enabling the inclusion of local decision-making while addressing governance models, thus enabling a participatory bottom-up co-creation which is essential to adapt AAM implementation to local needs. Our analysis in this paper is in the form of such a conceptual framework, as shown in Fig. 5.

As shown in Fig. 5, we see that establishing a governance model would require actively recognizing AAM as a mode of transport. To further plan for and enable AAM, its implementation within the transportation and regional planning procedures is necessary and appropriate.
policy pathways must be established on all levels. City and transportation planners from municipalities would be the responsible agents to understand the infrastructure requirements and how AAM would be integrated within current procedures and plans. Some prevalent policies that enable AAM activities can be identified and scaled up to make them AAM-centric while developing policy pathways. The governance model would also involve the participation of all appropriate stakeholders, i.e., players from the conventional aviation industry, drone manufacturers, new service providers, city planners, transportation agencies, environmental agencies, communities, potential customers, and interest organizations, from a national to local level. The roles and responsibilities of appropriate organizations must be identified and clarified. Further goals need to be set for AAM by assessing its suitability. The applications of AAM need to be explored appropriately and the roles that it will play should be defined through detailed assessments of its contributions to existing mobility issues and climate goals from a systems perspective.

Finally, for relevant bodies to actively take part in steering AAM deployment knowledge will be of key importance. The highlighted lack of knowledge regarding AAM adoption in literature and interviews calls for more research, public awareness, and fostering competence in judiciously evaluating the area and working with actors. Lack of capacity on local and regional levels would create risks and inefficiencies for steering AAM deployment in the built environment. Therefore, creating collaborative groups of different relevant backgrounds and assimilating AAM knowledge will allow local and regional bodies to make associations with existing procedures and plans.

Once such a governance model is established, it would allow relevant bodies to work with specific policies and policy pathways related to the themes revealed, (primary technology, functionality, and adoption), as shown in Fig. 5.

In this paper, specific policy requirements for the AAM system are shown and thematically categorized under 1) Primary technology, 2) Functionality, and 3) Adoption (see Fig. 5). Primary technology covers different types of vehicles that fall under the concept of AAM such as drones, UAVs, VTOls, eVTOLs, flying cars, and helicopters. Functionality consists of components in the AAM ecosystem that are necessary to bring AAM into effect. These components are further categorized into two sub-systems: operations, which relates to operational requirements for AAM, i.e., traffic management, and AAM vehicle operator and pilot; and infrastructure, which relates requirements such as airspace, vertiports, and data links. Adoption consists of components that AAM will impact while being adopted into societies. From a sustainability standpoint, they are categorized into three subsystems: environment, with people and ecology as the main components; market, with public and private sectors as the main components; and society, with users and non-users (during the time of flight) as the main components.

Major regulatory concerns with primary technology are addressed in current EASA regulations which provide ways for drone manufacturers to get certifications based on the category of planned drone operations, and risk assessments to establish if the drone is equipped with a remote pilot. Although fully autonomous operations are not yet allowed, preparations for this through digital solutions are enabled, since autonomous AAM is planned to be gradually deployed and upscaled for commercialization. Some EASA frameworks for the concept of AAM seem to specifically address eVTOLs and some VTOls. This raises the question of how the other type of vehicles will be addressed within the regulations. One conclusion based on the scientific review about vehicles is that available scientific papers assume or imply that the vehicles in question are mostly electric but do not provide a clear picture of what the primary fuel source for AAM vehicles should be. Since such specifications will vary based on energy mixes available locally, regional and local bodies, private operators and end users, in consultation with energy and environmental agencies will have to be actively involved to predefine primary fuels for AAM.

For functionality, the EU regulatory framework provides guidelines for digital architecture and data-sharing protocols and a preliminary structure on the role of technical and U-space actors that will fulfill operational requirements. However, airspace boundaries and responsible planning bodies will call for local authorities to work with mapping where flight paths for drones will be permissible, as also recognized in EU Drone strategy 2.0. FAA currently provides design standards for vertiports, and we expect similar standards to be followed in Europe as well. However, where these vertiports will be located will have to be determined by local authorities.

Security and privacy are governing principles for EASA regulations. However, based on the literature review we anticipate some trade-offs in privacy simply based on the type of application. To implement this on the local level, regional and local bodies will have to regulate the actions that drones will perform while providing a service. For example, instead of doorstep deliveries, rooftop deliveries can be a simple solution to minimize risks of intrusion. Furthermore, current studies do not explore necessary refueling or energy storage infrastructure, energy grid requirements, or energy management at vertiports. There is also a lack of insight into the impact AAM will have on regional planning processes.

The operational regulatory concerns addressed in the literature are well addressed within the concept of U-space regulations, where the roles of conventional aviation actors and national transportation agencies are established in line with new services to integrate AAM within the processes of AAM.

Effective policy measures regarding adoption will include addressing sustainability concerns. The current regulatory framework in Europe provides procedures to measure the acoustics of drone use. There is no clear demarcation of the acceptable level of noise yet. Drone strategy 2.0 also indicates that EASA envisions further regulatory support to local bodies in addressing noise, energy, emissions, and visual impact. However, addressing these issues will have clear trade-offs with other potential benefits of AAM. For example, AAM may increase urban sprawl. Delivery AAM vehicles in sparsely populated areas may have to return with no cargo, thus causing inefficient logistics and increasing energy use per capita. To reduce that impact, warehouses might have to be located much closer to one another, thus increasing land use. From a system perspective, a trade-off between providing equal service and accessibility to non-urban communities and enabling more dispersed settlements causing discursive environmental impacts must be evaluated. In addition, how this would affect species that are important to
socio-ecological systems that depend on the lower airspace is unknown. Studies indicate monopolies and high pricing are two main market threats. As recognized by EASA in Drone strategy 2.0, pricing and profitable business models for actors must address the implications this will have for people in terms of affordability and services. We presume industrial forces will carry on economies of scale with competition between new entrants which would lead to drones being available to a wider market. It is important that a balance is struck for the ownership of infrastructure between local private and public actors especially regarding airspace and vertiports. This will help address monopolization and provide incentive for innovation and low pricing. The infrastructure requirements for vertiports such as energy grid, charging stations, communication links, etc., will have impacts in the form of services needed at that location. This raises questions as to location and impact on residential communities. Land rents, energy prices, and other living rates could be impacted in locations with developed vertiport infrastructure and consequentially other developments that will unfold in the area. Further, property rights regimes that have so far been discussed by municipalities for land in two dimensions now call for extension in three dimensions including the lower airspace.

Policy implications

Based on the results and the specific policy requirements highlighted above, the main policy implications are 1) public–private arenas for co-creating solutions; 2) establishing test beds and demonstrations; 3) establishing an AAM governance structure; 4) local and regional capacity-building for lower airspace planning; and 5) setting up a carbon budget for AAM. Such policies will be needed to steer the use of novel AAM to contribute to improved sustainability and resilience-building in urban, suburban, and rural transportation systems.

1) Public-private arenas for co-creating solutions

We suggest public–private arenas for co-creating solutions since technology and new services in the system are market-driven which requires the technical competence of the private innovation niche actors, while public bodies are needed to regulate the systemic effects of implementation. Local public bodies are required to proactively address the exploitation of the lower airspace, its ownership and ecosystem services, and the regional planning process for infrastructures. Even from an economic standpoint, public stakeholders must steer the implementation of technology to address the labor market that will be affected by AAM and its deployment. Such public–private collaboration can enable co-learning and address human and ecological questions from the earliest phases. Thus, the role of AAM in the vision of a rapid sustainable transition in transportation can be established by navigating the evolution of technology for the common good.

2) Establish test beds and demonstrations.

Regulatory support is needed in establishing test beds and demonstrations, as envisioned in EU Drone strategy 2.0. This is necessary to experiment with the technology, understand the practical consequences of operating in real environments, and develop the technology and its complementary infrastructure to the highest needed TRLs. This would allow a deeper understanding of AAM’s potential, and guide its evolution and consequences on mobility goals. It would further allow key actors to practically understand their roles and reflect on existing processes and procedures. Such reflections will give local communities a role in decision-making. Not doing so may have unforeseen consequences.

3) Establish an AAM governance structure.

The governance structure for AAM today is disorganized. AAM brings together conventional aviation actors who will be the U-space service providers, UTM system providers, and information providers, with public actors responsible for various elements in the AAM system. Therefore, there is a need to map all the legal authorities in a regional regulatory framework, and to clarify their roles concerning AAM mobility services. New organized institutional regimes are expected to operate on different scales of AAM.

4) Local and regional capacity building for the planning of the lower airspace

Policy interventions for AAM on a regional and local level require a pre-existing understanding of regulations and procedures. Using absorptive capacity, it is apparent that the local and regional bodies are already fully equipped when it comes to current regulations, city planning, etc. However, for local city planners to start using a third dimension, the lower airspace, requires a fundamental shift in knowledge demands. While national and international bodies may be able to recruit persons with a novel knowledge of e.g., AAM, smaller cities and regions may have difficulty recruiting this type of expertise.

5) Setting up a carbon budget for AAM

Even though the findings from the review did not directly emphasize the need for carbon budgeting, AAM may entail mitigation potentials for indirect negative impacts from e.g. road construction that with AAM can partly be avoided or greatly reduced. Findings strongly suggest setting up a carbon budget for the whole life cycle of the AAM system before widespread implementation and commercialization. One major concern with Drone strategy 2.0 is that it is focused on unleashing the growth of drones and finding economic potential for businesses (EU, 2022h). Industry is a key driving force in establishing a market for drones and transitioning toward sustainable transportation. However, the risk with this is that it gives more opportunity for increasing global production and transportation which in turn might push fossil fuel emissions beyond the global carbon budget within the Paris Agreement. Therefore, it is essential to set up carbon budgets that allow steering to a fossil-free AAM system in the near future.

Conclusion

This paper addresses the evident research gap for AAM policy development on a regional level. The aim has been to develop a policy framework for regional AAM deployment. This is achieved by conducting a systematic review of identified literature on the subject of policy requirements for AAM which is then triangulated with interviews from experts and relevant authorities. Results show that AAM research is still in its early stages. Three key themes of the AAM system emerge: primary technology, functionality, and adoption (environment, market, society). Furthermore, the findings have been discussed in light of the current policy regime in Europe.

For national and regional policymakers, this paper provides valuable insights into the policy requirements for each theme and its subsequent categories that help identify specific considerations and policy actions for AAM. The paper provides a policy development framework for AAM that is applicable in establishing multi-level AAM governance structures, developing appropriate policies, and involving relevant local actors. Overall, the framework also encourages proactive implementation, governing, and policy support for the utilization of novel technologies of AAM that contribute to the energy transition to enable sustainability and resilience-building in societies. Participatory innovation models and new models for innovation systems are called for to establish the role of AAM in the sustainable transition of transportation. The main policy implications are: 1) co-create solutions to address complex environmental and societal issues through private–public collaborations; 2) invest in test beds to increase understanding about the more practical
consequences of operating AAM in real environments; 3) establish a new governance structure to clarify roles and responsibilities for AAM systems; 4) capacity building for regional and local bodies for adapting AAM to preexisting context of needs, plans, and procedures; and 5) setting up carbon budgets per Paris Agreement to stay within the emission limits for new transport systems.

For researchers, this paper shows the scarcity of scientific studies and uncertainty regarding AAM adoption, while the major research focus is on engineering, computer science, and technology development that can contribute to the functionality and primary technology. The authors argue that early research within the theme of adoption presented herein is necessary, particularly in science and technology studies, policy studies, socio-technical transitions and critical studies targeting issues related to quality of life of those that will not use AAM. This is to address the need for empirical studies that will support public and private organizations to proactively address many of the uncertainties and decisions for sustainable energy transition in the transport system. For future research, it is recommended to include a broader international range of experts to evaluate, validate, and complement the AAM policy development framework of this paper. Further evaluation of options and decision-making for each theme recognized in the conceptual framework is also needed. An add-on with time and improved policy establishments is to understand the policy development matrix and policy readiness levels for drone deployment. Accordingly, more empirical and qualitative case studies, scenario analyses, and multi-criteria decision analyses for AAM deployment are needed for policymakers. A critical call is to address the limited CO2 budgets according to the Paris Agreement, and evaluate how large a share of national carbon budgets projected investments in AAM systems may be claimed in the near future. Accordingly, there is a need for empirical studies discussing both environmental complexities and the practical landscape of the topic and opening the arena for more political studies in the decision-making of AAM implementation in societies.

Funding
This work has been carried out under the auspices of the industrial post-graduate school Future Proof Cities (grant number 2019–0129), which is financed by the Knowledge Foundation (KK-Stiftelsen). We kindly thank the funding bodies for their financial support.

Data Availability
The dataset consisting of articles included in this paper can be found in an open-source online repository hosted at Mendeley Data, link: https://dx.doi.org/10.17632/5gy6s8trbm.2

Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability(1)
I have shared the link to my data in the ‘Attach File’ step(2) Addressing the emergence of drones – a policy development framework for drone transportation systems (Reference data) (Mendeley Data)

Acknowledgments
We would like to thank the experts and public officials who provided their time and knowledge for validation of the results of this paper. We would also like to express our sincere thanks to the three anonymous reviewers whose useful comments have improved the quality of this paper considerably. The usual disclaimer applies.

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