BRYCE TECH

Advanced Air Mobility

An Assessment of a Coming Revolution in Air Transportation and Logistics

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Executive Summary

Interest in advanced air mobility (AAM) is intensifying, and introduction of vehicles into service is on the horizon. With this in mind, BryceTech was commissioned by DfT to conduct an extensive review of existing evidence on the impact, costs, and benefits of AAM globally and in the UK. This study summarises the findings of publicly available evidence on AAM, supplemented by interviews across industry, academia and regulators in the UK and internally, and market data.

To conduct the study, BryceTech collected publicly available evidence on AAM market characteristics, levels of development, and market outlooks, barriers and drivers. BryceTech also reviewed global government spending and interventions in the AAM market. Building on research into barriers, and using extensive industry interviews, BryceTech considered potential interventions UK government could make to further support the domestic AAM market.

Market Overview

Definitions of AAM vary, with a variety of use cases, few of which have fully entered commercial operations. For the purposes of this study, AAM was categorised under four broad categories:

- Regional Air Mobility (RAM): carrying up to 10 passengers on journeys between 100 and 1,000 km
- Urban Air Mobility (UAM): carrying between 1 and 6 passengers on journeys less than 100 km
- Regional Cargo: Carrying payloads of up to 2,000 kg over distances between 100 and 1,000 km
- Last-Mile Logistics: Carrying payloads of up to 20 kg over distances less than 100 km

The following use cases were identified for passenger and cargo transport:

Passenger	Cargo
On demand taxi services	Time-sensitive medical goods transport
Scheduled passenger shuttles	Disaster relief goods transport
Sight-seeing & tourism	Direct-to-consumer delivery
Emergency medical response	Internal business logistics
Patient transport	Heavy cargo transport
Disaster management	
National security & surveillance	

As the market matures, it will become evident which use cases can be commercially successful. Until then, governments should balance advancements in AAM and the potential improvements in passenger experience, connectivity, jobs and growth against wider safety, labour market and environmental considerations.

Key enabling technologies for initial flight operations of passenger vehicles are relatively mature, with active flight testing underway. However, whether the technologies integrated into current vehicles will meet certification standards is not yet certain. Once piloted passenger operations begin, and as manufacturers and operators integrate into existing airspace systems, further learning and development will take place. Technologies for scaled operations, and operational cost reductions are still in development, with no clear agreement on when these will be mature to a standard acceptable to regulators. These technologies include autonomous flight operations, advanced airspace management, unmanned aircraft traffic management (UTM), and fleet management integration technologies. Key enabling technologies for cargo vehicles, which are generally smaller and less complex than passenger vehicles, are more mature, with commercial operations underway. However, as with passenger vehicles, autonomous or remote operations, particularly in dense urban areas, will require further development, in tandem with close coordination with regulators. As AAM operations scale, the challenge will be not only developing the required technologies, but also networking of individual systems into an integrated aerial transport system.

Considering time to market, commercial cargo services are already in limited operation internationally, primarily for medical and emergency goods transportation, and other logistics applications. Several vehicles are in development for the purposes of logistics and direct-to-consumer goods delivery in varying levels of development. There is general agreement in the non-academic literature that initial operations of AAM passenger vehicles globally are expected to occur from 2025. This said, there is a certain degree of uncertainty to this figure. Expectations regarding entry into service have historically shifted by years, with some vehicle manufacturers originally expecting entry into service as early as 2021. Additionally, timelines for individual vehicles vary, as do expected certification timelines across different regulatory regions. Further, scaled and profitable manufacturing and operations, including commercial remotely piloted and autonomous flight, are expected on longer timelines, towards the late 2020s and into the 2030s. Additionally, expected points of profitability vary by use case.

Business models vary. At a high level, vehicle manufacturers are pursuing varying degrees of vertical integration, with several business models being pursued by AAM passenger vehicle manufacturers. For example, while some vehicle manufacturers intend to sell their vehicles to operators, others intend to operate them themselves, and others are pursuing a hybrid model. Vehicle manufacturers interviewed during this study generally agreed that it was too early to tell which business model along this dimension would prove most successful. Most interviewees also expected manufacturers to continue to pivot their business models according to market conditions. Multiple models also exist for service delivery to end-users. For example, passenger travel could be delivered on-demand, or as a regular shuttle service. Considering passenger market segments, UK-specific evidence suggests that emergency services, and services outside densely populated urban areas, such as rural rideshare services, and sub-regional shuttle services, are potentially the most attractive initial market segments.

UK Market Landscape and Global Context

The UK hosts around 100 organisations engaged in the development of AAM. Of these, 15 are vehicle integrators. The UK currently hosts three indigenous passenger vehicle integrators, most notably, Vertical Aerospace, and, further, multiple international vehicle manufacturers such as Joby and Volocopter are targeting the UK as a key market. Collectively, all UK organisations employed over 1,000 individuals, and generated over £73 million in revenue with £32 million direct gross value added impact in the 2021 financial year. The AAM sector is estimated to have contributed £78 million in gross value added to the UK economy, and supported around 2,000 jobs in total in 2021.

The International market indicates the size of the UK AAM sector is comparable to peer nations such as Germany and Japan. Globally, the People's Republic of China and the US lead in terms of market size, as well as number of domestic vehicles in development. The AAM related organisations examined in the BryceTech database have seen £8.1 billion in private investment between 2012 and 2022, with sharp growth between 2016 and 2021, though growth has dropped off since then in line with global trends in private investment. Public investments made by government bodies also play a critical role in funding AAM research and development, with investment pathways varying significantly between countries. The US and European countries have primarily deployed large industry wide funding projects, whilst Brazil, Japan, and the People's Republic of China funded individual AAM companies through wholly or partially state-owned investment institutions. In a UK context, AAM has been a clear beneficiary of the significant public investment made into future aerospace technologies and market development by initiatives such as the Future Flight Challenge and the Aerospace Technology Institute programme.

Potential Impacts

Pricing is frequently discussed in the context of passenger travel, however rarely addressed with regards to regional cargo or last mile logistics. The price of AAM enabled passenger travel is expected to be elevated upon initial introduction, lower than helicopter travel, and comparable to luxury car services. Whilst initial services will likely be expensive, it is expected that as operations and manufacturing are scaled, and automation and remote piloting are introduced, prices will fall. Pricing is also found to be use-case and location specific. Vertical Aerospace indicate that journeys across the UK may be priced at approximately £0.64 per kilometre, representing a significant potential cost saving when compared to current taxi services, which cost around £1.36 per kilometre.

Operational safety data for AAM passenger vehicles is not currently available. However, if AAM passenger vehicles are held to the same standards as commercial aviation, their introduction could therefore indicate a net increase in passenger safety if meaningful passenger volumes switch from ground based transport options to AAM alternatives.

Time savings: It is estimated that in both urban and rural settings, AAM can offer time savings benefits, with factors including road congestion, travel time to vertiports, boarding time, and travel distance all impacting the amount of time saved.

Noise levels are a key area AAM manufacturers are seeking to minimise, though some studies indicate that AAM vehicles may still generate noise close to significant traditional aircraft exposure at close proximity during take-off and landing. However, noise is considered to be less severe at cruising height, comparable to light urban traffic. Further evaluation of noise impact of scaled AAM operations is required.

In-flight carbon emissions of AAM vehicles is expected to be minimal, similar to those produced by terrestrial electric vehicles. Additionally, AAM use cases could increase local air quality in neighbourhoods by eliminating other pollutants. However, whilst electric powered AAM vehicles release zero in-situ emissions, it is important to consider the emissions associated with the power sources that provide charging capabilities.

Social impacts are expected to be widespread. AAM has the potential to create jobs and new employment opportunities across the UK. Further, so long as vertiports incorporate inclusive design, AAM could provide another mode of transport for disabled commuters. If pricing can be brought down, regularly scheduled AAM flights could also promote social equity in underserved communities. Use cases such as air ambulances, disaster relief, and medical delivery seemingly provide clear-cut social benefits. Finally, alternative modes of ride-sharing could provide socially safer and more comfortable transport modes.

Future Market Potential

The potential market size and economic viability of AAM has been examined across multiple public studies globally and in the UK. Whilst market size estimates vary, they range between £1 billion and £100 billion in service revenue globally in 2040, with UK specific studies indicating some AAM use cases as economically viable and having the potential to significantly contribute to the UK economy. Notably, RAM is highlighted as an attractive option for connecting locations where the construction of large-scale infrastructure may not be cost effective. The UK annual revenue potential is estimated to be in the hundreds of millions, with the potential for a multi-billion pound market from 2035 onwards, according to Vertical Aerospace and Roland Berger. PwC also estimates annual socioeconomic benefit delivered in a UK context could accumulate to between £1 and £2 billion by 2040. This said, unlocking these benefits would require that current and future barriers to market development are overcome.

Market Drivers and Barriers

Urbanization, economic growth, and technological advancements such as battery efficiency, electric propulsion, and automation, are considered drivers for the development and adoption of AAM. In some regions, urban congestion, rising incomes, and the increased demand in delivery services drive the demand for UAM services. In the UK, the current high cost and duration of regional journeys make AAM passenger travel an attractive alternative.

A number of barriers potentially impact the scalability of AAM commercial operations. These include:

- Social barriers including concerns around trust, automation, service reliability, personal security, and privacy, and in the longer term, automation
- Technological barriers including cybersecurity, air traffic management, battery and electric propulsion, noise reduction, and production costs at scale
- Infrastructural barriers are also key, as the market can only be enabled through sufficient availability of vertiports, ground infrastructure, and telecommunications infrastructure
- Economic barriers including affordability, as demand is sensitive to pricing, and the risk of capital and operating costs not reducing sufficiently to enable profitability
- Short term regulatory barriers for airworthiness certifications, and licensing requirements that must be met by AAM developers
- Long term regulatory barriers with regulation needing to adapt to the emergence of remote and autonomous piloting, and potentially considerable increases in the scale of operations
- Operational barriers including concerns about integrating AAM with other aircraft in congested airspace, and unfavourable weather conditions. Additionally, scaled AAM services may demand the development of new standards for air traffic management

Interviews with industry raised several barriers, many of which affect operations around the world. In the UK context, those of particular concern for UK actors include:

- Concerns around insufficient availability of AAM passenger infrastructure, with the suitability of the UK's current planning system being raised as a major point of concern
- Public concerns around vehicle performance, safety, and impact
- Certification, regulation, and licensing, in particular, the need for establishing a regulatory framework to enable initial operations, and ensuring clear guidance and consultation – matters that are under active consideration, among others, through the ongoing work of the Future of Flight Industry Group and the development of a Future of Flight Action Plan

Possible Government Interventions

BryceTech considered a wide variety of potential interventions that could address UK-specific industry concerns. These interventions were shortlisted according to feasibility, cost and benefit, resulting in four low-cost, and four more resource intensive interventions that could be considered in order to further support the UK's AAM sector:

The high-impact, low-cost interventions were:

- Issue a national policy statement, setting out the government's position on the prioritisation, nature and roll-out of AAM infrastructure in the UK
- Publish a strategic regulatory action plan for AAM in the UK, laying out envisioned timelines of AAM roll-out and regulatory milestones to be reached at each stage, clear assignment of responsibility, as well as perceived opportunities and risks of AAM in the UK
- Actively facilitate the conduct of test and demonstration flights of AAM vehicles for commercial use in publicly accessible sites
- Enable rolling airspace trials in order to enable initial operations and trial of AAM flights in the UK

The high-impact, resource-intensive interventions were:

- Conduct an information campaign to local planning bodies on AAM impact, infrastructure, and planning
- Increase CAA resourcing, particularly within design and certification teams, and assess pay scales for key roles to ensure the attraction and retention of necessary labour
- Provide funding for provision of AAM use cases where public value is clearly visible, such as patient transport and medical goods delivery
- Provide continued challenge funding for the development and fielding of technologies required for scaled AAM operations

Evidence Gaps and Uncertainties

This evidence review identified several evidence gaps, which are yet unanswered due to the early stage of the sector. Operational data, for example regarding noise, battery performance, etc. is still limited. Therefore, moving forward, safety-conscious, transparent, frequent testing of vehicles in order to gather the technical and operational data required to inject certainty into decision making will be important. Additionally, the timelines to maturation of future technologies, such as automation, integrated UTM system, greater energy density, etc. are uncertain. Likewise, vehicle manufacturing and maintenance costs will be critical in determining economic viability, but remain to be confirmed with certainty. Related to this, actual demand for both passenger and cargo services will not be known until commercial services begin. In the near term, pain-points throughout certification will likely prove impactful to associated timelines, however the exact nature of these delays are difficult to predict in advance. Finally, related to the economic and certification status of vehicles, are uncertainties around the future of the AAM investment climate.

1 Introduction

This section provides the background of advanced air mobility (AAM) and a quick overview of AAM initiatives in the UK. It then outlines the objectives and scope of the report by defining AAM activities and aircraft under AAM. The report takes a global approach in data collection, but some levels of analysis and details are tailored to provide a UK context.

1.1 Background

Advanced air mobility describes novel air vehicle designs and the infrastructure required to transport passengers and cargo in urban, suburban, and regional rural environments. Proposed AAM concepts are usually characterised by electrification to facilitate potential improvements in environmental impacts over traditional transport solutions, as well as planned autonomous or automated operations.

The introduction of novel aircraft types can support key UK Government and Department for Transport (DfT) objectives through enabling innovation, economic growth, and heading towards a decarbonised future. The Jet Zero strategy[1] announced in July 2022, outlined the UK's objective of achieving net zero aviation by 2050. Whilst multiple solutions will be required, low carbon AAM concepts have the potential to be a meaningful contributor in achieving this goal and introduce new opportunities for local and regional air mobility connectivity. Similarly, a core goal of the Flightpath to the Future report,[2] released in 2022, is to capture the potential of new technology and its uses, including AAM. DfT and the Civil Aviation Authority (CAA) have made clear the ambition to fully realise the new connectivity offered by AAM concepts in a safe and sustainable way.

Over the next decade, the UK aims to realise a period of rapid development and significant firsts in UK aviation, including in the AAM sector. These steps will be outlined in a Future of Flight Action Plan, developed between government and industry through the Future of Flight Industry Group (FFIG) which is co-chaired by Baroness Vere, the minister responsible for aviation, and Duncan Walker, CEO of Skyports. It will set out a clear and actionable delivery plan to create and achieve a UK future of flight ecosystem, including AAM. The Future Flight Challenge (FFC), a £125 million technology development programme funded by the Department for Science, Innovation and Technology (DSIT) and wider industry, has been running from 2019. It works with industry, academia, government and regulators to help build the ecosystem needed for the introduction of AAM in the UK. They have provided funding to innovative AAM and drone projects across the UK and aim to help position the UK as a global leader in advanced aviation solutions. The CAA has also published the Airspace Modernisation Strategy (AMS) which details the steps required to modernise UK airspace to enable simplified airspace design and the integration of innovative aviation technologies.

1.2 Objective

DfT commissioned BryceTech to conduct an evidence review to improve the global and UK-relevant evidence base on AAM, as well as its current and potential future impact on the UK economy and aviation sector. In addition to identifying the potential benefits of this sector, this evidence review identified market barriers and proposed government interventions to address them. This report documents the findings of this evidence review.

In 2023, DfT identified areas of research interest associated with key evidence gaps and research questions related to AAM.[3] This evidence review is intended to support and feed into the following research topics, within the context of a broader program of work.

- What are the definition and groups of new and emerging aviation technology? How will or could new and emerging aviation technology change travel patterns and demand, and fit in with the wider future of transport scenarios of seamless connectivity and living local?
- What are the benefits and risks of new and emerging aviation technology (for example, unmanned aircraft, advanced air mobility, etc.) to transport users?
- How can drones and other new technology be used safely and securely to open new opportunities; develop new markets; and deliver aviation services to realise their full potential in the UK and to deliver economic growth?
- How will new and emerging aviation technology such as unmanned aircraft, advanced air mobility, provide environmental benefits or disbenefits and what environmental assessment techniques should be applied?
- What is the market outlook for emerging aviation technologies and where should DfT prioritise its efforts to enable the UK's role in aviation?
- What are the infrastructure, airspace, regulatory and skills requirements for the emerging aviation technologies and what are the impacts of existing government interventions?
- What are public/industry perceptions of emerging aviation technologies/ services and how can these help inform government interventions?

1.3 Scope

The evidence review uses the following definition of AAM: "Novel aviation concepts designed for urban, suburban, and regional transport of passengers and cargo that utilise advanced technology such as electric propulsion and autonomous operation." A more detailed definition is provided in the Market Definition section. For the purposes of this study, AAM includes new or novel aircraft for carrying up to around 10 passengers or freight over a short distance (up to 1,000 km), including:

- Electric vertical take-off and landing aircraft (eVTOLs)
- Small electric or hydrogen powered conventional/short take-off and landing vehicles (CTOL/STOL)

It does not include:

- Small unmanned aerial systems/ drones, in the open risk category,[4] with a weight including cargo of less than 25 kg
- Systems that are not intended for the carriage of passengers or freight, e.g., unmanned aerial systems (UAS) designed specifically for infrastructure inspection
- Medium to large zero emission aircraft

2 Approach and Dataset

The evidence reviewed includes findings from interviews with government and industry stakeholders, as well as experts, relevant studies, policies, and publications, along with internal datasets from BryceTech. Modelling and analysis of market dynamics were conducted by BryceTech. Cambridge Econometrics provided economic impact analysis. Alexander Grous, of the London School of Economics, provided additional expertise.

2.1 Review Workstreams

The evidence review was performed across four interrelated workstreams: market definition, market characterisation, future market potential, and government interventions (Figure 2.1).

2.1.1 Market Definition

BryceTech created a database of AAM vehicles and key enabling technologies, which helped to validate and refine a taxonomies used throughout the report. Technology readiness level (TRL) ranges were assessed for proposed AAM vehicles and enabling technologies based on publicly available information from company websites, social media, and industry publications. The dataset created in this workstream enabled the team to identify and categorise the most common AAM use cases, and inform time-to-market assessments for the sector.

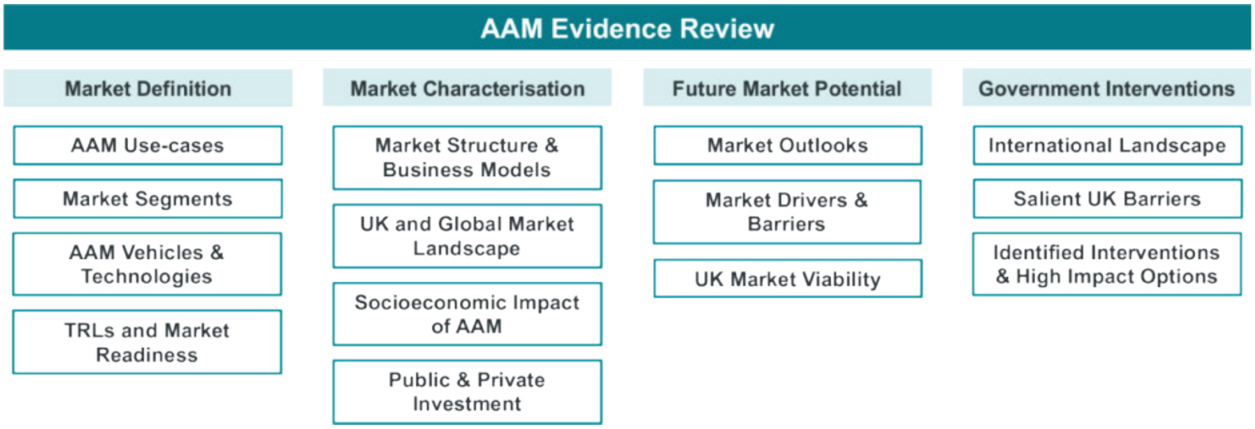


Figure 2.1. Evidence review workstreams.

2.1.2 Market Characterisation

BryceTech conducted an analysis of the current AAM market in the UK and globally, which included an examination of observable public and private investment as part of this analysis. Business model information was sourced by examining key AAM vehicle integrators. The AAM supply chain was characterised in order to identify companies operating in the UK, allowing for an economic impact assessment of AAM in the UK. This assessment measured the direct, indirect, and induced effects the AAM industry has on the wider economy.

2.1.3 Future Market Potential

In addition to assessing the current state of the AAM market, BryceTech conducted an evidence review of existing market forecast and demand assessments that including examining primary findings, study methodologies, and considering suitable market assessment methods in a UK context. BryceTech conducted a full review of market drivers and barriers in the UK context. In doing so, it interviewed leading figures in the industry, academia, and government. These interviews formed an initial evaluation of the economic viability of the AAM market in the UK.

2.1.4 Government Interventions

BryceTech examined potential government interventions in several steps. Firstly, salient UK market barriers were identified using reviewed literature, as well as targeted interviews with key UK market players. Additionally, existing UK government interventions, as well as major actions taken by governments globally, were reviewed. A longlist of potential UK interventions was produced for each barrier category, which was then assessed according to their feasibility, benefits and likely costs. This led to a shortlisted series of potential interventions, both low-cost and more resource-intensive, for which the theory of change, assumptions, and market/governance failure rational were expanded.

2.2 Data Sources

2.2.1 Publicly Available Literature

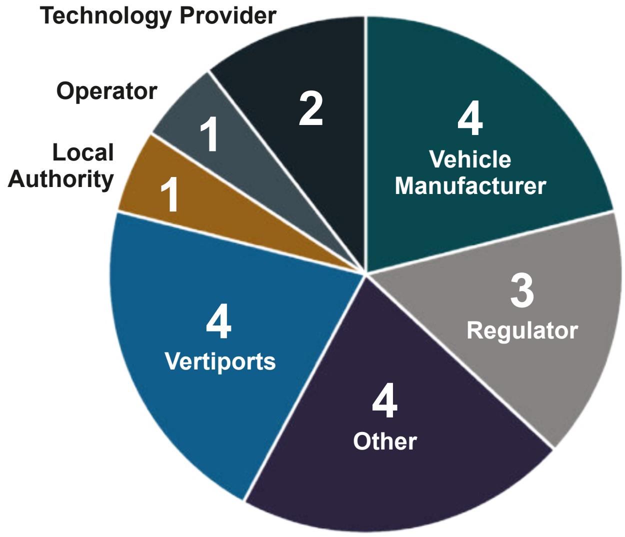
A broad literature review was conducted within each workstream to identify and characterise AAM-related reporting. BryceTech screened global governmental agency websites such as NASA's repository for AAM studies, consultancy and research organisation websites, academic journals, and press and news releases. References were assessed to identify additional related material and followed relevance-based studies to synthesise results and gather variables of interest according to the requirements of each workstream.

2.2.2 Expert Interviews

BryceTech conducted 26 interviews with individuals from 19 organisations, including leading regulators, industry players, and researchers in the AAM sector. These interviews, held in Q1 2023, provided valuable insights into current industry opinions and perspectives, which are integrated throughout this report to complement evidence collected from the literature review. Figure 2.2 presents a breakdown of the organizations interviewed. Interview findings significantly informed the identification of UK salient barriers, and potential interventions.

2.2.3 Industry Database

BryceTech developed and populated a tailored database on the AAM market. This database captures information on major players in the AAM market, key enabling technology providers within the UK, and vehicles fitting within the scope of this project. Data sources include national company registers, press releases, company websites, and third-party reporting. For the UK, revenue and employment figures were gathered for financial year end (FYE) 2021, and UK-specific figures provided in this report are for the financial year.



Source: BryceTech analysis.

Figure 2.2. Breakdown of interview targets by organization type.

3 Market Definition

This section discusses the use cases and market segments within AAM, along with an assessment of the technology readiness levels (TRL) for both key enabling technologies and AAM vehicles, a discussion on time to market, and the various factors that may affect entry into service.

3.1 Definition

AAM is an umbrella term with various definitions.[5] This makes assessing the sector's market size and outlook challenging, as existing studies differ considerably in their scope. The term advanced air mobility (AAM) sees its origins in efforts to expand on the concept of urban air mobility (UAM) to include use cases such as novel aerial regional passenger transportation and cargo transport.

The US National Academies of Sciences, Engineering, and Medicine, in March 2020, defined advanced aerial mobility (approximately equivalent to advanced air mobility) as a phenomenon characterised by "technological advances in electric propulsion and control systems, computer systems, sensors, precision position and navigation information, and other areas [which are] … facilitating the development and operation of new air vehicles potentially capable of safe, reliable, and low-noise flight, including vertical flight, with simplified vehicle operations or autonomy and with lower operating and maintenance costs than conventional aerial mobility." The Academy goes on to state that "Advanced aerial mobility includes manned and unmanned, autonomous and pilot-supervised aircraft of any size and mission operating safely and responsibly in an integrated National Airspace System. These can include both electric and hybrid aircraft. The term applies less to specific aircraft than to the overall method of operations and purpose."[6]

There is no universally accepted definition of AAM, and not every nation uses this terminology. This makes assessing the sector's market size and outlook challenging, as existing studies differ considerably in their scope. This study defined AAM under the following terms and scope, which are informed by, and consistent with large parts of existing literature, beginning on Page 9.

Key Findings

Use Cases

Seven core passenger use cases were identified:

- **On demand taxi services** between urban, rural, and metropolitan destinations
- **Scheduled passenger shuttles** in transport networks, including airport shuttles
- **Sight-seeing and tourism** around and above sites of interest
- **Emergency medical** response transporting first-responders
- **Patient transport** to hospital, or between hospitals
- **Disaster management** including monitoring, firefighting, and evacuation of victims
- **National security and surveillance** e.g., surveillance of national borders and territories

Alongside five core cargo use cases:

- **Time-sensitive medical goods transport** including cold chain products
- **Disaster relief goods transport** including food, medicine, etc.
- **Direct-to-consumer delivery** to individual properties or nearby collection hubs
- **Internal business logistics** within internal supply chains
- **Heavy cargo transport** e.g., for mail or consumer goods transport

Market Segments

These use cases are found to service six passenger market segments:

- **Commuting professionals** traveling to and from places of work
- **Airport passengers** including shuttle services
- **Tourists / leisure travellers** utilising AAM vehicles
- **Businesses** procuring the use of AAM passenger vehicles
- **Emergency response organisations** including healthcare organisations or natural disaster response entities
- **National security organisations** such as the coast guard and border control agencies

And five cargo market segments:

- **Individual consumers** using AAM services for delivery of goods
- **Emergency response organisations** using AAM services for the delivery of time-sensitive goods
- **Businesses** (other than logistics organisations) operating AAM vehicles
- **Logistics organisations** responsible for the movement of goods
- **National security organisations** such as the armed forces and border control agencies

Technology Readiness

The vast majority of vehicles under development are at a low status of technological readiness. A total of 176 AAM vehicles being developed and within the scope of this study were identified. Of the total vehicles identified, 43 had a high technology readiness level (TRL 7-9), which included 19 passenger and 25 freight transport vehicles (noting some vehicles have multiple use cases). The remaining 133 vehicles were assessed at TRL 6 or lower.

The technologies required for initial, small-scale, low-distance operations of AAM passenger vehicles are generally deemed mature. However, some key gaps still remain that require operational validation, for example in the area of battery thermal management. Further, even if vehicles are demonstrated in test flights, they must still be type certified, proving to governments that they are at a sufficient level of safety. This is seen as driving the time to initial operations.

Key Findings

Entry Into Service and Market Readiness

Most passenger vehicle manufacturers aim to bring their vehicles to market in the 2024-2026 timeframe, pending type certification. However, at least one vehicle, EHang's 216, sees poised for Chinese type certification in 2023, and some vehicles aiming for larger passenger manifests, longer ranges, or autonomous features, are aiming for longer timescales. Generally, governments across the world are aligned with industry goals, with several countries aiming to see initial operations begin in 2024 or 2025, and some roadmaps laying out a path to scale by 2030.

Considering cargo transport, several vehicles have already been operating across a number of use cases, such as medical goods delivery for several years. Additionally, local trials of emerging use cases such as consumer goods delivery have begun across the world. Regional cargo systems are also emerging, that are aiming to conduct initial operations of long-range goods transport in the 2024+ timeframe.

Urban systems <100 km

- Definition: Safe, efficient aviation transportation system using aircraft that will transport passengers or cargo at lower altitudes than traditional aviation within urban and suburban areas
- Trips up to 100 km
- Between 1-6 passengers or cargo to the vehicle's capacity, using urban vertiports

Regional systems 100-1,000 km

- Definition: The transport of people and goods using aircraft with significant improvement in efficiency, affordability, and community-friendly integration, building upon, and utilising existing airport or airfield infrastructure
- Trips up to 1,000 km
- Up to 10 passengers or cargo to the vehicle's capacity, using small airfields

3.1.1 Vehicle Configurations

The study took multiple vehicle configurations into account, capable of VTOL, STOL, or CTOL (informed by NASA,[7] the AAM Reality Index,[8] and EASA[9]):

- Wingless: Fixed propulsion in a single- or multi-rotor configuration, with cruise achieved via rotor pitch. Capable of VTOL
- Life and cruise: Uses different thrusters for take-off and landing, and cruise. Operates as a fixed wing aircraft for extended flight, utilising separate rotors on take off and landing. Capable of VTOL, STOL, and CTOL
- Vectored thrust: Same thrusters used for lift and cruise, with wing or thrusters tilting to transition between flight modes. Capable of VTOL, STOL, and CTOL
- Conventional and augmented lift: Fixed wing aircraft, typically capable of longer distance flight than other configurations. Augmented lift employs flaps, vortex generators, slats, and slots to reduce runway length requirements. Capable of CTOL (and STOL with augmented lift)

3.1.2 Infrastructure Configurations

Take-off and landing infrastructure for AAM, like vehicles, can adopt several configurations. This study considered several variations (informed by NASA[10]):

- Conventional aerodromes: Airfields and airports used for VTOL, STOL or CTOL (using on-site landing pads)
- Vertiports: Area for VTOL (and super-short take off and landing) operations, alongside associated buildings and facilities
- Vertistops: An area for vertical take-off and landing, without charging, storage and maintenance infrastructure, intended for short interim stops

3.2 Use Cases

AAM encompasses a diverse range of activities and use cases. Within the scope of this study, AAM can be conceptualised along two primary dimensions: operating range and payload. These dimensions lead to the classification of four high-level use-case categories as shown in Figure 3.1.

While each of these categories has distinct requirements, some AAM vehicles may have the ability to operate across multiple use case categories. For example, some AAM vehicles could offer both regional and short-range urban transport, and others may offer both passenger and cargo transport.

3.2.1 Passenger Transport Use Cases

Several distinct use cases were identified within the passenger transport categories. Table 3.2 summarizes the identified passenger use cases, which are synthesized from sources including NASA,[11,12] EASA,[13] the Organisation for Economic Co-operation and Development (OECD),[14] and a workshop by Mott MacDonald and the DfT. These sources represent the vast majority of use cases examined in the broader literature.

All passenger use cases have the potential to operate across a range of distances and

Operating Range \ Payload	Passenger Transport	Freight Transport
100 - 1,000 km Journeys	**Regional Air Mobility (RAM) / Long-Range Passenger** • Capacity: Up to 10 passengers • Offer higher efficiency and lower cost than conventional flight, and greater speed than driving. Operate from small airfields with charging infrastructure	**Regional Cargo** • Capacity: Up to 2,000 kg • Larger air systems operating across inter-city and rural routes, carrying aggregate cargo manifests or larger goods
< 100 km Journeys	**Urban Air Mobility (UAM) / Short-Range Passenger** • Capacity: 1-6 people • Operates over intracity, short intercity or urban-suburban routes. Value proposition in being able to trans-navigate congested or convoluted ground routes	**Last-Mile Logistics** • Capacity: Up to 20 kg cargo • May be capable of handling multiple consignments per flight. Carry letters, packages, medicines, lab samples, food, components and equipment, etc.

Source: BryceTech analysis.

Figure 3.1. AAM high-level use-cases within the scope of this study.

Use Case	Description
On demand taxi services	Point-to-point transport of passengers between urban, rural and metropolitan destinations, booked as and when vehicles are available, using either a rideshare or dedicated passenger model
Scheduled passenger shuttles	Transport of passengers on scheduled flights between fixed destinations, in the form of urban, metropolitan or rural transport networks, including airport shuttles
Sight-seeing and tourism	Scheduled flights for tourists around and above sites of interest
Emergency medical response	Transport of first-responders to medical emergencies
Patient transport	Transport of patients from the site of an accident to hospital, or between hospitals
Disaster management	Disaster area monitoring, fire observation and firefighting, and evacuation of victims from disaster areas
National security and surveillance	Surveillance and patrol of national borders and territories, fisheries, critical national infrastructure, coastal monitoring, and wide area surveillance

Source: BryceTech analysis of multiple sources.

Table 3.2. Passenger transport use cases.

environments, including both regional air mobility and urban air mobility categories. However, it is important to note that whilst use cases may be similar, cost factors and operational complexity can differ significantly depending on whether the use case is applied in a rural or urban setting.

3.2.2 Freight Transport Use Cases

Table 3.3 summarises the cargo use cases drawn from the aforementioned literature. Similar to passenger transport, most use cases in the cargo domain could be applied across both short-range and long-range distances, depending on vehicle capabilities. However, operational factors and unit economics are likely to constrain the profitable operating geographies for each use case.

3.3 Market Segments

Each general use case identified in section 3.1 encompasses multiple user groups; however, the combination of a general use case with a specific user group allows for the identification of several market segments.

Use Case	Description
Time-sensitive medical goods transport	Transport of time-sensitive goods, including cold chain products such as vaccines, medicines, and organs
Disaster relief goods transport	Transport and delivery of goods in disaster situations, including food, medicine, clothing, and temporary shelters
Direct-to-consumer delivery	Delivery of consumer goods such as prepared food, groceries, parcels, and mail, to individual properties or nearby collection hubs
Internal business logistics	Transport of goods and supplies within a business's internal supply chain. This could include the transportation of goods within delivery networks, such as local delivery hubs, as well as the transport of spare parts or components
Heavy cargo transport	Transport of heavy cargo manifests in standard volumes, e.g., for mail or consumer goods transport

Source: BryceTech analysis of multiple sources.

Table 3.3. Freight transport use cases.

When further considering announced commercial plans, a total of eight individual market segments are identified for AAM vehicles. A number of these market segments apply to both the passenger and freight transport categories, with six market segments applicable within the passenger transport category, and five in freight transport. Due to the emerging nature of this sector, it is likely that additional market segments will develop in the future. Table 3.4 displays primary passenger transport markets segments, and Table 3.5 provides freight transport market segments.

Initial trials for the emergency transport of time-sensitive goods have already taken place in the UK, with several drones transporting chemotherapy delivered by Apian to the Isle of Wight on behalf of the National Health Service (NHS).[15] In addition to the NHS, emergency response organisations such as the Royal National Lifeboat Institution (RNLI) and the UK Air Ambulance services could potentially benefit from AAM. Furthermore, entities like the Maritime and Coast Guard Agency, Border Force, and the British Armed Forces could be potential end-users for national security purposes.

Market Segment	Description
Commuting professionals	Individuals utilising AAM transport services to travel to and from places of work
Airport passengers	Individuals utilising AAM airport shuttle services to travel to and from larger airports
Tourists / leisure travellers	Individuals utilising AAM vehicles for tourism or leisure purposes
Businesses	Businesses procuring the use of AAM passenger vehicles, for example for the use of business aviation
Emergency response organisations	Healthcare organisations or natural disaster response entities, utilising AAM passenger vehicles for the fulfilment of their duties.
National security organisations	National security organisations, such as the coast guard and border control agencies, utilising AAM passenger vehicles for incident response, surveillance, or routine patrols

Source: BryceTech analysis of multiple sources.

Table 3.4. AAM passenger transport market segments (identified in literature).

Market Segment	Description
Individual consumers	Individuals or households purchasing AAM services for delivery of goods to their residence or vicinity
Emergency response organisations	Healthcare organisations or natural disaster response entities, operating AAM vehicles or procuring AAM services for the delivery of time-sensitive goods
Businesses	Businesses (other than logistics organisations) operating AAM vehicles internally, or procuring AAM services to move goods within their logistics chain
Logistics organisations	Organisations responsible for the movement of goods e.g., postal services, delivery companies, operating AAM vehicles or procuring AAM services to move goods in order to provide their service
National security organisations	National security agencies, such as the armed forces and border control agencies, operating cargo vehicles or procuring AAM services for the transport of time-sensitive equipment

Source: BryceTech analysis of multiple sources.

Table 3.5. AAM freight transport market segments (identified in literature).

Market Segment	Destination-flexible, on demand taxi services	Destination-fixed, scheduled passenger shuttles	Sight-seeing and tourism	First aid	Patient transport	Disaster management	National security and surveillance
Commuting professionals							
Airport passengers							
Tourists and leisure travellers							
Businesses							
Emergency response organisations							
National security organisations							

Source: BryceTech analysis of multiple sources.

Table 3.6. Mapping of AAM passenger transport market segments to use cases.

Market Segment	Time-sensitive medical goods transport	Disaster relief goods transport	Direct-to-consumer delivery	Internal business logistics	Heavy cargo transport
Individual consumers					
Emergency response organizations					
Businesses					
Logistics organisations					
National security organisations					

Source: BryceTech analysis of multiple sources.

Table 3.7. Mapping of AAM freight transport market segments to use cases.

Finally, to provide a clear view of the use cases by market segment, Table 3.6 and Table 3.7 show the mapping of market segments against individual use cases for passenger and freight transport respectively.

3.4 Status of Technological Development

BryceTech assessed the technological development status of both AAM vehicles and the key enabling technologies by undertaking a technology readiness assessment and assigning a technology readiness level. TRLs, first developed by NASA, are used to assess the maturity of technologies using a defined set of definitions as shown in Table 3.8. Vehicle TRLs were assessed based on evidence of vehicles meeting testing milestones, taking into consideration company announcements, and third party reporting. Enabling technology readiness levels were assessed on a category-basis, taking into consideration evidence of deployment, commercial availability, reporting from research bodies, and government technology development contracts. BryceTech finds that many key enabling technologies related to autonomous operations are unlikely to be ready in the near term, and the majority of AAM vehicles for UAM are early in the TRL scale (1-3).

3.4.1 AAM Vehicles

A total of 176 AAM vehicles being developed and within the scope of this study were identified. The current stage of development for each vehicle was assessed, and a TRL was assigned. Of the total vehicles identified, 43 had a high technology readiness level (TRL 7-9), which included 19 passenger and 25 freight transport vehicles (noting some vehicles have multiple use cases). The remaining 133 vehicles were assessed at TRL 6 or lower. An overview of the TRL assessments is presented in Table 3.9 and is further broken down into the use cases as defined in Section 3.1.

Prominent companies with a vehicle assessed at TRL 7-9 include:

- Passenger transport: Volocopter (Germany), Lilium (Germany), EHang (China), Archer Aviation (USA)
- Freight transport: Zipline (USA), EHang (China), Flylogix (UK)

TRL	Definition
9	Actual system flight proven through successful mission operations
8	Actual system completed and "flight qualified" through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem model or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in relevant environment
4	Component and/or breadboard validation in laboratory environment
3	Analytical and experimental critical function and/or characteristic proof-of-concept
2	Technology concept and/or application formulated
1	Basic concept principles observed and reported

Source: NASA.[16]

Table 3.8. Technology Readiness Level (TRL) definitions.

Within the UK, one of the most notable companies developing a regional passenger and freight AAM vehicle, is Vertical Aerospace. Vertical achieved first flight of its VX4 vehicle in September 2022 and currently aims for certification by the end of 2026.[17,18]

Whilst the companies developing the assessed vehicles were deemed to still be active, consolidation in the AAM sector was put forward in interviews as likely, and it is expected that many of the lower TRL vehicles identified will not see commercial operation.

3.4.2 Key Enabling Technologies

BryceTech examined AAM-related literature to identify key enabling technologies. These were conceptualised as technologies without which AAM could not emerge as a commercially viable sector. Technologies identified are indicated in Table 3.10. While these technologies do not represent the entire AAM value chain, they are widely considered the primary technological components to making widespread adoption of AAM services a reality.

AAM technologies are considered sufficiently mature to enable initial passenger operations to take place in the near term, with most estimates pointing to 2025 as a likely year for initial entry into service. However, AAM concepts vary in ambition, from scheduled airport shuttles to fully autonomous on-demand air taxis. Generally, most experts interviewed did not anticipate the technology for autonomous operation to be ready for acceptance by regulators and the public before 2030. However, passenger vehicle technologies necessary for initial piloted operations are considered mature, with several vehicle manufacturers having conducted expansive testing of prototypes, such as Joby Aviation.[19] At least 30 passenger and cargo vehicle manufacturers expect to be able to fly a commercial model of their vehicle by the 2024 to 2026 timeframe. Cargo delivery is already being conducted in certain use cases such as medical goods delivery. However, the technology available for more ambitious operational concepts, such as warehouse-to-door delivery of consumer goods, is again considered less mature.

	TRL			
Use Case Category	**1 - 3**	**4 - 6**	**7 - 9**	**Total**
Passenger Transport	56	42	19	117
Regional Air Mobility	28	23	10	61
Urban Air Mobility	29	23	13	65
Freight Transport	35	34	25	94
Regional Cargo	32	28	17	77
Last Mile Logistics	3	6	8	17
Any	71	62	43	176

Note: Numbers may not appear to sum correctly due to vehicles falling into multiple use case categories.
Source: BryceTech analysis.

Table 3.9. Technological status of AAM vehicles, showing individual vehicle counts by use case and TRL range.

Technology gaps exist in areas required to enable large-scale, profitable, and societally accepted operations. Vehicle manufacturers need to be able to scale production sufficiently once operational, and in time, vehicle operators will require the technology to transition away from piloted vehicles to remote and autonomous operations. Airspace management systems and procedures require considerable development to accommodate a new class of vehicles that can operate safely in an increasingly congested environment. Whilst batteries enabling the transportation of small passenger loads (~4) over distances of up to approximately ~200 km are fairly mature, energy densities are not yet at a level that would allow for the carriage of larger passenger loads over longer distances. Further, battery

Category		Key Enabling Technologies	TRL
Vehicle Subsystems	Propulsion systems	Distributed electric propulsion	7 - 9
		Vertical lift flight	7 - 9
		Hybrid powertrains	4 - 6
	Flight computing and avionics	Propulsor fault detection and recovery	4 - 6
		Flight quality monitoring	1 - 3
		Flight control security	1 - 3
	Power and energy storage	High capacity, high power battery cell	7 - 9
		Battery cooling and thermal protection	7 - 9
		Battery charge, discharge, and lifecycle monitoring	4 - 6
		Propulsor power electronics	7 - 9
		Ground energy storage	4 - 6
	Sensors and instruments	Noise impact prediction	4 - 6
		Vehicle-specific sensors for navigation	7 - 9
	Manufacturing, materials, and structures	Airframe integrated battery pack	7 - 9
		Structural health monitoring	4 - 6
		Weight and balance detection	7 - 9
	Guidance, navigation, and control systems	Vertical lift to horizontal flight control	7 - 9
Communications, Navigation, and Air Traffic Management	Communications and navigation	Remote piloting, supervision, and intervention	4 - 6
		Weather hazard alerts and rerouting	4 - 6
		Fleet management integration	4 - 6
		Customer platform interfacing	7 - 9
	Automated and autonomous systems	Pilot incapacitation detection	4 - 6
		Autonomous collision avoidance	4 - 6
		Autonomous flight operations	4 - 6
	Air traffic management	Advanced airspace management	4 - 6
		Unmanned Aircraft Traffic Management (UTM)	4 - 6
Ground Infrastructure	Ground, test, and surface systems	Vehicle access rights management	1 - 3
		Ground smart grid integration	4 - 6
		Vertiport vehicle ground handling	4 - 6

Source: BryceTech analysis.

Table 3.10. Technological status of key enabling technologies.

safety technologies, such as thermal protection, are deemed less mature and require further operational demonstration. All of these novel technological systems additionally require necessary regulatory frameworks and guidance to be in place.

Apart from in-house development of novel technologies by vehicle integrators, which is a common feature among many of these companies, critical systems and components come from a wide range of both well-established aerospace suppliers and novel specialised firms. For example, Vertical Aerospace is partnering with Rolls-Royce for the development of their vehicle's electric powertrain. Honeywell Aerospace, another well-established name in the aviation sector, provides several components to AAM vehicle integrators such as turbogenerators, electric propulsion, and actuation components. A number of start-ups have also emerged recently with a focus on developing necessary technologies for AAM adoption. Skyway, a US-based start-up, develops unmanned traffic management software for drone operations for example.

3.5 Time to Market

Given the relatively mature status of core technology required for initial entry into service, the key hurdle to initial piloted commercial operations of AAM vehicles was not considered by interviewees to be technological but regulatory, although this may vary depending on the country. Crucially, vehicles must be certified and approved for operations under their respective national regulatory regimes, therefore, time-to-market will be at least somewhat dictated by geography-specific certification timelines. Additionally, this report will assess the different methods used to assess time to market and discuss the variance in methodology.

3.5.1 UK and Global Time-to-Market

Entry Into Service

Freight transport use cases for last-mile delivery are already in operation in several regions across the world. For example, Zipline currently provides services, including the transport of medical goods, in 7 countries.[20] Other last-mile logistics companies such as Flytrex and Wing have also begun limited services.[21,22] In addition, some regional cargo vehicle manufacturers, such as Elroy Air, are expecting to begin early international operations in 2024, and type certification with the FAA in 2026.[23]

Within passenger transport use cases, the AAM Reality Index (ARI),[24] a rating tool that assesses AAM operators "progress toward the delivery of a certified product at mass scale production" or assesses the expected service introduction for UAM passenger vehicle integrators such as Joby, Lilium, and Archer to be 2025.[25] Some passenger vehicle companies such as Eve, Jaunt, and Airbus are speculated to begin service later, in 2026.[26] Supernal is expected to be ready by 2028[27] while Wisk, who are developing an autonomous UAM vehicle, is "unlikely to certify its vehicle before 2028."[28] However, it is important to note that these expectations are partly based on company announcements, and if vehicle manufacturers are unable to meet certification requirements and satisfy regulators, these timelines may be delayed. In 2023, Vertical Aerospace amended its expectations of entry into service from 2025 to 2026, citing certification timelines as the reason, and commenting that it was likely other vehicle manufacturers would follow, under a broader industry timeline correction.[29]

While certification may enable initial operations, the next challenge for manufacturers will be scaling production. Industry analysts note that whilst vehicle deliveries are scheduled to occur in the next few years, a number of companies have significant pre-orders, providing further indication that scaling up manufacturing, as well as certification, will be a significant consideration in the route to market.[30] For example, due to the complexities of vertical integration, and the FAA's shift in regulatory framework, Joby's planned year for service entry was moved from 2024 to 2025.[31]

Market Readiness

EASA suggest that entry into service (EIS) timelines differ between piloted and autonomous vehicles, with certification for piloted passenger operations currently planned around 2025, and autonomous operations to begin after 2030.[32] Capgemini also suggest that 2025 will be "the year [passenger] eVTOL vehicles could become [a] commercially viable option."[33]

In contrast, specific to Urban Air Mobility, Crown Consulting as part of NASA's Technical Reports Server (NTRS) market study suggest that a "commercially viable market for last-mile parcel delivery and air metro could be in place by 2030."[34] The report suggests this timeline is less likely for air taxis, with a "limited potential market [constrained to] concentrated areas of [wealthy] individuals and businesses," one reason for this being the considerable capital cost of achieving large-scale, ubiquitous urban air taxi operations. In the same market study, McKinsey & Co agrees with Crown Consulting that air taxis are "unlikely to be ubiquitous and profitable in 2030" and that parcel delivery could be commercially viable around 2030. However, McKinsey's estimate

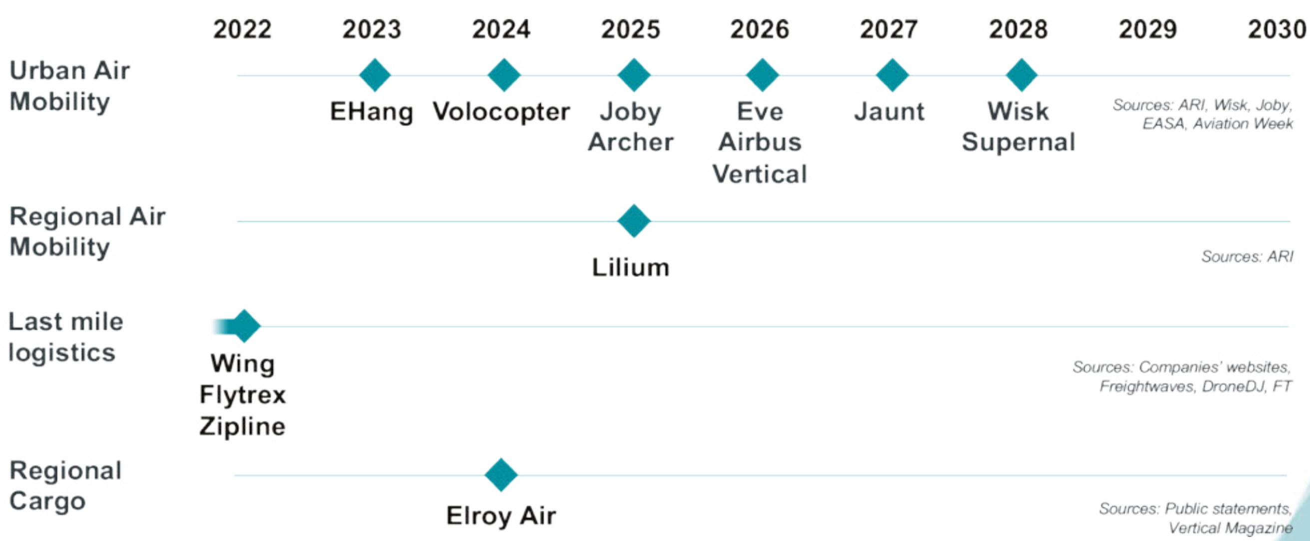


Figure 3.11. Summary of initial AAM service timelines by use case.

is slightly more optimistic and suggests that "air metro may have a viable market in 2028" in which the following years will be profitable, and that for air taxis, "some localized or niche markets could run profitably."[35] Similarly to McKinsey, modelling in a separate report from Deloitte suggests scaled AAM operations may occur around 2030.[36]

EASA ranks the viability of intracity transport and suburban transportation by 2025 as 'medium', and 'low' for city-to-city transport.[37] For emergency medical response and medical supplies, categories such as accident response, disaster management, firefighting, patient transport, cargo deliveries, and supplies deliveries were all ranked 'high" by EASA for market viability during the same timeframe.[38]

In agreement with EASA on the 2025 timeline but slightly more optimistic, Capgemini suggests that cargo drones could be in service by 2023 with on-demand deliveries in multiple cities around the globe. Capgemini suggests that in 2025, eVTOL VIP services will start to compete with helicopter services, followed by mass production of eVTOL by 2030.[39] Capgemini stipulates that by 2028, there will be multiple cities operating air taxi services on pre-defined routes and wide-spread adoption will happen between 2031 and 2040.[40]

By Country and Regulation

The earliest type certification of a passenger aircraft may take place in China, with EHang reporting that it has completed 90% of compliance tests required for PRC type certification.[41] Whilst EHang has one of the earliest expected times-to-market for identified operators, some analysts believe that the certifications received from China may not be directly transferrable abroad, therefore suggesting extended timelines for introduction into the United States and Europe.[42]

Aviation Week suggests that first certifications of AAM passenger vehicles are targeted for 2024 and harmonizing regulations will be crucial in time-to-market.[43] Paris plans to roll-out services by summer 2024 in partnership with Volocopter, conditional on Volocopter receiving its first Special Condition certification by EASA in the same year.[44] Singapore also plans for initial UAM operations to begin from 2024.[45]

Japan expects to introduce AAM operations at the Japan World Expo 2025, where package delivery and passenger transportation services will launch in 10 flight areas including isolated islands, gulf coasts, and low population areas.[46] To prepare for a 2025 launch timeline, Japan is engaging a "proactive implementation" strategy and aiming to complete regulatory framework and vehicle demonstrations before 2025.[47] Japan further aims to launch passenger urban transportation services by 2030 between urban and suburban areas.[48] South Korea similarly aims to commercialize UAM operations by 2025.[49] In Europe, cities such as Cologne and Dusseldorf have announced intended entry into service and certification for passenger services by 2025.[50] Looking towards Middle East and North Africa (MENA), the UAE plans for 2026 as the intended target dates for UAM services, partnering with Joby and Skyports.[51]

The KPMG Air Taxi Readiness Index 2022[52] (ATRI) quoted the founder of eVTOL Careers as stating the "level of investment in the UK is strong" and highlighted the Future Flight Challenge as helping to demonstrate the feasibility of AAM within the UK. The ATRI provides an overall ranking of countries' market readiness, based on five pillars: consumer acceptance, infrastructure, policy and legislation, technology and innovation, and business opportunity. This report ranked the UK as 3rd in the world overall, behind the US and the People's Republic of China, and 1st in the world for policy and legislation, noting "mature regulatory functions and significant government investment" along with "[industry players] being encouraged to work together to create viable and sustainable concepts of operation" and "choosing to adopt the [EASA] certification standards for next generation eVTOL (SC-VTOL)" as driving factors. Furthermore, the report states the UK can offer a "diverse use cases for the air taxi market" such as shuttle services to improve regional and rural connectivity networks that can bypass a London-centric radial system.

Conclusion

Sources from different perspectives such as the ARI, market studies (McKinsey, Crown, Capgemini, Deloitte), and reports from EASA and Japan, agree that some AAM services such as UAM passenger transport will begin initial operations from 2025 onwards and it is likely that AAM delivery services will be more successful than passenger transport in the first few years. Some passenger services may start even earlier, depending on geography and country-specific certification and licensing timelines. However, this perspective is from a technology standpoint and doesn't necessarily lead to implementation of AAM in targeted cities. Often, company projections do not reflect regulatory progress or government decisions but mostly technical numbers and production rate. Further, initial entry into service is not equivalent to operational break-even, with consulting firms such as McKinsey and Capgemini suggesting that most AAM services will be commercially viable by the late 2020s and early 2030s. In general, country-specific context is important in determining time to market, and can lead to variation in market estimates.

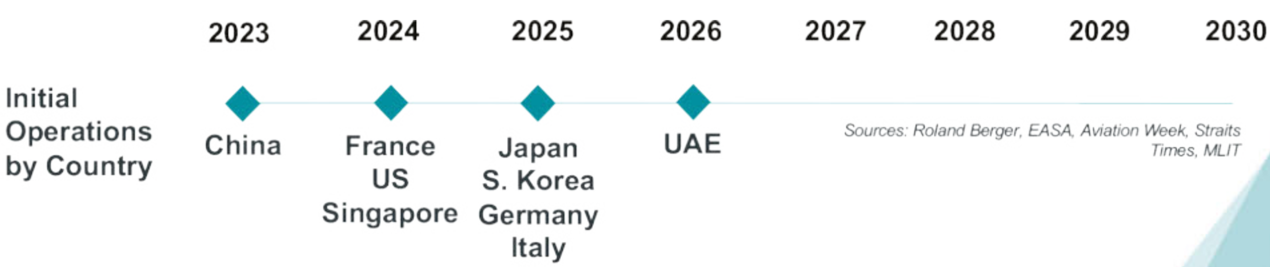


Figure 3.12. Summary of initial AAM passenger services by country.

4 Market Characterisation

This section examines the market structure and business models present in the AAM industry through the conceptualization of the AAM value chain. The UK market landscape is presented, looking at the ecosystem, revenue, and employment in the UK AAM sector, and how these factors compare to the global AAM market. The socioeconomic impact of AAM activities are discussed, including economic impacts (GVA, employment, investment), passenger impacts (pricing, safety, and time) and environmental impacts (noise, GHG emissions, and energy usage), as well as social impacts (including accessibility and inclusivity, regional connectivity, job creation, and more).

Key Findings

UK Market Landscape: BryceTech finds around 100 organisations in the UK providing AAM-related goods and services. In 2021, the UK AAM sector directly employed approximately 1,200 individuals and generated £73 million in AAM related revenue.

Economic Impact: UK organisations employed over 1,000 individuals, and contributed £32 million direct gross valued added impact in the 2021 financial year. The total estimated impact of the AAM sector in the UK in 2021 was approximately £78 million in gross value added, and supported approximately 2,000 employees. The UK market size is found to be comparable to countries such as Japan and Germany, with the global market led by the United States and the People's Republic of China. AAM continues to be a significant beneficiary of specific and non-specific public and private investment, however to date this has not translated into revenue.

Passenger Impact: AAM passenger services are estimated to have initial prices lower than those of helicopter services but higher than current ride sharing options, with long term prices expected to fall. Services can offer time savings benefits with factors including road congestion and travel time to vertiports impacting time saved. Safety is a concern for AAM operations and a key factor influencing public adoption. However, AAM passenger services have the potential to be safer than road transportation.

Environmental Impact: AAM vehicles are designed to minimise noise and be quieter than traditional vehicles, however, further studies are required to evaluate the noise impacts of scaled operations. AAM has the potential to reduce greenhouse gas emissions, however impacts are highly dependant upon a number of variables notably including use case and the energy mix of the grid power supply. Factors including vehicle design, flight profiles, vehicle utilisation, and weather can significantly influence energy usage and consumption.

Social Impact: AAM could provide alternative transport options for many users, connect communities, and increase access to education, healthcare and other essential services. Job creation and socioeconomic impacts are highly dependant upon AAM adoption, and whilst there is potential for job creation, concerns exist regarding job displacement and job losses due to automation.

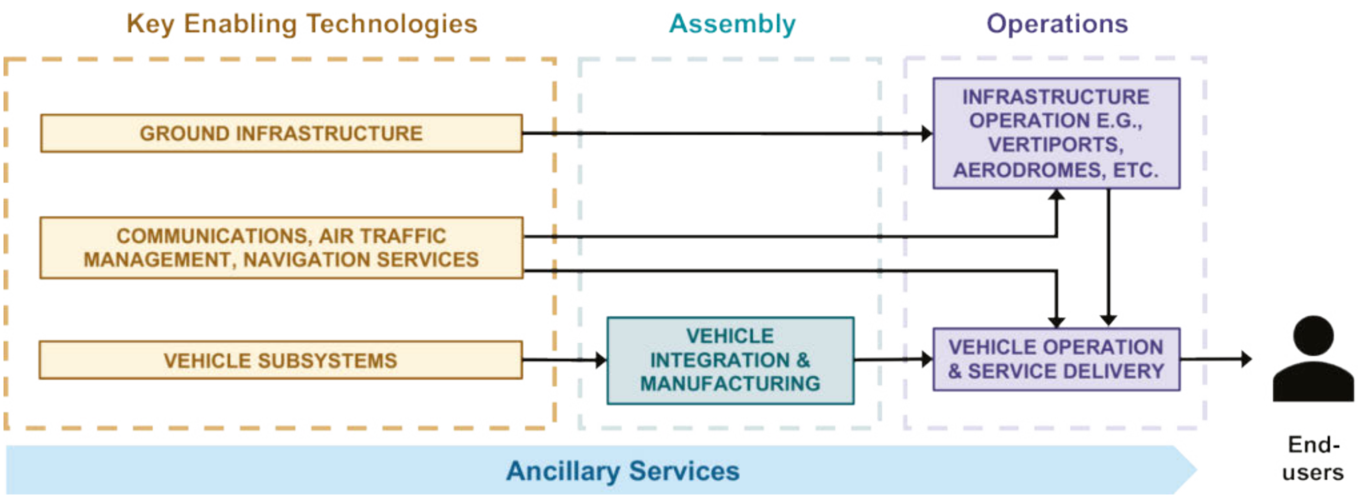


Figure 4.1. AAM value chain conceptualisation.

4.1 Market Structure and Business Models

BryceTech created an AAM value chain and identified business models determined by the level of vertical integration of vehicle operators.

4.1.1 Value Chain

To identify key organisations within the AAM sector, and evaluate and measure the industry's revenue and socioeconomic impact, a high-level value chain diagram (Figure 4.1) was created. In order to facilitate and inform the UK-specific socioeconomic impact assessment conducted by BryceTech and Cambridge Econometrics, the organisations identified and included in the study's database were categorised according to their value chain activities and aligned with 2-digit standard industry classification (SIC) codes.

4.1.2 Business Models

The AAM value chain for vehicles results in four key business models, as detailed by HSBC,[53] driven by the level of vertical integration of vehicle operators: pure vehicle integration, pure vehicle operation, exclusive vertically integrated operator, and non-exclusive vertically integrated operator. In these business models, vehicle manufacturers have also opted for varying levels of vertical integration along the supply chain. For example, some produce almost all their subsystems in house, while others source from a variety of specialist suppliers. While HSBC's report focuses on AAM passenger vehicles, these high-level business models could equally apply to cargo services.

Beyond the four business models in Figure 4.2, some vehicle manufacturers have also indicated a further level of integration, whereby they build and operate their own take-off and landing infrastructure. However, interviews for the study indicated that some vehicle manufacturers are moving away from this model, given its capital requirements. Several dedicated vertiport construction and operation companies have gained prominence in recent years. Public statements from companies such as Skyports suggest these will operate similar business models to current airports, charging landing, handling, hangar or storage fees, though

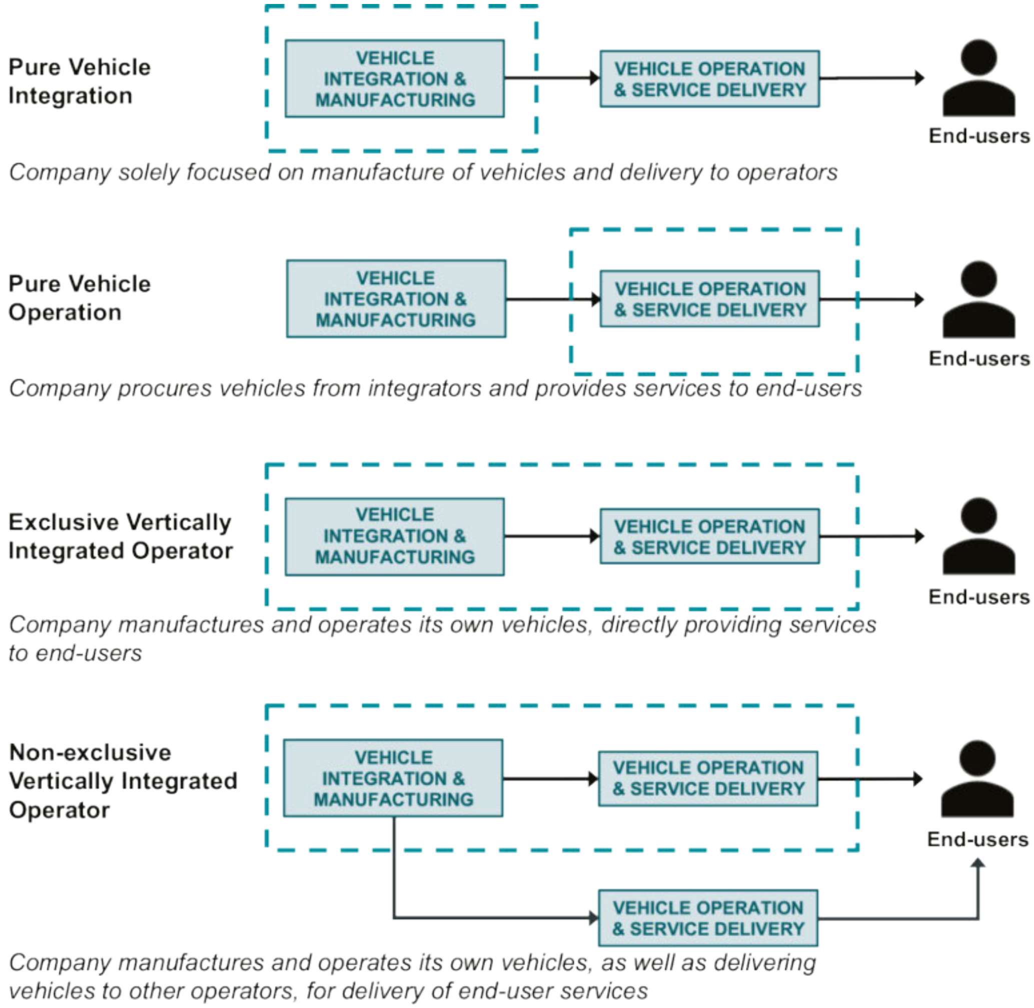


Figure 4.2. AAM vehicle business models.

with a reduced reliance on retail for income. However, vertiport operators could also plausibly charge the end-user for access to the vertiport.[54]

In the domain of vehicle operation and service delivery, several potential options exist for the provision of AAM passenger travel and cargo transport. These relate closely to AAM passenger use cases. Pricing methods and structures vary considerably. Some forms of regional travel, for example, may operate similarly to traditional aviation, with customers purchasing tickets for scheduled flight ahead of time. Similarly, some services for higher net worth individuals may be similar to chartered aircraft or helicopter business models. Departing from traditional models, some services may see consumers purchasing seats on rideshare shuttle services through an app, or at the point of departure. Several propositions put forward an on-demand model, incorporating multi-modal transport concepts, whereby individuals book travel through an integrated transportation app, which calculates the most viable route, and incorporates pricing based on route, timing and network demand.[55]

Cargo services meanwhile may either be provided as a business to business service, as for example Zipline has done,[56] with drone delivery and freight transport companies offering logistics services to businesses in sectors such as healthcare and consumer goods. Alternatively, companies may operate their own internal fleets of drones, with consumers paying directly for delivery services, as Amazon is pursuing with Prime Air.[57]

Given the relatively nascent stage of the industry, AAM business models are still in flux, and will likely not settle until regular operations are established, and financially optimal paths forward are determined. Pricing levels and structure are in particular likely to change, as production is scaled and optimised, and as automation is gradually introduced across operational elements. Pricing levels and structure will also almost certainly vary by use case, even once regular operations are established.

4.2 UK Market Landscape

This section discusses the organisations involved in AAM operations within the UK, looking at the ecosystem, and providing an assessment of the revenue and employment in the sector.

Key Findings

Organisations and Ecosystem: The UK AAM market is comprised of around 100 AAM-related organisations, including vehicle integrators, vehicle operators, and vertiport operators. 67 of the organisations were identified as enabling technology providers, ancillary services, or groups such as educational establishments.

Revenue and Employment: In 2021 the UK AAM sector employed around 1,200 individuals and generated £73 million in AAM-related revenue.

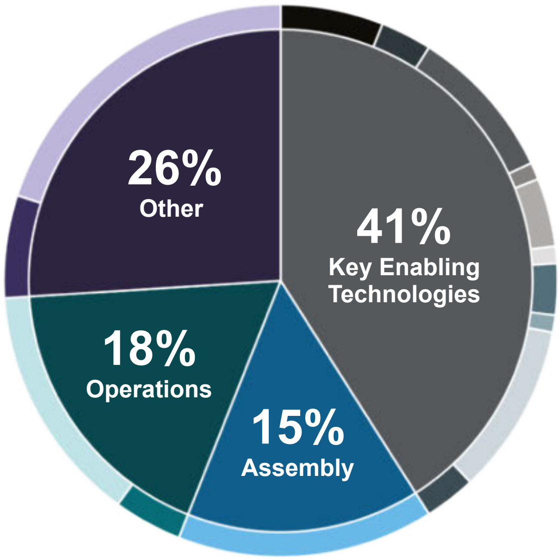
4.2.1 Organisations and Ecosystem

BryceTech analysis identified around 100 organisations providing AAM-related goods and services in the UK.

These organisations may operate in several areas of the value chain. However, each has been categorised based on the value chain segment that aligns with their most significant activity and product mix, as well as their SIC code designation. It is important to note that whilst the companies identified in this study are involved in the AAM industry, some may also be involved in non-AAM related activities.

Figure 4.3 evaluates the organisational count of the UK's AAM sector. Vehicle integrators represented the most common AAM subsector within the UK, with 15 organisations identified followed by vertiport operation with 14 organisations identified. In addition, 4 vehicle operators were identified. These three subsectors constitute 33% of the total AAM organisations in the UK. The remaining 67 were identified as enabling technology providers, ancillary services, or groups such as educational establishments, with organisations involved in air traffic management being the most common.

The UK currently has three indigenous passenger vehicle integrators, most notably, Vertical Aerospace, as well as multiple international vehicle manufacturers such as Joby and Volocopter targeting the UK as a key market. Additionally, the UK hosts several indigenous organisations producing cargo vehicles, such as Dronamics and Arc Aerosystems. While there are currently no operational vertiports in the UK, recent announcements have been made, including those from Urban-Air Port and Ferrovial, surrounding the possibility to build out vertiport networks, incorporating use of existing airports and airfields, as



Primary Value Chain Segment	Company Count
Key Enabling Technologies	
Vehicle Subsystems	
Propulsion Systems	6
Flight Computing and Avionics	3
Power and Energy Storage	9
Sensors and Instruments	1
Manufacturing, Materials and Structures	4
Guidance, Navigation and Control	1
Communications, Navigation and Air Traffic Management	
Communications and Navigation	3
Autonomous Systems	1
Air Traffic Management	10
Ground Infrastructure	
Ground, Test and Surface Systems	3
Assembly	
Vehicle Integration	15
Operations	
Vehicle Operation	4
Vertiport Operation	14
Other	
Ancillary Services	6
Other	20

Sources: BryceTech analysis.

Figure 4.3. Breakdown of UK AAM sector composition.

well as novel sites.[58] Additionally, Urban-Air Port, in partnership with Coventry City Council, conducted a vertiport technology demonstration in Coventry in 2022.[59]

4.2.2 Revenue and Employment

BryceTech analysis, based on an estimated percentage for AAM-related revenue and jobs on a company-by-company basis, shows that in 2021 the UK AAM sector employed around 1,200 individuals and generated £73 million in AAM-related revenue (derived from the provision of AAM goods or services). This figure is small compared to the UK's domestic civil aerospace industry (£26 billion).[60] However, it is important to note that the AAM sector is still emerging, and certified commercial passenger operations have not yet occurred. Additionally, commercial freight transport is still in its early stages.

4.3 Economic Impact

This section includes an economic impact analysis of the UK AAM sector on domestic GVA and employment, examines the UK position in a global context, and discusses private and public investment in AAM organisations.

Key Findings

GVA and Employment: UK organisations employed over 1,000 individuals, and contributed £32 million direct GVA impact in the 2021 financial year. The total estimated impact of the AAM sector in the UK in 2021 was approximately £78 million in GVA, and supported approximately 2,000 employees. GVA multipliers are comparable to values reported in the aviation sector in 2014, however lower for employment.

UK in a Global Context: The UK's current estimated market size is comparable to that of Japan and Germany, and larger than that of South Korea and France who have a similar sized market. Both the United States and China dominate in terms of relative market size.

Private and Public Investment: AAM continues to be a significant beneficiary of specific and non-specific public and private investment, however to date this has not translated into revenue. This is consistent with the emerging state of development of AAM commercial markets and service offerings. Significant open questions exist regarding companies' abilities to close their business cases absent of continued investment.

4.3.1 GVA and Employment

Economic multipliers allow the estimation of the total economic impact of the UK AAM sector on the national economy. The economic impact can be measured in terms of direct, indirect, and induced economic impacts and can be reported using Type I or Type II multipliers. Type I multipliers represent direct and indirect effects, and Type II represents the total impact of direct, indirect, and induced effects.

Direct impacts on the economy refer to the initial economic effects of a particular activity, whilst indirect and induced effects result from the knock-on effects of the activity. For example, organisations within the AAM sector provide an income to supplying industries. The suppliers use such income to purchase their inputs (a part of the indirect impact), whereas their employees, with their salaries, will purchase consumer goods within the economy (an induced effect). Thus, the indirect effects represent the value added and employment generated within the value chain that supports the AAM sector, while the induced effects refer to the additional economic activity that results from employee spending.

In this report, the total economic impact of the UK AAM sector has been estimated using input-output analytical tables (IOATs) published by the Office for National Statistics[61] to develop a series of multipliers.

The multipliers estimate the extent to which the AAM sector's direct output generates additional activity throughout the economy through indirect and induced effects. Indirect and induced employment effects were estimated using further data such as household spending and employee compensation. Further details on the methodology used throughout this analysis can be found in Appendix A1.

For the purposes of this study, the Type I and Type II multipliers in terms of GVA and employment are presented to indicate the total economic impact of the AAM sector on the economy in 2021. It should also be noted that input-output analysis does not take into consideration or quantify displacement effects. Although the sector may appear to currently have a small impact, it is an emerging industry that holds significant potential for future growth if current and future barriers to market development are overcome. For additional insight, see the Future Market Potential section for further information.

Results

The Type I GVA multiplier was estimated at 1.7. This figure implies that for each £1 of AAM sector GVA in 2021, an additional ~£0.70 of GVA was generated in the supply chain and supporting sectors. The sector's direct GVA of £32 million therefore produced an additional GDP contribution of £24

	Direct Impact	Type I Multiplier	Type I Impact	Type II Multiplier	Type II Impact
GVA	£32 million	1.7	£56 million	2.4	£78 million
Employment	1,210	1.3	1,625	1.6	1,970

Sources: BryceTech and Cambridge Econometrics Analysis.

Table 4.4. AAM sector impacts and multipliers, 2021.

Industry	GVA		Employment	
	Type I Multiplier	Type II Multiplier	Type I Multiplier	Type II Multiplier
AAM	1.7	2.4	1.3	1.6
Aviation	1.7	2.3	2.0	2.8

Sources: BryceTech and Cambridge Econometrics Analysis, Oxford Economics.[62]

Table 4.5. AAM and Aviation Economic Multipliers.

million to the UK economy through indirect effects. When factoring in induced effects, the Type II GVA multiplier, estimated at 2.4, indicates the indirect and induced impacts of the sector generated an additional ~£1.40 for each £1 of AAM sector GVA, contributing an additional £46 million to the UK economy. Therefore, the total estimated impact of the AAM sector in the UK in 2021 is approximately £78 million.

The Type I and Type II employment multipliers were estimated at 1.3 and 1.6, respectively. These imply that in addition to the approximately 1,200 people employed directly through AAM organisations, the sector generated indirect employment for around 400 people, and induced employment for nearly 350 people. Therefore, the total estimated employment supported by the AAM sector in the UK in 2021 is approximately 2,000 employees.

Comparison to Aviation

The AAM Type I and Type II GVA multipliers closely align with the values reported in a 2014 Oxford Economics analysis of the UK aviation industry, however AAM employment multipliers are lower. This indicates that the AAM industry currently supports fewer indirect and induced jobs per employee in the sector. However, it should be stressed that the AAM sector is still in its early stages, with current multipliers representing a snapshot. It is very likely these values will change as the sector develops. It is important to note that the aviation multiplier provided here does not incorporate the catalytic effects from tourism, as outlined in the Oxford analysis, in order to ensure a more accurate and representative comparison.

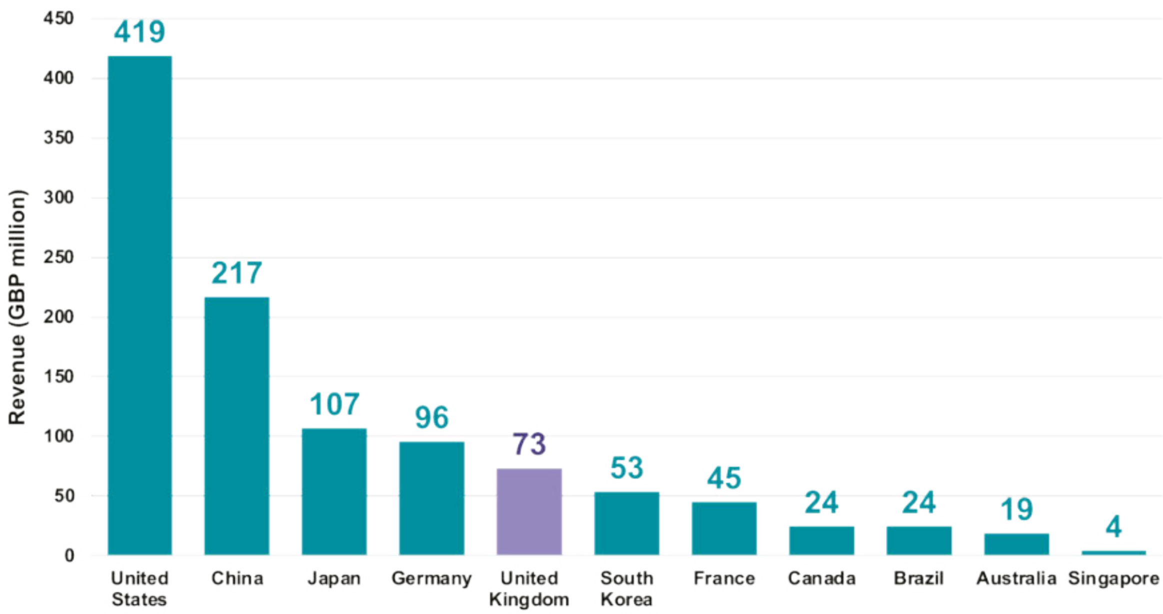
4.3.2 The UK Sector in a Global Context

BryceTech conducted a comparative assessment of UK revenue and employment with 10 countries deemed to be amongst the global leaders for AAM, defined by domestic vehicle and technology manufacturing activities, regulatory innovation, or future market potential based on available literature. These countries were the United States, China, Japan, Germany, South Korea, France, Brazil, Canada, Australia, and Singapore.

The size of these countries' AAM vehicle manufacturing and gross manufacturing activities, and the number of firms participating in these industries, were selected as proxies to estimate their market share relative to the other countries. The manufacturing industry allows for the closest approximation to future development due to similarities with the AAM industry, including utilising similar processes, tooling in some cases, and supply chains and OEMs. To estimate the AAM market size for each country, the segmentation of market share based on the selected proxies was then combined with UK AAM market revenue, employee, and company count data.

This assessment comprises a top-down approach, driven by the inherent cost and logistical constraints to comprehensively review the global market, and therefore represents a high-level comparative assessment. Additionally, the start-up and formative nature of the AAM sector at present results in considerable uncertainty, and includes a lack of clarity on regulations related to AAM, hesitation by some funders to participate further or at all, and other factors related to the supply chain and intellectual property, amongst others. Further, the UK may not represent the optimal reference point to extrapolate other countries, given likely differences in economic profiles, industrial makeup, labour and capital costs, and other variables. This, as well as the nascent nature of the sector introduces considerable uncertainty into the absolute scale of by-country sector sizes beyond the UK. However, across potential ranges and other proxies explored by BryceTech, the relative positions of other counties changed comparatively little. Therefore, this approach provides a useful overall picture of an emerging sector with a few leading players and the rest of the market on fairly equal footing, with competitive dynamics yet to play out to their conclusion.

However, it is believed that the UK provides a suitable and consistent method for estimating several factors. The UK shares a developed path of automotive, aerospace, aircraft, satellite (hardware), advanced technology, and general manufacturing history with the countries selected. As such, it reflects similar investment approaches, issues encountered in start-



	United States	China	Japan	Germany	United Kingdom	South Korea	France	Canada	Brazil	Australia	Singapore
Companies	573	296	146	131	100	73	61	33	33	25	5
Employees	9,930	3,582	1,768	1,585	1,210	881	739	405	403	307	64

Source: BryceTech analysis.

Figure 4.6. Comparative assessment of AAM sector size, by revenue, of leading AAM nations, 2021, GBP million.

up stages of complex manufacturing, labour demand (especially with skilled labour in niche manufacturing), and finally, government support and assistance in the development of these sectors. Taking all factors into consideration, the above approach was deemed the most objective, in the absence of additional data, with the constraints of a lack of in-country primary research, and given the formative stage of the AAM sector.

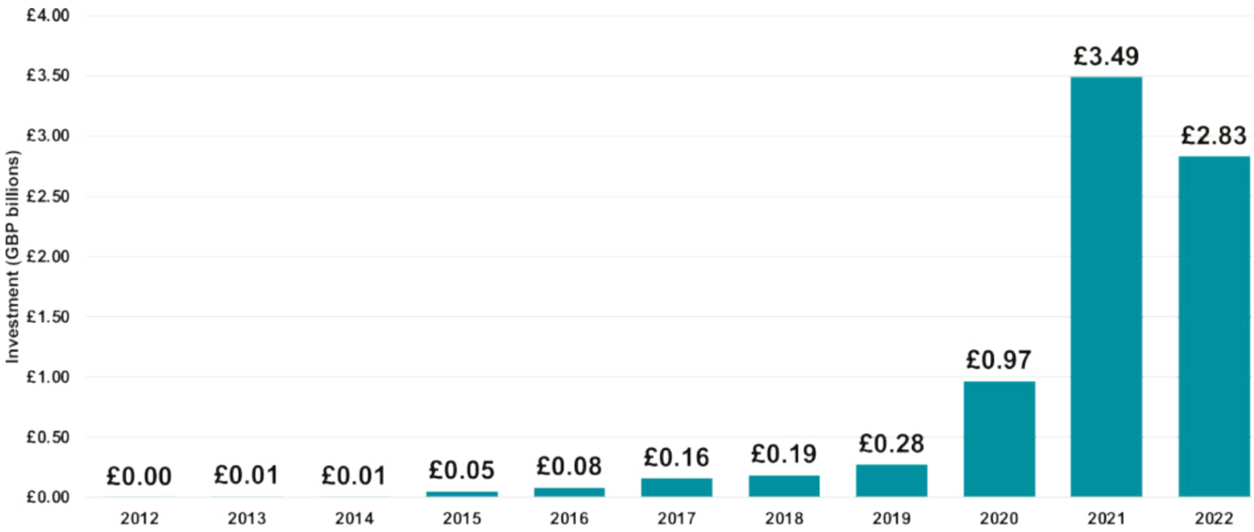
This assessment finds that the UK's current market size is likely comparable to that of Japan and Germany, and larger than that of South Korea and France who have similar sized markets. However, both the United States and People's Republic of China dominate in terms of relative market size, around 6x and 3x of UK revenue respectively. This is unsurprising, given the considerable number of vehicle manufacturers in each country, their respective large consumer markets, and the considerable testing of passenger vehicles and roll-out of drone delivery programmes that has already occurred in the People's Republic of China. Given the considerably novel state of the sector, some of these indicative results will change over time. The competitive landscape of the AAM sector may therefore shift as time goes on.

4.3.3 Private and Public Investment

This section discusses private and public investment in AAM organisations. For the purposes of this study, private investment was defined as any external investment by a private entity e.g., venture capital, private equity etc., and did not include internal private investment by individual companies. Public investment (not to be confused with initial public offerings), were defined as investments, contracts or grants from government entities to the private sector, in order to support the development of AAM. AAM service and product providers have received substantial private investment from venture capital firms and have raised money through initial public offering (IPO). In addition, organisations have received public investment through government funded activities. Although the companies identified in this study are involved in the AAM industry, it is important to note that some of these companies may also be involved in non-AAM related activities. Therefore, the investment made in these companies may not necessarily be related to AAM.

Private Investment

Private investment, which includes venture capital, private equity, debt, and post-IPO financing, into AAM related companies in BryceTech's database, totalled £8.1 billion between 2012 and 2022, with the UK accounting for approximately 5% of private investment in 2022. The most significant growth occurred between 2016 and 2021 when investment grew from £84 million to £3.5 billion. However, after 2021, investment dropped off, falling by 19%. Investments are irregularly distributed over time due to the nature of private investment cycles and the organisations involved. Early stage companies will raise funding on a semi-regular basis, with intervening gaps, meaning funding will not be observed on an annual basis. Small-medium sized enterprises, as well as well-established corporates, will fund activities through internal investment or other funding means (e.g., debt financing), which was not captured.



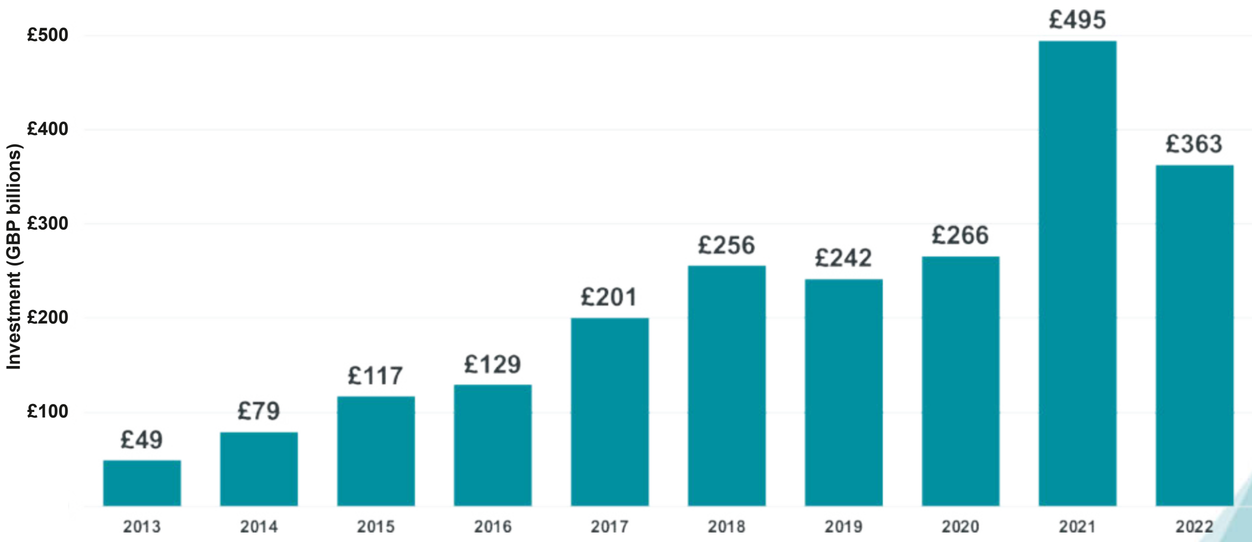
Source: BryceTech AAM database, Crunchbase.

Figure 4.7. Private investment into AAM-related companies, 2012 – 2022, GBP billion.

This trend may be a reflection of broader global macroeconomic trends in capital markets. More than £2 billion was privately invested in the global AAM ecosystem in 2022 in the midst of a global economic downturn, which saw reduced venture funding across all industries. Major economies, including the UK, broadly witnessed significant growth in 2021, driven by the resurgence of economic activity following the impact of COVID-19 in 2020. In 2022 the global economy experienced a slowdown, with the IMF estimating that global GDP growth fell from 6% in 2021 to just 3.2% in 2022. As can be seen in Figure 4.8, global venture investment similarly surged between 2016 and 2021, subsequently falling by 27% between 2021 and 2022.

Public Investment

Public investments made by government bodies also play a critical role in funding AAM research and development. Table 4.9 presents a non-exhaustive summary of the most notable or prominent public sector financial activities of governments



Source: Crunchbase.

Figure 4.8. Global venture investment, 2013 – 2022, GBP billion.

Country	Government Agency	Nominal Spending Volume	Details
United Kingdom	UK Research and Innovation (UKRI), Department for Science, Innovation and Technology (DSIT) (formerly Department for Business, Energy and Industrial Strategy (BEIS))	£125M	30/09/2019: UKRI announce **£125M** of government-industry funding to be shared by projects focusing on developing air transport systems and enabling new vehicle technologies through the Future Flight Challenge. The challenge is a single challenge running from 2019 to 2024, with three funding phases. Amongst other grants under the programme, the UK's Advanced Mobility Ecosystem Consortium were awarded **£9.5M** to demonstrate the feasibility of AAM in the UK.[63] Approximately £40 million of the released funding is estimated to have been awarded to AAM-related projects.
	UKRI, DSIT (formerly BEIS)	£685M*	29/03/2022: The Aerospace Technology Institute (ATI) Programme is renewed to receive an increase of over 50% in government funding, with **£685M** allocated over the next 3 years. This programme's scope ranges across the aerospace industry, with the objective of supporting the development of zero-carbon and ultra-low-emission aircraft technology. The ATI delivers a **£3.2B** industry-match funded programme, including **£1.6B** grants awarded to UK organisations across 343 projects.[64]
United States	U.S. House of Representatives	£20M	14/06/2022: The house passed the Advanced Aviation Infrastructure Modernization (AAIM) Act on June 14 that aims to provide **$25M** in grants over two years to plan and build vertiport infrastructure for AAM and future eVTOL operations (pending federal approval).[65]
	U.S. Air Force	>£78M	04/2020: The USAF AFWERX Agility Prime program seeks to develop and accelerate the commercial market for AAM. With over **$100M** awarded, the program works with industry on testing and experimentation, accelerating the development of the commercial eVTOL industry.[66]
Canada	Canadian Advanced Air Mobility Consortium (CAAM)	£1M	04/2021: CAAM launched a **C$1.75M** regional project in British Columbia to launch a revenue generating proof of concept flight. The objective was to complete in stages using an RPAS on an alternate route before larger aircraft were used.[67]
	Strategic Innovation Fund (SIF)	£29M	16/04/2018: The government of Canada invested **C$49.5M** in Bell Textron Canada through the SIF, for the development of "next generation vertical lift aircraft and novel unmanned aerial systems technologies."[68]
Brazil	Brazil's National Development Bank (BNDES)	£75M	23/12/2022 Eve Air Mobility announced approval by the executive board of BNDES to support Eve's eVTOL development efforts with two distinct credit lines, totalling **$92.5M**. Both credit lines are expected to offer beneficial terms and conditions to Eve with a 12-year maturity and amortization grace period.[69]
China	Qingdoa West Coast New Area	£17M	23/12/2022: The People's Republic of China-based AAM aircraft manufacturer EHang strikes investment deal worth up to **$20M** with a Chinese state-backed urban and economic development zone. The deal with the Shandong Province's QWCNA involves a binding **$10M** capital stake in the company and an option for another **$10M** purchase in the future.[70]
Japan	Tokyo Ministry of Finance (via Development Bank of Japan)	£28M	08/2020: Development Bank of Japan (owned by Tokyo's Ministry of Finance) participated in SkyDrive's **¥3.9B (£28M)** Series B fundraising drive.[71]
Germany	Federal Ministry for Digital Affairs and Transport	£13M	30/09/2022: Innovative Air Mobility funding guideline, under the Federal Ministry for Transport and Digital Infrastructure (BMDV), will provide a total of **€15M** for AAM projects until 2023. Funding issued includes support for AMI-FlyingIN2Air, part of the Air Mobility Initiative (AMI) funded by the Free State of Bavaria and the Federal Republic of Germany, which aims to promote the development of electric air transport.[72]
	Ministry for Economic Cooperation and Development	£21M*	22/05/2020: The German Ministry for Economic Cooperation and Development (BMZ) hosted a **€24M** hackathon which solicited innovative digital solutions to tackle the challenges caused by the coronavirus outbreak in low- and middle-income countries. An autonomous delivery drone company named Wingcopter was named one of nine winners and received up to **€3M (£2.67M)** in government funding.[73]
France	Ministry of Higher Education, Research and Innovation	£19M	04/06/2020: The Minister of Higher Education, Research and Innovation announced that **€21M** would be mobilised for the Institute for Energy Transition Vedecom in 2021 and 2022 with the objective of supporting technological innovation and French industrial sectors working on the mobility of the future.[74]

Source: BryceTech analysis. Currency values converted to GBP using average annual exchange rates. Exchange Rates UK. Available Online: http://exchangerates.org.uk/.

Table 4.9. Public sector financial activities in the AAM market (non-exhaustive).

"Going into financing right now in such an environment is the challenge…you're in the famous valley of death. You're not early stage anymore, you're pre-revenue…and this in combination with these uncertainties that people don't understand the certification pathway is the stress factor to the industry."

– Dirk Hoke, Volocopter CEO
European Business Aviation Convention & Exhibition (EBACE), May 2023

in the AAM market, this includes grant awards, procurement, contract awards, direct investment, and credit facilities. Investment pathways vary significantly between countries. The United States and European countries such as France and Germany have primarily deployed large industry wide funding projects, whilst Brazil, Japan, and the People's Republic of China funded individual AAM companies through wholly or partially state-owned investment institutions. Broad industry investments often split their funding between AAM and other related sectors, in these cases an exact AAM spending volume is not necessarily obtainable and such entries are marked with an asterisk (*).

In a UK context, AAM has been a clear beneficiary of the significant public investment made into future aerospace technologies and market development by initiatives such as the FFC and the ATI (Aerospace Technology Institute) programme. These funding programmes are broad in scope, supporting the development of solutions to a range of challenges, with many clearly aligned to the ATI technology strategy Destination Zero,[75] which focuses on zero-carbon emission, ultra-efficient, and cross-cutting enabling technologies. As such, AAM has at times been a direct recipient of funding (e.g., ATI's "Initial Demonstration Platforms," 2020-2022; £11.88 million grant; lead partner Vertical Aerospace Group; development of demonstration platforms for a high-performance VTOL Urban Air Taxi[76,77]). In many cases, AAM may benefit from non-application-specific funding of enabling future technologies more generally. For example, a survey of experts by the US Department of Energy (DOE) states that eVTOL and "short-range consumer aircraft usage cases [are] opportunities that are benefiting from electric vehicle (EV) battery R&D and commercial deployment."[78]

Whilst AAM has and continues to be a significant beneficiary of this specific and non-specific public and private investment, to date, this has not translated into revenue. This is consistent with the emerging state of development of AAM commercial markets and service offerings—with no passenger vehicles operational, and a few last mile logistics operations only beginning to emerge operationally internationally. As a result, there are significant open questions regarding companies' abilities to close their business cases absent of continued investment.

4.4 Social Impact

The following section considers the social impacts of AAM and its enabling technologies. Existing evidence has been reviewed and summarised to assess the impacts on passengers, the environment, and wider society.

4.4.1 Passenger Impact

Key Findings

Price: Multiple studies and analyses estimate AAM pricing based on varying assumptions, business models, and geographic areas. Price per passenger km varies across multiple sources; however, it is likely that AAM pricing will be lower than current helicopter pricing and higher than current ride-share options. Prices are expected to fall over the longer term due to reduced operating costs, and potentially remote or autonomous operations.

Time Savings: It is estimated that in both urban and rural settings, AAM can offer time savings benefits,[79] with factors including road congestion, travel time to vertiports, boarding time, and travel distance all impact the amount of time saved.[80]

Safety: Comprehensive safety data for AAM passenger vehicles is not currently available. However, if AAM passenger vehicles are held to the same standards as commercial aviation, their introduction could indicate a net increase in passenger safety if meaningful passenger volumes switch from ground based transport options to AAM alternatives.[81]

Price

To allow for comparisons with alternative modes of transport, and across geographies, values are presented for price per passenger/seat kilometre based on the announced or speculated pricing by AAM providers and industry analysts. However, it is important to note that reported pricing is highly variable and varies on a number of factors such as location, vehicle cost, capacity, ride sharing, and more. For example, McKinsey & Co (2018), as part of a NASA study, estimate the cost of an air taxi trip (to the operator) could range anywhere from between $91 to $3,126 per trip (£68 to £2,345). Variables such as vertiport density and annual running costs significantly impacting the overall cost, and therefore the profitable price level, of running such a service.[82] Therefore, given the differences in base pricing, and the nature of services and location, the values provided are indicative of price ranges but are not necessarily conducive to comparisons.

The estimated end user price per passenger/seat kilometre ranges significantly across studies, from £0.64 to £5.12. However, it is worth noting that these values reflect the expected pricing of both initial and longer-term services, with expectations that as the industry matures a lower price point will be realised. The driving factors behind this include advancements in manufacturing and autonomy affecting both fixed and variable costs.[83] Table 4.10 provides an overview of the price per passenger/seat kilometre values reported across the industry or based on calculations of reported trip costs.

By 2035, PwC find that despite economies of scale, decreased operating costs, and autonomous operations, urban private

Source	Nominal Price Per Passenger/Seat Per Kilometre
Vertical Aerospace (2021)[84]	£0.64 – £0.77
Lilium[85] (2020)	£0.74 – £0.87
Uber Elevate[86] (now Joby Aviation) (2018)	£0.86 – £2.67
Lilium[87] (2021*)	£1.02
Archer[88] (2021*)	£1.49
Eve[89] (2021*)	£2.59 – £2.82
NASA[90,91] (2018)	£2.91 – £5.12

Source: Refer to table endnotes. Prices converted to GBP/km using average exchange for year presented
Note*: Prices calculated using exchange rate for articles year of publication.

Table 4.10. AAM price per passenger/seat per kilometre overview.

hire use cases will be unable to achieve lower journey prices when compared to traditional taxi services, and are expected to be 22% higher.[92] This implies that "mass market take-up is unlikely," and that the "takeup demographic is more likely to be individuals who place a higher value on time and a lower value on monetary cost/fares." Furthermore, PwC report similar findings with the rural private hire use case in 2035, with an eVTOL journey expected to cost 55% more than the same journey. However, when rideshare alternatives replacing three individual journeys are considered, by 2035 both the urban and rural use cases show cost savings of 31% and 18% respectively. Similarly, Deloitte suggest that the AAM price/seat for a 40-km trip will be cheaper than that of a premium taxi (£54 vs. £75.90; £1.35 vs. £1.89 per km) and provide a significant time-savings.[93]

Fixed price offerings may be suitable for point-to-point travel in the few cases where there are no existing transfer options or for destinations with a higher level of demand certainty, such as going from a downtown vertiport to the local airport. Since many cities have airports located outside of urban centres, UAM may offer significant time-saving opportunities for passengers willing to pay a premium, especially in cases where traditional journeys would require lengthy journeys via car or public transport. Cases such as these have been extensively examined by service providers. Volocopter has aims to price a seat at $80-90 (£62–70; [£3.48 per km]) for a ride from JFK to downtown Manhattan, similar to the price of a premium taxi.[94] The Korean Ministry of Land, Transport, and Infrastructure (MOLIT) suggests a trip from Incheon Airport to Seoul is expected to cost ₩110,000 (£68; [£1.43 per km]) in 2025 and will drop to ₩20,000 (£12; [£0.25 per km]) after 2030.[95]

Lilium (2020)[96] and Vertical Aerospace (2021)[97] have provided indicative prices

Journey	Price Range	Source
Point-to-Point Routes		
Palo Alto – Downtown San Francisco	$50 (£39) [~£0.87/km]	Lilium
Palo Alto – Hayward	$25 (£19) [~£0.74/km]	Lilium
Palo Alto – San Rafael	$70 (£55) [~£0.79/km]	Lilium
Palo Alto – Lake Tahoe	$250 (£195) [~£0.75/km]	Lilium
Belfast – Glasgow	£127 [~£0.77/km]	Vertical Aerospace
Liverpool – Hull	£112 [~£0.64/km]	Vertical Aerospace
Plymouth – Cardiff	£89 [~£0.64/km]	Vertical Aerospace
Cambridge – Heathrow Airport	£58 [~£0.64/km]	Vertical Aerospace
Edinburgh – Aberdeen	£94 [~£0.64/km]	Vertical Aerospace
Airport Transfers		
JFK – Downtown New York City	$80-90 (£62-70) [~£3.20/km]	Volocopter
Incheon Airport – Seoul	₩20,000 – ₩110,000 (£12 – £68) [£0.25 – £1.43/km]	MOLIT

Source Lilium,[98] Vertical Aerospace,[99] Volocopter,[100] and MOLIT.[101]

Table 4.11. Summary of scenario prices.

for notional services between locations. Based on the distances between locations, these services indicate the price per passenger ranges between £0.62 and £0.79 per kilometre. The trips proposed show potential use cases for regional transportation and connectivity between key destinations outside urban centres. These locations currently have sizeable populations and demand for travel, however lack transportation options that are direct, high-speed, and on-demand.

While price offerings fluctuate and are highly dependant upon use case, to stay competitive it is likely that initial UAM services will be priced lower than limos or helicopters on a price per passenger basis, but higher than rideshare and taxis alternatives. As technology matures, and operating costs decrease, prices are expected to fall.

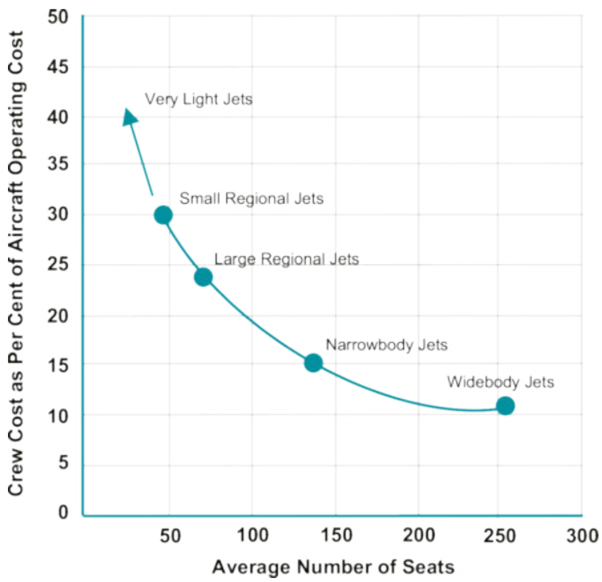
Transport Option	Price Per Passenger/ Seat Per Kilometre
Rideshare	£0.68
Taxi	£1.36
Limo	£5.19
Helicopter	£4.06 - £13.98

Source: Booz Allen Hamilton.[102]

Table 4.12. Price per kilometre for alternative transportation options.

Implications of Automation on Price

AAM operators generally anticipate single-pilot or fully autonomous designs for their vehicles. Air taxi companies such as Wisk have advocated for autonomous designs, arguing that procedures such as consulting manuals and checklists can be automated.[103] Wisk further states that fully autonomous vehicles are more responsive than a remote or a less experienced pilot. Since training eVTOL pilots is estimated to be a high-cost factor, eVTOL manufacturers are incentivised to reduce the need for pilots. Further, McKinsey (2020) suggests that it is uncertain whether aviation pilots have transferable skills to eVTOL operations, implying additional costs for the training or retraining of eVTOL pilots,[104] and estimates that it could take more than $4 billion (£3.12 billion) to train 60,000 new UAM pilots.[105] Moreover, the impact on employment through future automation of AAM operations is uncertain. Given the opportunity to improve margins, companies such as Lilium are also considering autonomous concepts.



Source: NASA ARC.[106]

Figure 4.13. Crew cost decreases as number of seats increases.

NASA ARC[107] shows that crew cost is as high as 40% of aircraft operating cost for very light jets, with this percentage decreasing as the number of seats on the aircraft increases. McKinsey models indicate that the cost per passenger-seat-km of a piloted UAM passenger vehicle may be twice that of an autonomous vehicle.[108] Joby Aviation, whose estimated revenue per available seat km is $1.07 (£0.87),[109] suggest the pilot costs about 26% of the total costs per available seat mile.[110] A piloted vehicle designed to carry five persons, would have at least 20% of the seats available occupied by crew. Therefore, removing the pilot could lead to higher revenue per ride and cut up to 23% of total eVTOL operating costs.[111] Due to the substantial proportion of vehicle operating costs associated to crew, reducing eVTOL crew numbers is an economically attractive opportunity.

Time Savings

AAM passenger use cases often seek to reduce travel time. The monetary value of time saved time can be estimated based on personal earnings, and therefore varies across end users. In addition, a 2023 PwC study found that factors including road congestion, travel time to vertiports, boarding time, and travel distance can all impact the amount of time saved when using AAM compared to traditional alternatives.[112]

PwC finds that urban and rural air taxi use cases both "present time saving benefits," leading to lower time related costs compared to business as usual.[113] EASA provides an example that during a rush hour, an AAM city to airport transfer in Paris could be "2 to 4 times faster" compared to a car journey taken at the same time. Time savings for the transportation of vital organs and emergency services may create a compelling AAM business case. EASA[114] suggests that delivery of medical equipment can be "73% faster by drone than by ambulance [..] during rush hour."

However, accurate comparison and evaluation for time-saving potential may depend on vertiport density. McKinsey & Co suggests that a higher concentration of vertiports in urban areas could lead to greater potential time savings.[115] Their report suggests that in a low density vertiport scenario, where vertiports are a 15-minute drive away, a 64 km journey would take a total of 60 minutes to complete. By comparison, in a high vertiport density scenario where vertiports are 2-5 minutes away, the same journey would take approximately 30 minutes, or 90 minutes without the use of AAM.[116]

A NASA-sponsored study[117] also suggests that since AAM vehicles are faster (100 mph compared to a car speed of 30 mph for intra-metro trips), AAM could "reduce travel time by 50% or more." A UKRI and EAMaven Report suggests that for 20 routes addressing both the UK governments "levelling up and northern powerhouse agendas," as well as the Union Connectivity Review, AAM could save up to ~89,000 hours a week for road and public transport users, with an average of 2.4 hours saved per journey.[118] Rothfield et al. (2021) assess the effect that operational parameters such as cruise flight speed, vertiport density, and processing time can have on overall travel time. Their findings indicate that when factoring in these parameters across the three cities included in their study, UAM demonstrate time saving benefits for journeys beyond the equivalent of a 50-55 minute car journey.[119]

The DfT value of travel time saving (VTTS) reflects "the amount of money a traveller is willing to pay to save time" and the benefit a traveller would receive from being able to put 'saved' time to alternative uses following a transport investment."[120] According to Mayakonda et al. (2020),[121] the VTTS is the value an individual would place on time saved. This metric can therefore be used to measure the benefits of different modes of transport. The VTTS is considered as the value per unit time as a function of the income of the traveller and trip purpose, and ranges between "35% and 60% of earnings per unit time for personal trips," and "80% to 120% for business trips." This value is factored into a calculation of a traveller's willingness to pay (WTP) and can be used to indicate whether a traveller would choose one transportation method, e.g., AAM, over other modes of transit. DfT transport analysis guidance places the market price of the average value of working individuals' time by mode at approximately £28 per person per hour.[122] Mayakonda et al. present an example scenario where a time saving of 40 minutes, utilising a VTTS of £0.78/min, and factoring in the price of a £3.90 public transport ticket, would equate to a WTP of approximately £35. Assuming therefore that a AAM trip costs less than the WTP, passengers would be willing to choose AAM as a viable alternative.

Safety

NASA's NTRS study found safety to be a top priority, as "passengers are not receptive to accepting a new transportation mode until their perception of safety satisfies a high standard."[123] An EASA study states "safety concerns come first," but the public would be "reassured if [commercial aviation standards] levels were applied for UAM," which would make AAM approximately "1,500 times safer" on a passenger-kilometre basis compared to road transport data.[124] It is important to note that the degree of increased safety may vary across regions due to significant differences in road safety worldwide. For reference, the EU aviation level of safety in 2018 was 0.01 fatalities per billion passenger kilometres.[125] Additionally, EASA's study methodology highlighted different scales for measuring the safety of UAM services vs drones, as UAM pose a risk to both passengers and pedestrians.

Drone rules within the UK

Within the UK, the rules regarding the operation of drones fall into three categories:[126]

Open: low risk, light weight drones

Specific: higher risk, may use heavier drones

Certified: large drones required to meet specific safety certficiations similar to aircraft

In the 2022 UK DfT Transport and Transport Technology Public Attitudes Tracker, 58% of participants identified "collision, crashes or accidents" as a disadvantage of UAM vehicles, 43% indicated thoughts such as the "technology is still unproven," and 34% highlighted concerns over the "vulnerability to hacking or terrorism."[127] Notably, when compared to self-driving road vehicles, despite a significantly increased awareness of these vehicles, an increased number of respondents (68%) identified the "technology is still unproven" category.

A 2021 survey by EASA found that 44% of participants highlighted safety in their top three concerns regarding drone use, with 22% ranking it as their top concern.[128] As a pedestrian, 70% respondents indicated they would accept crewed UAM vehicles flying above their heads, however only 44% accepted unmanned vehicles. By comparison, 56% responded they would feel safe with unmanned delivery drones, indicating that as a pedestrian, the public would feel safer with a crewed UAM vehicle flying above them than a delivery drone. The perception of UAS is measured since people already have some knowledge of drones flying in cities. Therefore, the concern of overhead safety with regards to drones is more immediate, whereas there is more uncertainty in terms of comfort for new technologies like UAM. Furthermore, the report outlines how safety standards can change public perception; if UAM services were as safe for passengers and pedestrians as a commercial aircraft (~0.01 fatalities per billion passenger kilometres), public acceptance would increase by nearly 33% compared to a safety standard similar to that of motorcycles (~5 fatalities per billion passenger kilometres).

These findings show that safety concerns are a key factor to public adoption of AAM and that AAM has the potential to be safer than road transportation. According to DfT transport analysis guidance, the average value of preventing a fatal road casualty in the UK is approximately £2.5 million. Should a proportion of road users therefore switch to AAM passenger transport, this could result in substantial socioeconomic benefit.[129] However, there is uncertainty about how AAM safety levels will compare to regional and commercial passenger aviation. Therefore, to gain public trust and eventual adoption, it is important to ensure and maintain high safety standards throughout UAM operations.

4.4.2 Environmental Impact

A general indication of environmental benefits and disbenefits of AAM operations was achieved by evaluating metrics including noise, greenhouse gas emission, and energy usage. While there are other important metrics to consider, such as land usage and ecological impact, these specific metrics were chosen due to the nascent state of the industry and the uncertainty surrounding the scale of future operations.

Key Findings

Noise: AAM vehicles are designed to minimise noise and be quieter than traditional vehicles. However, further studies are required to evaluate the noise impacts of scaled operations, and whether community tolerance of noise levels will impact AAM business cases.

Greenhouse Gases: AAM has the potential to reduce greenhouse gas emissions, however impacts are highly dependant upon a number of variables including use case, journey length, substituted transport options, and the energy mix of the grid power supply used to charge batteries.

Energy Usage: Factors including vehicle design, flight profiles, vehicle utilisation, and weather can significantly influence energy usage and consumption.

These metrics therefore address the potential environmental impacts of AAM vehicle usage. This evaluation utilised openly available research from academic and commercial sources, with impacts compared against data on the environmental impacts of conventional transport modes.

Noise

Noise is considered by many to be a critical factor when considering AAM impacts. Many AAM vehicles are being designed to be far quieter than traditional aircraft such as helicopters or light aircraft. This will be critical to achieve for widespread operations, as noise is particularly important for public acceptance. In the UK, 38% of UK DfT Transport and Transport Technology Public Attitudes Tracker survey participants identified noise pollution as a potential disadvantage of AAM operations.[130]

There are multiple ways to measure noise, one of which is the A-weighted integrated maximum sound level a vehicle produces at a certain distance: $L_{A,max}$. A white paper by Uber Elevate recommends that AAM vehicles should aim to achieve noise levels "half as loud as a medium-sized truck passing a house," equating to a noise level of 67dB$L_{A,max}$ at 75 m above ground, or 62dB$L_{A,max}$ at 150 m. If achieved, this study also notes AAM vehicles would be one-fourth "as loud as the smallest four-seat helicopter on the market."[131] The World Health Organisation (WHO) recommends that noise levels outside a bedroom, with the window open, should not exceed 60 dB$L_{A,max}$, and that commercial shopping and traffic areas (indoors and outdoors) should not exceed 110 dB$L_{A,max}$.[132]

Currently available data for AAM passenger vehicles indicates they will likely meet these criteria, at least for overhead flight. A joint study by Joby and NASA, testing Joby's passenger vehicle, finds that an observer would experience 45 dB ($L_{A,max}$) during overhead flight at 500 m.[133] Vertical Aerospace also reports 45 dB for overhead flight in an SEC filing,[134] however it is unclear if this is using the A-weighted scale which adjusts noise measurements to account for the sensitivity of the human ear. At take off and landing, Joby's vehicle did not produce noise exceeding 65 dB (LA,max) during tests for an observer at 100 m. Despite these findings, a multi-university report sponsored by the FAA which reviews existing noise literature and testing notes that "With the novelty of UAM configurations, few studies are publicly available on full-scale vehicle noise tests."

A 2023 CAA report also summarises literature around AAM noise found different studies mention the need for further research into the health effects of drone noise and unified metrics of acceptable noise levels. This report further noted that a 2021 EASA study highlighted the need for detailed exposure-response curves as seen in aircraft noise research. Furthermore, various studies note that individuals generally find the noise produced by small electric propeller aircraft as more annoying than helicopter noises, given the high-frequency broadband noise produced by such systems.[135] This highlights the need, as also noted in other studies, to not only consider volume of these vehicles, but also other metrics such as pitch and timbre, when making impact assessments and determining flyover and take-off and landing requirements.[136]

Whilst some metrics measure community acceptance, further studies are needed to evaluate noise impacts on scaled UAM operations. NASA suggested that the effectiveness of noise certification-based metrics "as predictors of annoyance to long-term UAM vehicle noise exposure is unknown." While survey respondents in a NASA study seem sceptical of AAM noise levels, this could be due to survey participants' associating AAM services with traditional helicopters.[137]

In addition, future studies should consider whether community tolerance of noise levels can have an impact on the success of AAM business cases. As vertiports become integrated into urban environments, noise acceptance levels may require additional infrastructure investments in the form of soundproofing to support AAM viability, further increasing AAM development costs.

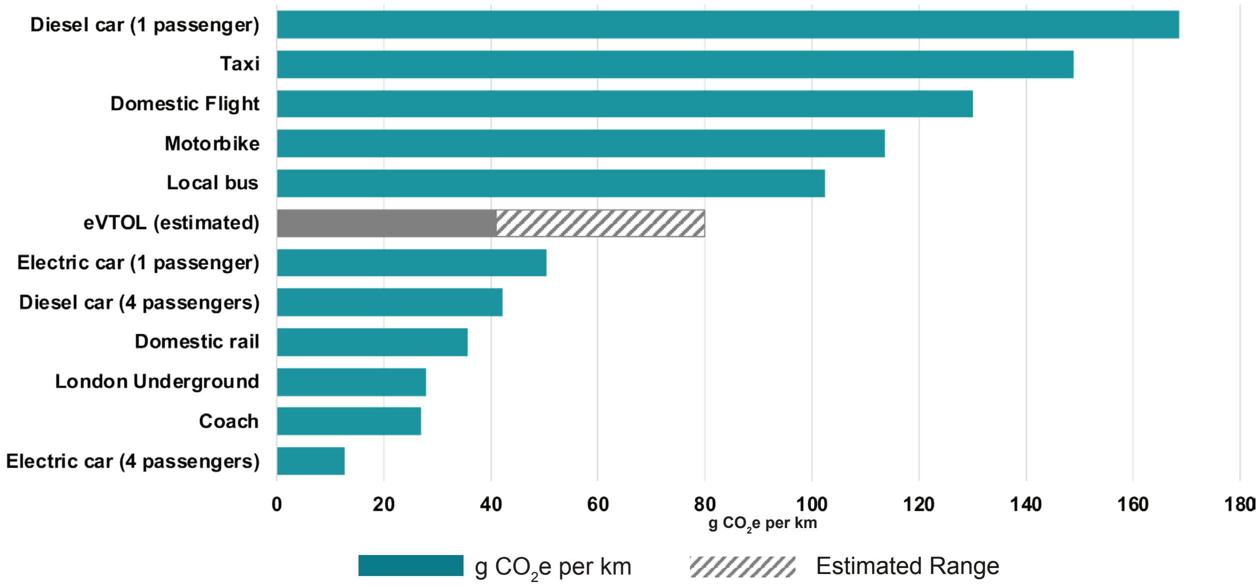
Greenhouse Gases

Electrically powered AAM vehicles claim to produce zero tailpipe emissions. However, greenhouse gas emissions associated with these vehicles depend on the energy sources used to charge their batteries through the grid power supply. Therefore, as the energy mix of the grid power supply becomes more sustainable, the environmental impacts of electrically powered AAM vehicles are reduced. Comparatively, non-electric AAM vehicles use a mix of hydrogen, hybrid and sustainable aviation fuel (SAF) power sources, each of which have varying emissions profiles and are not dependent on the grid in the same way. CO_2 equivalent (CO_2e) emissions in kg per km per passenger allows for a like-for-like comparison between multiple power source types to conventional transport values.

Studies by Canadian Advanced Air Mobility Consortium[138] and EASA[139] suggest that AAM electric vehicles may have almost zero emissions and be more environmentally friendly than other modes of transport. Vertical Aerospace's VX-4 vehicle claims to be "zero-emission" which would lead to a "lighter environmental impact than any existing form of air travel" and would produce no more than a fifth of the emissions generated by a comparable helicopter, even if the grid were supplied by a coal power station.[140]

The Canadian AAM Consortium and NEXA Advisors suggest that AAM clean electric and hydrogen fuel cell technology can support "decarbonizing over time" as part of zero-emission aviation.[141] CAAM suggests that AAM as an alternative delivery mode may reduce the environmental impacts of truck exhausts in neighbourhoods and "eliminate other pollutants" such as nitrous oxides and unburnt fuel.[142] EASA suggests that local emissions associated with UAM may be "almost zero" if vehicles used battery electric propulsion systems, and that there could be a 100% reduction of local emissions for electric propulsion when compared to a helicopter with conventional kerosene propulsion.[143]

Vertical Aerospace suggests their VX-4 vehicle has the potential to significantly reduce carbon emissions when compared to other modes of transportation.[144] Vertical's 2021 white paper indicates that by 2025, the carbon intensity per kilometre (i.e., the carbon equivalent emissions per kilometre) for eVTOLs based on the UK



Source: Vertical Aerospace, BEIS.
Vertical assume a 113 km journey and a 68% load factor. Other transport mode data is sourced from BEIS Greenhouse Gas Reporting: Conversion Factors 2021. Note: eVTOL carbon intensity values estimated from graphic presented in Vertical Aerospace white paper. Estimated range reflects uncertainty in conversion of graphic.

Figure 4.14. Estimated carbon intensity by transport mode.

energy grid, is estimated to be between approximately 40 and 80 g CO_2e/km. When compared to other modes of transport, utilising data provided in the 2021 BEIS greenhouse gas reporting conversion factors,[145] eVTOLs demonstrate potential carbon intensity benefits over local buses, motorbikes, domestic flights, and single-occupant diesel vehicles. By comparison, coaches, domestic rail, and the London Underground have a lower impact, with less than 40 g CO_2e/km.

However, it is important to note that these values indicate emissions on per km basis and do not take into account the potential benefits of shorter point to point journeys made possible by AAM. Vertical further reports that for trips between Belfast and Glasgow, and Cardiff to Plymouth, eVTOLs have the lowest overall emissions (<10 kg CO_2e per passenger) compared to other modes (EV, motorbike, diesel car, domestic flight). For trips between Aberdeen – Edinburgh, Cambridge – Heathrow, and Liverpool – Hull, eVTOLs have the second lowest emissions (<10 kg CO_2e per passenger), behind domestic rail. Vertical suggests that “commercial VX-4 services will have a carbon footprint on par with an electric car” and could serve as a low carbon intensity option for routes where rail or many alternative options are not provided.[146]

Similarly, PwC found rural rideshare use cases produced less CO_2 per km when compared to the counterfactual, and found that longer journey lengths resulted in improved CO_2 savings, even in the case of one car journey being replaced. However, this study also highlights that emissions from AAM urban and rural private hire journeys are expected to be higher than emissions from equivalent car journeys. Additionally, emissions from sub-regional shuttles are also expected to be higher than those of equivalent rail journeys as “rail travel is a relatively efficient mode of transport.”

Considering the impact at a larger scale, an analysis conducted by UKRI and EAMaven of 20 potential UK based routes estimates AAM journeys would emit 134 tonnes of carbon emissions, and lead to an annual reduction of ~9,100 tonnes through reduced car journeys.[147] In the Seoul metropolitan area, Cho & Kim (2022) estimate that 30,000 UAM trips could lead to 90,000 tons of CO_2 reduction from ground traffic,[148] and that a 0.1% modal shift to UAM from ground trips (approximately 30 million trips) could lead to a 0.1% reduction in overall CO_2 emissions.[149]

Many studies have conducted emissions analysis on a case-by-case basis and illustrate how potential environmental benefits are dependant on a number of variables and factors, including journey length and vehicle occupancy. When assessing a base case (a 100 km, 27 minute journey), Kasliwal et al. (2019) found that eVTOLs result in 35% lower GHG emissions than an internal combustion engine vehicle (ICEV), but 28% higher in GHG emissions when compared to battery electric vehicle (BEV).[150] Kasliwal et al. (2019) also find that with three passengers, VTOL GHG emissions per passenger could be "52% lower than ICEVs and 6% lower than BEVs." Additionally, Kasliwal et al. find that GHG emissions for VTOLs "drop substantially below ICEVs for trips longer than 50 km," suggesting that UAM is more efficient for longer journeys. Kasliwal et al. also suggest that "operators would have to ensure VTOLs fly at near-full capacities for them to outperform conventional ground-based vehicles." An HSBC report presents similar findings to Kaslilwal on the limits on AAM's environmental benefits, suggesting that a small vehicle with few passengers travelling a short journey could be energy intensive and emission inefficient.[151] HSBC also suggest that to be a green route to decarbonising transport, widespread use of eVTOLs could exert additional demand for CO_2-free electricity and compete with other low-carbon technologies.[152]

In relation to last mile logistics, the Center for Economic and Community Engagement finds that a drone delivery service, after five years of operating in cities, could eliminate up to 113,900 tons of CO_2 every year through a reduction in vehicle use.[153] Furthermore, a study conducted by PwC in 2022 estimated that by 2030, drones could contribute a reduction of 2.4 million tons of CO_2e. This reduction is equivilant to removing 1.7 million diesel cars off the road for a year.[154] However, it is important to note that the figures quoted in the PwC study included use cases beyond the scope of this evidence review. In a separate PwC study, it was found that when transporting a 350 kg payload over a distance of 70 km in a regional cargo scenario, an eVTOL produce approximately 6.8 kg less CO_2e compared to a van making the same journey.

Energy Usage

Evidence on the energy usage and consumption of AAM vehicles is reported here to further assess the environmental impacts related to AAM activities. It is found that vehicle design, flight profiles, vehicle utilisation, and weather can influence energy usage and consumption.

Sripad & Viswanathan (2021) indicate that energy usage depends on AAM vehicle design and utilisation. The report indicates that novel UAM aircraft consume between 80 and 745 Wh/passenger-km at their designed flying range, with variations dependant upon vehicle occupancy.[155] Sripad & Viswanathan (2021) also note that "as the length [of the] cruise segment increases with longer flying range, the efficiency improves drastically," and "total energy consumption per unit [kilometre] for a trip is directly proportional to the fraction of time spent in vertical flight." Kasliwal et al. (2019) agree that for shorter journeys, a significant proportion of the flight profile is dominated by the "energetically intensive hover" phase, and that "VTOL compare less favorably." The analysis presented by Sripad and Viswanathan (2021) demonstrates that the Joby five-seater, Beta Alia-250, and Lilium Jet, when fully occupied, exhibit expected energy consumption rates lower than an electric vehicle (139 Wh/passenger-km) within their respective flight ranges. This highlights the efficiency advantages of fixed-wing horizontal flight phases. This report also shows that when compared to fully occupied ICEVs, eVTOLs are expected to be more energy efficient when travelling over 44 km, with energy consumption potentially lower than that of an EV over 161 km.

Booz Allen Hamilton further indicates that when analyzing the system at the level, terrestrial transport options may be more energy efficient than UAM vehicles.[156] However, it should be noted that this analysis only considers short-range use cases, such as air taxi and airport shuttle services. Furthermore, Booz Allen Hamilton suggests that energy usage also depends on the size of the aircraft, with larger aircraft requiring more power and resulting in higher costs per vehicle kilometer. EASA suggests that energy is required not only during the operations of AAM vehicles but also during their manufacture, assembly, and disposal.[157] Therefore, EASA recommends that further studies should focus on assessing the overall environmental impact of AAM aircraft during the design phases.

Kasliwal et al. (2019) note that weather, and elements such as wind, may also impact energy usage.[158] Using emissions as a proxy, Kasliwal et al. estimate there would be a 16% reduction during favourable 30-knot winds tailwinds, and a 26% increase with a similar speed headwind.

4.4.3 Social Impact

This section uses qualitative assessment through discussion of various aspects of AAM to evaluate the sectors potential social impacts.

Accessibility and Inclusivity

Accessibility to AAM operations can determine how AAM impacts different passenger groups, and can be evaluated based on design-elements commonly used to assess public transit stations. UK-based CIVATA Global, the Canadian Advanced Air Mobility Consortium,[159] and Aerobility have raised the need for AAMs to provide "accommodation for disabled passengers" and emphasized the importance of inclusive design elements. Vertiport accessibility can be judged using design elements such as step-free access, hand/grab rails, large-print signage,

Key Findings

Accessibility and Inclusivity: AAM has the potential to offer alternative transport options for disabled users and connect underserved communities, thereby improving social equity. However, in order to address these areas and prevent discrimination, the design of AAM infrastructure should consider aspects including user requirements, physical accessibility, affordability, and existing infrastructure.

Regional Connectivity: AAM could connect remote communities across the country, for example the Scottish Highlands and isles, introduce new or improved connections between regional centres, and increase access to education, healthcare, and other essential services.

Healthcare Access and Time-Critical Delivery: Electric air ambulances could take patients to hospital more efficiently and cheaper than current helicopter services and potentially improve response times for medical personnel and patient transport. Additionally, AAM could provide options for time-critical cargo deliveries of vital medical supplies such as blood, plasma, organs, and radioisotopes.

Job Creation and Socioeconomic Impacts: Job creation and socioeconomic impacts are highly dependant on AAM adoption and the market growth of the sector. However, whilst AAM offers the potential for job creation, concerns exist regarding job displacement, and the possibility of job losses due to automation of services.

Transit Comfort: AAM may provide an alternative transport options that could offer safety and comfort benefits. However, the extent of these benefits is unclear and would likely depend on several factors, including the suitability of AAM as a substitute to public transport options.

lighting, visible pathways, visual reference, elevators, and tactile surfaces.[160] Centre for London suggests that the whilst the London Underground has limited step-free access, the staff assistance offered is invaluable.[161] Centre for London also notes that disabled passengers may rely on "private cars and taxis more," and offering UAM with accessibility in mind can provide another mode of transport to disabled commuters. CIVATA further suggests that community involvement is imperative to design and rollout phases as AAM operations will affect many different businesses and users of transportation.[162] However, CIVATA also note that there has been "very little consultation with disabled groups."[163] CAAM suggests that "a network of regularly scheduled AAM flights for cargo and passengers throughout underserved communities would go a long way toward reconciliation and social equity."[164]

In 2021 UKRI highlighted a number of research themes that the FFC considered to be priorities for social and economic research, and outlined initial research areas to encourage engagement across academia, industry and the public sector.[165] Notably, UKRI stated that there are "fundamentally important questions about the implications of Future Flight on communities including in relation to social inclusions and equality that need to be addressed." A later UKRI study found that within the scope of accessibility and inclusivity, participants expressed concerns that "future flight technologies may unequally benefit different groups in society," and that there was a "[desire for] the technology to address inequality and ensure that the technologies promote accessibility, both from a socio-economic and disablilities perspective."[166] To address these concerns, participants noted that services should be affordable for people on everyday incomes, link to existing infrastructure, be accessible to all, and be publicly centrally management to avoid discrimination based on geographical residence.

Mayakonda et al.[167] cite 31 cities, previously identified in a KPMG market report, where initial AAM operations will likely take place. These cities suggest that AAM is likely to tap into existing transportation networks and might not bring accessibility to areas without prior transportation infrastructure, raising concerns regarding equity and accessibility. Targeting cities with a large urban population and an existing robust transportation hub, such as San Francisco, Dubai, London, New York, and Paris, can introduce an alternative mode of transportation to a large group of consumers. This therefore brings AAM services to a higher total number of people when compared to smaller cities. However, the aforementioned cities also have a high cost of living, which may implies that initial AAM services are likely to be utilized primarily by high earners or those with a high willingness to pay. Fifty-two per cent of participants in the UK DfT Transport and Transport Technology Public Attitudes Tracker highlighted a potential disadvantage of UAM as "not affordable to users and passengers."[168] Some cities have considered addressing affordability in their plans, the Canadian Advanced Air Mobility (CAAM) consortium proposed a policy to subsidize 15% of AAM flights at no or low cost to low-income residents,[169] however there has been little evidence that other urban centres plan to subsidize AAM trips. Looking at regional connectivity, subsidising flights to maintain a reasonable transport standard for communities that would not otherwise be served is a recognised method for governments to address equity and social considerations, as well as realising potential positive externalities that arise for local communities as a result of these transport links.

Regional Connectivity

One major potential benefit of AAM is the connection of remote communities across the country.[170] The UK has many rural and non-urban centres, such as the Scottish Highlands and isles.

Many existing rail networks connect through large urban centres in a hub and spoke design, making travel between small towns in the UK time consuming. The UKRI Future Flight Challenge Report suggests a high time cost would be incurred in scenarios with poor rail connectivity.[171] AAM would provide alternative travel options by creating direct and faster routes between small regional centres, improving regional connectivity. The UKRI report states that routes with poorer transport links will benefit more from AAM. Furthermore, the report finds that utilising air taxis for interregional journeys in areas with poor transport connectivity could potentially be more cost-effective compared to train travel.[172] By establishing new or improved connections between regional centers, AAM has the potential to increase access to education, healthcare, and other essential services outside of local areas, bridging the gap between remote communities and vital resources.

Similarly, UAM could increase tourism for popular rural areas such as the Scottish Highlands by easing travel access. Utilizing UAM services may offer a potential cost-effective and time-efficient alternative to connect rural areas to urban centers in the UK, compared to the construction of rail or road infrastructure, which could be costly and environmentally impactful. By leveraging vertiports or existing airports, UAM services could potentially establish connections between currently unconnected or underserved rural communities, without the need for extensive construction projects that may not meet the appropriate level of demand. This approach has the potential to provide a more efficient use of resources and tailored solutions that could bridge connectivity gaps in rural areas.

The provision of subsidised airline routes, such as through public service obligations (PSO), can have important social impact and are intended to maintain air routes that might not otherwise be commercially viable, and are vital for regional economic development.[173] An example is the government providing up to £4.3 million to fund flights from Dundee and Newquay to London, aiming to bolster union connectivity and encourage tourism and business travel.[174] These regional links will also create hundreds of jobs and support economic growth. Since there are already many important PSO routes, AAM can also offer an alternative that suits the demand of even more rural regions within the UK. As the UK has stated its 2040 target on Jet Zero strategy,[175] PSO routes could be operated by UAM providers for cleaner and potentially more efficient transport.

PwC's 2023 AAM economic impact study found that a AAM sub-regional shuttle journey could provide significant time savings when compared to a corresponding rail journey,[176] highlighting that where a train would likely stop at multiple points, the journey via eVTOL would be point to point along a fixed route. In the scenario presented, a sub-regional shuttle could save ~111 minutes compared to the equivalent 120 km train journey. Furthermore, the UKRI Report shows that in rural areas, for an individual undertaking a 25 km journey, the time cost is 37% lower than the business as usual case using a car, however the cost could be 65% costlier in monetary terms.[177] However, both reports note that costs may change over time as operating costs fall, AAM becomes more widespread, and autonomous operations are introduced.

Healthcare Access and Time-Critical Delivery

While some reports imply that AAM does not benefit some vulnerable communities due to UAM serving urban and high-income users, CAAM suggests that specific AAM use cases in healthcare and time-critical deliveries may have many social benefits;[178] AAM could provide critical support to rural communities and connect regional cities. CAAM and NEXA advisors suggest that AAM can also provide "near term solution[s] for time-critical medical cargo delivery such as blood, plasma, organs, and radioisotopes" and potentially improve response times for medical personnel and patient transport.[179] Electric air ambulances could take patients to hospitals more efficiently than helicopters and allow "lower-income groups" access to healthcare and economic centres.[180] PwC report that an 80 km air ambulance journey in 2025 would be 38% cheaper when compared to existing EC135 helicopters, with savings increasing to 55% in 2035 when autonomous operations, technological developments, and falling vehicle costs provide additional cost savings.[181] AAM may be beneficial for rural populations separated by water, during emergencies and medical relief efforts, and provide transportation to larger hospitals. Examples of UK based remote communities that could benefit from AAM include the Scottish Isles, where flying between Scotland's regional airports is the quickest way to travel between islands.[182]

Currently CAELUS, a consortium led by AGS Airports, is working on the UK's first medical distribution network using UAS and will be able to leverage AAM to transport essential medicines throughout Scotland and remote communities.[183] The Mercury Drone Port and NHS Tayside has begun on-demand drone collection and delivery service of medical equipment and samples in Scotland.[184] During the COVID-19 pandemic, Windracers, a UK based vehicle integrator and operator, successfully delivered 50 kg of medical supplies from Cornwall to the Isles of Scilly, "[highlighting] the power of this technology to safeguard and futureproof the transportation of vital aid."[185] Current efforts therefore demonstrate a large and meaningful opportunity for AAM services in rural and remote areas of the UK. The UKRI Socioeconomic Report states that the cost of delivering prescribed medicine to four patients at different locations in an urban area is 20% less when utilising a delivery drone, compared to business as usual case where pharmacy staff are responsible for delivery.[186] Additionally, the study suggested that if the use case was to apply to a rural area, the benefits would be greater than those observed in urban areas.[187]

Job Creation and Socioeconomic Impacts

Job creation and socioeconomic impacts are highly dependant on AAM adoption and the market growth of the sector. Further information on market outlooks and drivers of variance can be found in Section 5.

EASA estimates that by 2030, approximately 90,000 jobs could be created or sustained due to construction and operations related to UAM demand.[188] McKinsey (2022) reports that the AAM industry "could require about 60,000 pilots by 2028," with some later becoming "remote supervisors capable of overseeing multiple flights from the ground."[189] Deloitte suggest AAM may employ more than 280,000 workers in the United States by 2035, and estimates that the AAM workforce could represent 8% of the US aerospace and defence workforce.[190] Furthermore, Deloitte assesses that within the US, the AAM industry could pay about $30 billion in wages and benefits by 2035, as well as generating $20 billion in exports.

However, while AAM offers the potential for job creation, participants in the UKRI mini public dialogue highlighted concerns regarding job displacement. Survey respondents noted the possibility of job losses in areas such as haulage, deliveries, and taxi services, due to automation and services being assumed by AAM operations. However, opinions were mixed, as some participants noted that AAM could provide opportunities for increased productivity, improved jobs accessibility through enhanced connectivity, and indirect job opportunities related to AAM operations.[191] Additionally, a CAAM paper focused on AAM opportunities in Toronto further supported this by stating that the increased connectivity that AAM could offer may provide new employment opportunities for people living outside urban centres and allow businesses to access a larger labour market.[192]

Transit Safety and Comfort

Another method to assess societal impact is by examining the safety of transportation in cities and the level of user comfort. In future, these impacts could be monetised using the Home Office's economic and social costs of crime second publications using reference values, though transferability of these values to an AAM specific transport context may still pose challenges.[193]

Taxis and ridesharing services are most comparable to what one would expect in transit safety and comfort with AAM. Participants in a Uber report indicated the services provided by the company offered improved flexibility, availability, and safety when compared to other transport options in the UK.[194] In this report, 88% of female riders stated that safety is a factor when travelling, with 52% of young riders noting they occasionally felt unsafe on public transport.[195] However, there are some concerns when it comes to safety in ridesharing vehicles; in a different study, female participants note that they felt "less safe"[196] sharing a vehicle with strangers at night, and critics have suggested a level of uneasiness toward ridesharing companies in the US.[197] Whilst safety issues and concerns are highlighted in media reports,[198,199] a study by Steer showed users rated personal safety in taxis as "good," and convenience and comfort as the two highest ranked reasons users choose this form of transport.[200]

In relation to public transport, a customer experience survey involving more than 12,000 Los Angeles Metro riders, one of the centres identified for future UAM services, noted "safety from crime" as a top concern, and that female bus ridership has declined yearly.[201] According to a survey conducted by San Jose State University, 63% of student respondents reported experiencing some form of harassment while using, waiting for, or travelling to and from public transport.[202] Concerns and incidents related to safety disproportionately affects twice as many women compared to men.[203] In the UK, a survey of 1,000 Londoners by TfL indicated that 12-15% of women experienced sexual harassment in transit environments.[204] Centre for London's report notes that black and ethnic minority Londoners are "more likely to cite cost and safety" as barriers to using public transport.[205]

These findings suggest that AAM may provide an alternative that can offer safety and comfort benefits for many users. Offering alternative ridesharing options may have positive impacts in ridership in cities where public transit safety is unsatisfactory and riders prefer alternative options. However, the extent of these benefits is unclear and would likely depend on several factors, including the suitability of AAM as a substitute to public transport options. Furthermore, traveller safety can be improved by incorporating features such as direct phone lines, CCTV, platform patrols, and timetables into vertiport designs.[206]

5 Future Market Potential

This section explores the future market potential of the AAM industry, covering market outlooks, market drivers and barriers, and considers future UK market viability.

The review of market outlooks considers information provided by commercial reports across several areas including revenue and global vehicle fleet projections, passenger and cargo demand, and drivers of variance across studies. Specifically within the context of the UK, the review considers market outlooks and the implications for future studies on the UK market.

An overview of the market drivers assesses the technological, economic and commercial, societal, and performance-based factors driving adoption of AAM. To provide further context, the report also examines the social, technological, infrastructural, economic, regulatory, operational, and environmental barriers that may hinder AAM adoption.

Lastly, following the assessment of market drivers and potential barriers to AAM operations, this section provides an analysis of the future viability of the UK AAM market.

5.1 Market Outlooks

This section provides an overview of studies of AAM market outlooks, including general methodological features, global market outlook results, and drivers of variance in forecasts. It also summarizes methodological best practice in a UK context and what these outlooks mean for the UK across multiple dimensions (business models, company, and market).

5.1.1 Literature Assessed

BryceTech followed a three-step process to identify and prioritise market outlook studies for review. Firstly, an initial batch of potential market studies was identified through internet search, with further studies identified by examining referenced studies in the initial set. Secondly, studies were characterised on a high-level based on their attributes listed in Section 5.1.2, and those not providing public, quantified market outlook estimates were filtered out. Finally, studies were grouped according to their geographies and the comparability of their outputs, and their findings analysed.

Key Findings

Market Outlooks and Future UK market viability

The potential market size and economic viability of AAM has been examined across multiple public studies globally and in the UK. Whilst market size estimates vary, they range between £1 billion and more than £100 billion in service revenue globally in 2040, with UK specific studies indicating some AAM use cases as economically viable and having the potential to significantly contribute to the UK economy. Notably, RAM is highlighted as an attractive option for connecting locations where the construction of large-scale infrastructure may not be cost effective. The UK annual revenue potential is estimated to be in the hundreds of millions, with the potential for a multi-billion pound market from 2035 onwards, according to Vertical Aerospace and Roland Berger. PwC also estimates socioeconomic benefit delivered in a UK context could amount to between £1 billion and £2 billion by 2040. This said, unlocking these benefits would require that current and future barriers to market development are overcome.

Market Drivers and Barriers

Urbanization, economic growth, environmental benefits, and technological advancements such as battery efficiency and electric propulsion are considered drivers for the development and adoption of AAM. In some regions, urban congestion, rising incomes, and the increased demand in delivery services drive the demand for UAM services. In the UK, the current high cost and duration of regional journeys make AAM passenger travel an attractive alternative.

A number of barriers potentially impact the viability and scalability of AAM commercial operations in both the near and long term. These include:

- Social barriers including concerns around trust, service reliability, personal security, and privacy, and in the longer term, automation
- Technological barriers including cybersecurity, air traffic management, battery and electric propulsion, and noise reduction
- Infrastructural barriers are also key, as the market can only be enabled through sufficient availability of vertiports, ground infrastructure, and telecommunications infrastructure
- Economic barriers include affordability, demand is sensitive to pricing, the initial investment cost required for entry-into-service, and production costs at scale
- Short term regulatory barriers for airworthiness certifications, and licensing requirements that must be met by AAM developers
- Long term regulatory barriers with regulation needing to adapt to the emergence of remote and autonomous piloting, and potentially considerable increases in the scale of operations
- Operational barriers including concerns about integrating AAM with other aircraft in congested airspace, and unfavourable weather conditions. Additionally, scaled AAM services may demand the development of new standards for air traffic management

Interviews with industry raised several barriers, many of which affect operations around the world. In the UK context, those of particular concern for UK actors include:

- Concerns around insufficient availability of AAM passenger infrastructure, with the suitability of the UK's current planning system being raised as a major point of concern
- Public concerns around vehicle performance, safety, and impact
- Certification, regulation, and licensing, in particular, the need for establishing a regulatory framework to enable initial operations, and ensuring clear guidance and consultation - matters that are under active consideration, among others, through ongoing work through the Future of Flight Industry Group and the development of a Future of Flight Action Plan

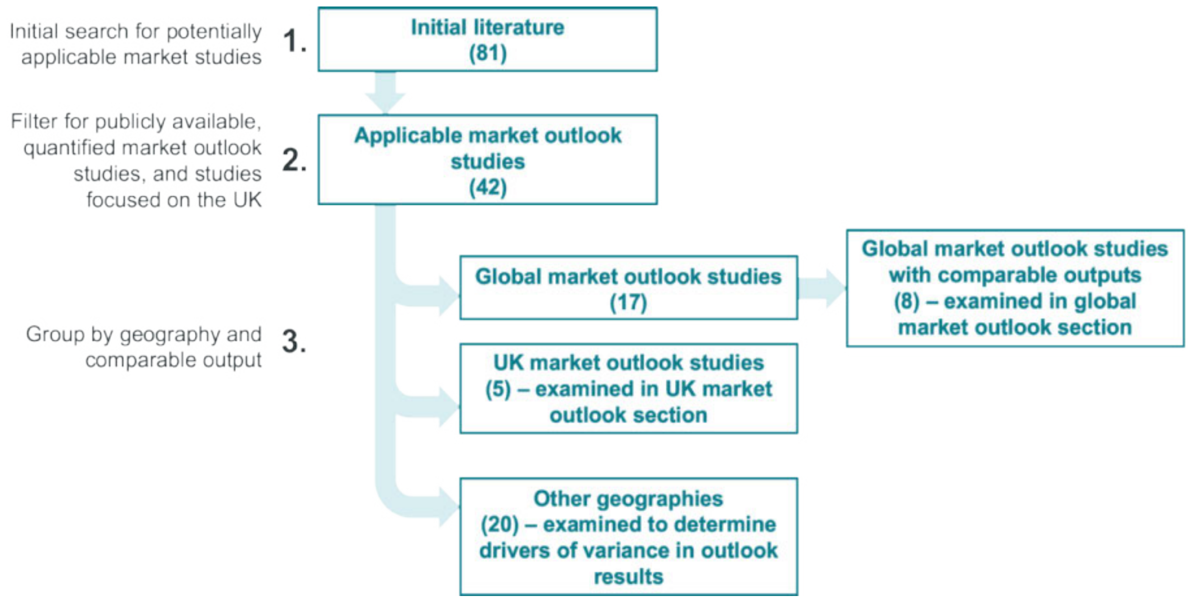


Figure 5.1. Flow of market outlook literature selection.

5.1.2 Methodologies and Approaches

Studies either estimate the total addressable market (TAM), or an estimate of potential demand which applies certain constraints on realised demand and is smaller by definition than TAM. In essence, TAM calculates the maximum possible revenue potential for a product, onto which demand and supply constraints can be layered, depending on analysis requirements. Studies also vary in the market outlook period. Some studies provide annual projections, while some provide year-specific market estimates, and others provide year-agnostic demand assessments. However, it should be noted that studies that do not attach a specific year to their market estimates are nonetheless assuming a certain applicable period, given that their inputs, such as demography, existing infrastructure, etc. are year dependent.

Axis of Variability	Variants
Periods Assessed	• Annual projections • Year-specific • Year-agnostic • Time horizon
Demand Assessed	• Total addressable: Total market potential of all customers • Potential: Estimated effective demand, considering consumer preferences, affordability, and other factors

Market Analysis Approach	• Top-down
	• Bottom-up
	  • *Agent-based modelling*
	  • *Equation-based modelling*

Geography	• Global • Regional (global) e.g., Asia Pacific, North America • National • Regional (sub-national), e.g., Bavaria, California • Local
Use Cases Examined	• Urban air mobility • Regional air mobility • Regional cargo • Last-mile logistics • Small UAS services (not in scope of this study)
Outputs	• Revenue • Fleet size • Vehicle Deliveries • Passenger volume • Cargo deliveries

Source: BryceTech analysis.

Table 5.2. Summary of key differences in market outlook approaches across reports examined.

5.1.3 International Market Outlooks

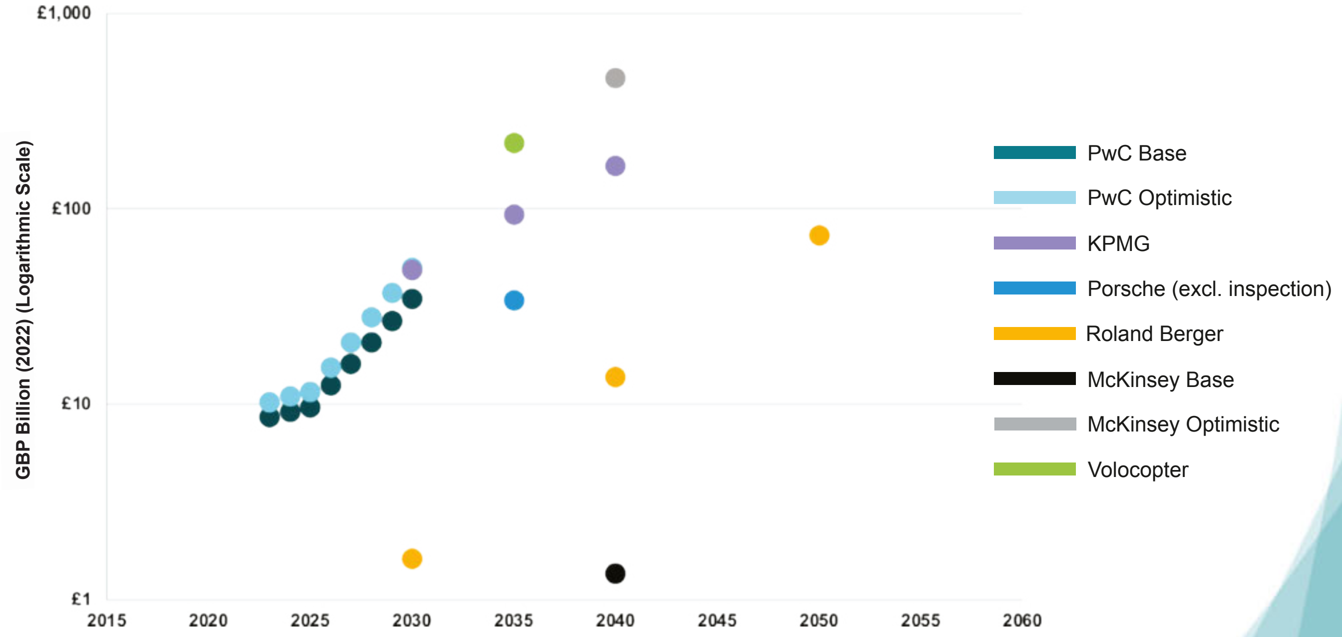
Market Growth

Of the eight global market studies considered, BryceTech identified six commercial reports which provided projections of market revenue, as detailed in Table 5.4 for specific years, and four reports which provided projections in terms of fleet sizes, as shown in Table 5.6.

Considerable variance is observed in the range of market sizes across the 2023-2050 period as shown in Figure 5.3. While precise details regarding study methodologies are unavailable, this is expected to be driven primarily by market definition and the approach taken to market sizing. For example, while KPMG's and Roland Berger's estimates vary by approximately an order of magnitude in their market projection for 2040, the former estimates TAM, while the latter estimates a function of potential demand. Similarly, while PwC's projection is similarly an order of magnitude larger than Roland Berger's estimates in the year 2030, the former's market definition is wider, capturing freight transport and small UAS services alongside passenger transport.

A further study, not included in Figure 5.3, produced by Morgan Stanley Research (Jonas et al.[207]), estimates significantly higher figures of TAM. Jonas et al. place global TAM for AAM (spanning passenger and freight transport, and including military applications) at $10 billion (£7.3 billion) in 2025 in their base case, growing to $9 trillion (£6.5 trillion) by 2050. Their analysis is driven partially by assumptions made regarding the share AAM solutions can take from existing transport and passenger travel markets. While this study is not displayed below as it was a comparative outlier, it can be seen as representing a possible maximum potential of the global AAM sector.

AAM passenger vehicle fleet projections show similar variance in projected market size, however they do display some overlap in the nearer term. It should be



Source: BryceTech analysis of multiple sources.

Figure 5.3. Global AAM sector revenue projections, 2022 GBP billion, (logarithmic scale).

Report	Year Published	Use Case Categories Examined	Demand Assessed
PwC Battaglia, C. et al. *The path towards a mobility in the third dimension: How to create a national system for Advanced Air Mobility*[208] Sponsored and published by PwC Strategy&	2021	Regional air mobility, urban air mobility, regional cargo, last-mile logistics, small UAS services	Potential
KPMG Brown, C. et al. *Aviation 2030*[209] Sponsored and published by KPMG	2022	Urban air mobility, regional Air mobility	Total addressable
Porsche Consulting Grandl, G. et al. *The Future of Vertical Mobility: Sizing the market for passenger, inspection, and goods services until 2035*[210] Sponsored by Porsche SE and Volkswagen AG. Published by Porsche Consulting	2018	Urban air mobility, regional Air mobility	Potential
Roland Berger Hader, M. et al. *Advanced Air Mobility: Market Study for APAC region*[211] Presented at Singapore Airshow 2022, based on existing Roland Berger forecasts. Commissioned by Rolls Royce and published by Roland Berger	2022	Urban air mobility, regional Air mobility	Potential
McKinsey Riehdel, R. Sahdev, S. *Taxiing for Takeoff: The flying cab in your future*[212] Sponsored and published by McKinsey & Co.	2019	Urban air mobility	Potential
Volocopter *The Roadmap to Scalable Urban Air Mobility*[213] Sponsored and published by Volocopter GmbH	2021	Urban air mobility; regional Air mobility, last-mile logistics	Potential

Source: BryceTech analysis of multiple sources.

Table 5.4. Market revenue projection study information.

noted that while the studies displaying fleet projections all estimate measures of potential demand, they vary in use cases covered. The Aerospace Technology Institute's (ATI) forecast displayed is not strictly within the bounds of this study, as it covers any aerial vehicle with between 9 and 19 seats. However, the institute notes "The subregional aircraft segment is defined as aircraft with less than 20 seats. The [global] subregional fleet is now quite old, with an average age of 29 years, and its share of the [aerospace] market has been in steady decline due to trends towards larger aircraft with better per-seat operating economics." The development of electric aviation has the potential to reverse this trend, with new subregional electric aircraft offering zero emissions flight with competitive operating economics on short routes, up to about 200 nautical miles [370 km] in distance." Some, though not all, regional AAM passenger vehicles considered within the scope of this study would therefore fall under the ATI definition. Similarly, the figures taken from Grandl et al. comprise UAM, while Hader et al. cover both UAM and RAM. This likely drives a notable portion of the variance observed.

Source: BryceTech analysis of multiple sources.

Figure 5.5. Global AAM sector vehicle fleet projections (logarithmic scale).

Report	Year Published	Use Case Categories Examined	Demand Assessed
Aerospace Technology Institute (ATI) *Market Forecasts and Strategy*[214] Published under the FlyZero project, funded by the Department for Business, Energy and Industrial Strategy (now Department for Business and Trade)	2022	Regional air mobility	Potential
Porsche Consulting Grandl, G. et al. *The Future of Vertical Mobility: Sizing the market for passenger, inspection, and goods services until 2035* Sponsored by Porsche SE and Volkswagen AG. Published by Porsche Consulting	2018	Urban air mobility	Potential
Roland Berger Hader, M. et al. *Advanced Air Mobility: Market Study for APAC region* Presented at Singapore Airshow 2022, based on existing Roland Berger forecasts. Commissioned by Rolls Royce and published by Roland Berger	2022	Urban air mobility, regional air mobility	Potential
Boston Consulting Group Aaronson, M. et al. *The Aerospace Industry Isn't Ready for Flying Cars*[215] Sponsored and published by BCG	2018	Urban air mobility, regional air mobility	Potential

Source: BryceTech analysis of multiple sources.

Table 5.6. Fleet size projection study information.

5.1.4 Passenger and Cargo Demand

Of the market studies indentified, four also provide segmentation of cargo vs. passenger revenue, shown in Table 5.7.[216] This indicates considerable variance in the expected split of passenger vs. cargo revenue by 2035. However, the geographic scope of the studies varies, and a generally larger proportion of the market is attributed to cargo in the two studies focused on the United States, as opposed to Porsche Consulting's global study. It is not possible to say with the available data whether this indicates a fundamental difference in the US market vs. the global market, or whether this is driven primarily by differences in scope and/or methodology.

5.1.5 UK Market Outlooks

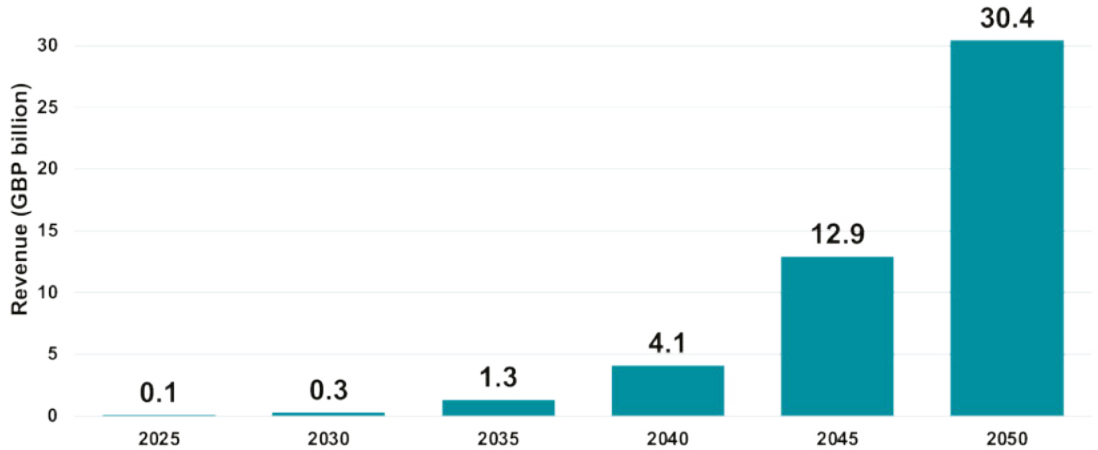
Five UK market outlook studies were identified in total. Three of these provided revenue projections of some form of potential demand, published by Vertical Aerospace in 2021,[217] ADS in 2021,[218] and UKRI in 2022.[219] The analyses of the latter two were delivered by EA Maven (formerly Swanson Aviation Consultancy). The 2021 ADS report, assessing 15 routes in the UK, is an indirect precursor to the 2022 UKRI report, which analyses 20 potential routes. Both provide year-agnostic demand assessments based on current or near-term economic and flight data. A further two studies by PwC were also examined, which provide a more holistic assessment of the socioeconomic impact, viability and outlook of the AAM market in the UK.

The vehicle and trip volumes cited in Vertical Aerospace's report are sourced from Roland Berger, and estimate that a total of 321 VTOLs could be flying in the UK by 2030, accommodating 1.2 million flights. This implies very high flight cadences for each aircraft per day, and it is likely that these projections assume improvements in vehicle performance, uptime, and maintenance requirements. Vertical Aerospace also extrapolated projections made by Morgan Stanley and Roland Berger, estimating the UK market could be worth up to £300 million in annual revenue by 2030. UKRI's 2022 report concludes "AAM is indeed economically viable and would provide a

Study	**Morgan Stanley Research** *Flying Cars: Investment Implications of Autonomous Urban Air Mobility*	**Porsche Consulting** *The Future of Vertical Mobility: Sizing the market for passenger, inspection, and goods services until 2035*	**Deloitte** *Advanced air mobility: Can the United States afford to lose the race?*	**Volocopter** *The Roadmap to Scalable Urban Air Mobility*
Proportion of Passenger vs. Cargo Revenue	Passenger (35%) Cargo (65%)	Cargo (11%) Passenger (89%)	Cargo (50%) Passenger (50%)	Cargo (41%) Passenger (59%)
Geography	USA	Global	USA	Global

Source: BryceTech analysis of multiple sources.

Table 5.7. Proportion of passenger vs. cargo revenue in 2035.



	2025	2030	2035	2040	2045	2050
VTOLs in Operation	69	321	927	2,060	4,245	6,456
VTOLs Flights (000s)	196	1,152	4,212	11,810	30,732	58,795

Source: Vertical Aerospace, Roland Berger, Morgan Stanley.

Figure 5.8. Vertical Aerospace UK air taxi market forecast, revenue, GBP billion.

significant contribution to the economy, whilst also reducing carbon emissions of travel." The routes analysed indicate an annual service revenue potential of £704 million, inducing £124 million in additional economic activity through productivity effects.

The report's focus on RAM is notable in itself, given that 1) the study notes AAM can play an important role in the UK "in connecting the four nations through the provision of services not economically viable through building of new road or rail infrastructure" providing transport between currently underprovided regions and 2) UAM has tended to receive greater focus over RAM In global literature. The report therefore highlights the attractiveness of RAM in the UK, where the construction of large-scale transport infrastructure, including rail, between regional locations may be cost prohibitive. This said, further study examining the market potential of UAM in the UK would be beneficial in uncovering the economic impact shorter range AAM passenger services could play.

A further study, developed by PwC, with input from Future Flight Challenge and DfT, explores six use cases of AAM in the UK, calculating unit-level and national projected economic impact in the 2025-2040 period.[220] The research examined:

- Urban private hire (over 10 km)
- Rural private hire (over 28 km)
- Rural rideshare (over 60 km)
- Sub-regional shuttle (over 85 km)
- Air ambulance (over 80 km)
- Cargo (over 75 km)

The study found that three of the six use cases were socioeconomically attractive, i.e., exhibited net reduced costs compared to a use-case specific counterfactual. These use cases were: rural rideshare; sub-regional shuttle, and air ambulance, which exhibited cost reductions compared to the counterfactual of between 33% and 99%. Urban private hire, rural private hire and cargo were found to not be socioeconomically attractive. Assuming between 2.5% and 5% adoption by 2040, the socioeconomically viable use cases identified in the study were estimated to deliver a potential of between £1.1 and £2.1 billion in socioeconomic benefit, with the majority of benefits flowing from time and fare savings.[221]

5.1.6 Drivers of Variance

The variance in outcomes of global AAM studies has not gone unnoticed. Robin Riedel, Head of the McKinsey Center for Future Mobility laid out some of the reasons for this in an interview in 2022.[222] Some of the reasons listed are already explained in prior sections, for example "whether [studies] target the 'total addressable market', how that market is defined and over what time period." Choices regarding these factors are driven by the goals of individual studies. The total addressable market, for example, may be chosen to give insight into the total revenue potential of the market, and opportunities for growth. Timelines and market definitions will be determined by the interests and focus areas of those commissioning the study, as well as, potentially, data availability. However, Riedel also states studies can produce a "broad range of answers purely depending on the assumptions you start with." Further, most market predictions also start with a survey of people involved, so the "survey targets are also relevant."

Alongside the market projections discussed in Section 5.1.3, a number of academic studies estimate year-agnostic demand for various regional and local geographies. These studies employed agent-based (whereby the travel behaviour of individual agents is modelled) or equation-based models (whereby aggregate travel behaviour of consumers is modelled using equations) of consumer behaviour, offering useful insights into the assumptions that may drive variance in market outlooks. Two of the most significant factors examined in these studies are explored below.

Price

Expected consumer demand for all forms of AAM passenger transportation is almost universally found to be fairly price elastic. In other words, demand is likely to be responsive to pricing levels, and may drop below economically viable levels if pricing is unsuitably set. Price is dependent on factors such as location, time, cost, density of vertiport networks. For comparison against AAM services, revealed preferences in the UK indicate that long-term income and price elasticity of aggregate land transport demand (comprising rail, bus, and cars) is relatively inelastic, estimated to be 0.8 and 0.6, especially during peak hours.[223]

Kreimeier et al. (2016)[224] examining national demand for regional on-demand air mobility (ODAM) services in Germany (using revealed preferences from existing transport data) found that a 25% increase in price per kilometre to 0.5€/km (£0.41) decreases ODAM market share of all transportation tenfold, from 19% to 1.9%. Similarly, Rimjha et al. (2021),[225] using revealed preference data (of consumer behaviour under existing transport modes), studying UAM for Los Angeles Airport (LAX) access trips find that demand drops by 50% if the passenger cost per km is increased from £0.64 to £1.38.

Balac et al. (2019),[226] in examining UAM implementation in Zürich, and using stated preference survey data, produce similar results, finding that a 50% reduction in price leads to “a substantial increase in the amount of trips” and that price reductions can increase turnover up to fivefold, though “the increase in the amount of added infrastructure, fleet size, maintenance, might overcome this increase in turnover.” Pu et al. (2014),[227] studying on-demand UAM in California and New York, and using revealed preference data, find that doubling the price of the service, from £0.23 per km to £0.45, decreases the number of trips taken sixfold.

Rimjha et al. (2021),[228] examining UAM in northern California find that a similar sixfold decrease in trip volumes is induced by a 60% price increase from £0.48 per passenger km to £0.78. As such, given these findings, AAM passenger travel forecasts are likely to vary considerable in their results, depending on pricing assumptions made.

Performance and Availability

Kreimeier et al., in their study of regional ODAM in Germany, examine a range of cruise speeds, and find that market share of ODAM decreases from 19% to 13% if cruise speed is reduced from 350 km/h to 250 km/h. Balac et al. also find that “decreasing speed, increasing liftoff and access time all have negative effects on the turnover,” though they note that “this does not necessarily mean lower profit as this depends on the cost of the vehicle production, maintenance and so on.” This finding ties into broader discussions around time savings, as several studies find that assumed realised time savings for consumers are a notable factor in driving variance in projected demand. Infrastructure availability is also a notable factor. Considering vertiport prevalence and accessibility, Rimjha et al. find that the number of vertiports has a notable effect on demand in Northern and Southern California, though find a more muted effect in the case of access services to Los Angeles International Airport (LAX). This is explained by the fact that centres of demand are more concentrated around specific hubs. Therefore, population distribution and vertiport catchment areas could impact the final realised demand.

5.1.7 Implications for Future UK Market Studies

Published UK market studies, such as those by Vertical, UKRI, and EA Maven, provide demand assessments and insights into the market for AAM in the UK. These reports indicate economic potential for AAM operations in the UK. They present a market size at similar order of magnitudes and future demand across many regions, and provide examples of routes in which AAM services could take place. Therefore, existing studies provide a helpful start to understanding what AAM services in the UK may look like and the levers needed for action. Uncertainties remain such as the variance in pricing based on vertiport availability, performance, and sensitivity depending on locations where services are offered. The insights from these studies provide several new areas to examine for future UK market studies. It should be noted that no comment is made as to whether these further areas of study are best suited to be conducted by government or industry. Indeed, many of the areas of analysis listed below may already be underway or completed outside of the public domain by private companies.

Future market studies could assess potential routes and cities in greater detail across the UK. These studies could aim to analyse the different use cases offered by AAM, particularly those where little public data is currently available, for example direct-to-consumer last mile drone delivery. In addition, it would be useful to assess which use cases are best suited for specific cities and the UK overall. The most recent analysis by PwC already goes considerable ways to addressing this question. Perhaps most importantly, given that regional air mobility has been noted by several UK studies to potentially offer the most attractive value proposition, it may be prudent to dedicate further resources to examining the business case and operational challenges to establishing RAM networks, given considerable focus to date in the broader literature has been on intra-city transport applications. Additionally, UK demographic trends such as income, age, gender, and location should be considered when evaluating demand for UAM services, especially in early stages of operations, to avoid overestimation of demand and to inform which cities are best suited for initial services.

For identified RAM routes, such as those by operators including Vertical Aerospace, market studies can provide an assessment on why certain routes are more competitive and suitable for AAM services than others, through factors including location, cost of construction, weather, urban density, existing modes, existing infrastructure. Additionally, future market studies should identify potential vertiport sites for better assessment of the environmental impact of construction and to calculate ridership. By expanding location-specific knowledge, this could help provide a better estimate of time to service for each location. Lastly, market surveys can be implemented to determine users willingness to pay and the variance in how passengers in multiple UK cities value comfort, safety, noise, visual pollution, convenience, environmental impact of AAM, and privacy differently. These factors are explored further under barriers in later sections.

Furthermore, additional research can be conducted on weather applicability to AAM services and the impact of weather on ride comfort, safety, and service reliability for UK cities. Additional studies can be conducted to examine the impact UAM and RAM services would have on existing modes such as traditional aviation and rail travel, and also on urban sprawl. Market studies can also examine implication of job losses or job growth from AAM services and the skills required to support AAM operations. More details are needed on the short-term vs. long-term trends in transportation and potential supply chain challenges for AAM services.

5.2 Market Driver Review

The emergence of AAM as a potentially viable industry has been driven by several factors. These include novel transport value propositions, technological developments, and perceived societal and environmental necessity. Of course, none of these market drivers are unqualified, and potential barriers are discussed in the next sub-section. Drivers can be grouped under four main categories:

1. Technological
2. Performance-based
3. Economic and commercial
4. Societal

5.2.1 Technological Drivers

Intracity VTOL and short-duration regional passenger transport has been in existence for several decades. Similarly, the delivery of cargo by uncrewed aircraft has been observed for two decades, albeit, initially by military users. The promise of AAM is to use novel technologies to reduce cost, increase reliability, and reduce environmental impacts to a degree that allows novel, convenient, value propositions that are widely accessible to members of the public. This is driven by a host of technological trends, of which the most important are in the fields of batteries, electric propulsion, sensors, guidance, navigation and control, and communications.

Considering battery technology, specific energy (energy stored per unit mass) has progressed sufficiently to enable some AAM concepts using existing technologies. A 2021 US Department of Energy report, integrating broad stakeholder views, states that "Energy densities of today's Li-ion batteries, approximately 150–170 Wh/kg_{pack} (i.e., energy per unit weight at the pack level), allow initial demonstrations, and are close enough to enable near-term eVTOL and 9- to 20-passenger, thin-haul applications with limited range capability."[229] For example, Vertical Aerospace aims to use a battery system that delivers 220 Wh/kg of specific energy.[230] The DOE states that pack specific energy in the 300-400 Wh/kg range would enable "eVTOL and 9- to 20–passenger, thin-haul all-electric aircraft, while at the same time making it possible for initial introduction of electrified regional aircraft with short-haul capability." This range is seen as "achievable within the current DOE research framework," and a notional timeline places the capability in the 2030-2035 range.

Driver	Description
Batteries	Energy density of lithium ion batteries has sufficiently improved to enable early AAM vehicle designs. It is expected to continue improving, approaching the AAM "sweet spot" of 400 Wh/kg by approximately 2030-2035
Electric propulsion	Distributed electric propulsion offers benefits in efficiency, safety and noise, and propulsors have become sufficiently powerful and light to make vehicle concepts feasible
Sensors, guidance, navigation and control	Sensor, guidance, navigation and control technologies have progressed in tandem with battery and distributed electronic propulsion technologies, enabling "user-friendly" piloting systems and the potential for remote and autonomous flight in future
Communications	Communications systems are being fielded that meet the requirements of AAM vehicles within acceptable limits of adaptation

Technological drivers.

Further, distributed electric propulsion (DEP) technologies have progressed sufficiently to enable the fielding of small-scale unmanned and passenger air vehicles.[231] Compared to traditional aircraft propulsion technologies, DEP can enable improved efficiency, lift performance, and increased tolerance to outages, as well as reduced noise signatures.[232] These benefits have driven the adoption of the technology, and, therefore of AAM aircraft. DEP, coupled with the increasing or anticipated availability of compact fly-by-wire systems, sensors for navigation, and onboard computing power, mean that the complexity of flying AAM vehicles is viewed as sufficiently low to not be cost prohibitive in terms of pilot training, or unacceptably risky.[233,234] It also opens the possibility of autonomous or remote flight, as is already being seen with cargo vehicles, and is anticipated for crewed flight, though timelines are less certain.[235]

Finally, communications systems that are reliable, secure, and scalable, that appear suitable for AAM applications, are currently being rolled out and would enable the required communications between aircraft and various ground systems. These include 5G and low Earth orbit (LEO) satellite communication systems, which are both nearing scaled rollout but would require some adaptation for AAM applications.[236]

Trends in all of these technology categories have progressed to a point where early operations and initial entry into service is possible. It should also be noted that technological progress in these fields is ongoing and gradual. It would therefore be reasonable to expect a gradual increase in capabilities of fielded AAM vehicles as systems relying on next generation technologies are brought to market, and existing vehicles are updated. Indeed, modular, redundant, and updatable designs are something that industry researchers have recommended,[237] and manufacturers such as Joby have indicated their intent to design their vehicles with potential upgrades in mind, for example making use of new batteries to improve range, as energy density continues to improve.[238]

5.2.2 Performance-Based Drivers

Closely related to technological drivers are the performance increases compared to existing transportation modes that AAM promises to deliver.

AAM vehicles are expected to compare favourably against other forms of transportation in terms of speed, timesaving, and convenience. Roland Berger, Williams Sale Partnership, and Deloitte all suggest AAM operators promote their vehicles in this light.[239] Studies of AAM use cases generally demonstrate improved mobility outcomes, which could encourage urban cities to integrate UAM services with other modes of transportation, which could in turn reduce congestion and offer inter-modal journeys. In a study conducted as part of the Future Flight Challenge, participants were receptive to AAM use cases for emergency services (given performance increases), and were more likely to consider AAM technology if they led to significant improvements to convenience, travel conditions, or connectivity for rural communities.[240]

Driver	Description
Speed, time-savings, and convenience	Reduced journey times may drive consumer adoption if price points reflect the value of time saved Integration of AAM in a multi-modal transport system, as well as the potential for increased timeliness and comfort, may provide improved convenience to customers, driving adoption
Reduced emissions	Fully-electric AAM vehicles produce no tailpipe emissions. Assuming a continued increase of the share of renewables in the grid, expanded use of AAM vehicles over carbon intensive transport modes therefore offers opportunites for emissions reduction
Increased safety	The redundant nature of distributed electric propulsion means AAM vehicles could offer safety benefits over travel by helicopter. Further, assuming AAM vehicles are held to high safety standards, AAM travel is expected to be safer than travel by road
Reduced noise	Thanks to novel propulsion technologies, AAM vehicles are expected to be far less noisy than other forms of aerial transport. This increases the range of areas and use cases in which AAM vehicles can deliver their benefits without insurmountable community push-back

Performance-based drivers.

As discussed under environmental impacts in Section 4.4.2, the use of electric propulsion has the potential to reduce in-situ emissions in local communities, and lead to an overall reduction in carbon emissions, if users substitute away from carbon intensive travel modes such as ICEVs or traditional aviation. Indeed, Deloitte suggests that AAM services are "community-friendly and cost-effective," and can address pollution concerns and "increase the efficiency of current transportation networks."[241] This has the potential to drive AAM adoption through increasing the attractiveness of AAM services to consumers and policymakers. These factors are discussed further under societal drivers in Section 5.2.4.

So long as safety standards are achieved and maintained, industry and regulator sentiment indicates that AAM can deliver safety benefits. Vertical Aerospace expects that "with the advent of new AAM vehicles, regulators and the public will expect the same exacting safety standards as they do with jet aircraft … as people move from road, rail and helicopter to eVTOL aircraft for cross-country journeys, injuries and accidents will fall dramatically."[242] Safety considerations are expected to drive AAM adoption, given that these rank highly among consumer priorities as discussed further under societal drivers in Section 5.2.4.

Additionally, AAM vehicle manufactures generally advertise the low noise profiles of their aircraft, especially compared to those of light aircraft and helicopters. Vertical Aerospace, for example, describes eVTOL aircraft as exhibiting noise profiles "similar to background urban noise," and joint testing by Joby and NASA indicate noise levels of 45 dB ($L_{A,max}$) during overhead flight at 500m from the observer, and less than 65dB ($L_{A,max}$) at 100 m from the observer during take-off and landing.[243] For a point of comparison, the weekday noise in the City of London ranges from between 53 dB ($L_{Aeq,T}$) to 74 dB ($L_{Aeq,T}$).[244]

5.2.3 Economic and Commercial Drivers

A perceived improving business case for AAM services is driving investment into AAM development. Considering AAM delivery services, increasing cost-competitiveness with existing delivery options is a major driver. McKinsey suggests that, "in regions with poor road infrastructure or when pooling deliveries does not make sense" deliveries by drone may already be the most cost competitive delivery option. Looking forward, the ability for operators to manage multiple drones simultaneously, if enabled through regulation and technological innovation, could make AAM delivery services cost competitive with terrestrial alternatives, driving adoption.[245] Research commissioned by NASA indicates that last-mile delivery could become a commercially viable market by 2030, assuming autonomous delivery can substitute current delivery options.[246]

Considering passenger transport, cost-competitiveness with traditional alternatives is also driving AAM development. PwC estimates that in a UK-specific context, several potential AAM services offer socioeconomic cost savings upon entry into service in 2025 over counterfactual alternatives. These services are: rural rideshare, sub-regional shuttle, and air ambulance. Further, these results are robust to increases in vehicle cost, reductions in vehicle lifetime, and reduced flying windows.[247] Both PwC and LEK Consulting find cost-competitiveness of AAM services, across a range of use cases and counterfactuals, are also expected to improve dramatically over time (driven by continued technological advancement, increasing economies of scale, and improvements in airspace integration and scaling). LEK expects the cost per km of eVTOLs and vertiports to drop by 77% between 2025 and 2040 for urban services, and by 85% for regional services. At a high level, passenger services are expected to offer cost-advantages in certain use cases upon entry into service in 2025, and these will only expand as the technology matures and services are rolled out. LEK expects commercial attractiveness to be

Driver	Description
Improving business case	Projected falling costs of service delivery, coupled with perceived consumer interest, is driving AAM investment and development
Geographical factors	Terrain not easily traversed by traditional transport modes e.g. mountains, seas, swamps, provides a powerful case for AAM
Traditional transport infrastructure cost	Favourable comparison between infrastructure costs for an AAM network (which is also more flexible), and traditional road or rail infrastructure, especially across difficult terrain
Increasing urbanisation, congestion, and urban sprawl	Socioeconomic and demographic trends across global urban centres are perceived as complementary to UAM and last-mile delivery adoption
Rising wealth and incomes	Increasing disposable income among populations in areas which are highly attractive as AAM target markets

Economic and commercial drivers.

driven by factors including network scale effects, vehicle cost reductions, increased utilisation, ride sharing, remote piloting and increased automation.[248]

Country-specific terrain and geography may also drive the adoption of AAM in certain areas, with difficult-to-traverse terrain improving the economic case for AAM due to cost and time savings compared to terrestrial alternatives. In Europe, for example, Lilium has put forward an indicative transport network demonstrating the potential of AAM. This notional network spans Switzerland, Germany and France, and would offer direct routes over mountainous terrain and water, providing travel faster than rail or road alternatives at a fraction of the physical infrastructure cost.[249] In the UK, Vertical Aerospace has similarly proposed routes using its vehicles such as Belfast-Glasgow, crossing the Irish Sea, or Liverpool-Hull, transversing the Pennines.[250] Some observers have also noted the potential for AAM passenger transport in the Asia-Pacific for similar reasons, for example noting the potential for AAM services between Singapore, Malaysia and Indonesia.[251]

Related to considerations around terrain, economic considerations around infrastructure cost and flexibility are also driving the development of AAM. Lilium argues a RAM service offers benefits in that "it doesn't require expensive land-based infrastructure like roads or rails." Similarly Vertical Aerospace notes "comparatively limited infrastructure investment" for AAM travel, as well as highlighting AAM passenger services as a valuable complement to road and rail, easing terrestrial transport bottlenecks.

Broader macroeconomic trends are also driving interest and development in AAM. The combination of high income per capita and congestion, in cities such as Los Angeles, has provided a compelling case for UAM operations.[252] Economic growth in major global centres can lead to more congestion with enhanced job availability bringing more people to urban centres for work, an increased demand for delivery services due to growing urban population, rapid growth in number of high-income individuals, and to some extent, urban sprawl. Additionally, as cities grow, the demand for housing may lead to developers building further away from city, leading to the expansion of urban areas and urban sprawl.[253] These factors have combined to improve the attractiveness of UAM. Continued increases in urbanisation could enable a business case for AAM operations and has been explored in some survey efforts as a driver of AAM. KPMG, Garrow et al. (2021), and Roland Berger suggest the anticipated "urgency" of road congestion issues[254] from the growth of urban areas can enable AAM as a "potentially viable solution."[255] Roland Berger anticipate that urban sprawl and rapid urbanisation[256] will increase globally, driving the emergence of UAM systems as users look for alternative modes of transport.

Population growth in urban centres such as London may also drive demand for AAM services. The UK Government Office for Science[257] suggests that built-up areas in London were the "fastest growing places in population percentage terms, with Inner London having the most significant growth rate of 27%," compared to an average of 16% for cities outside of London, and that

London's contribution to England's GVA has been increasing since 2001, indicating the city's continuous economic growth over the past two decades.[258] The UK Office for National Statistics (ONS) finds that whilst London had the highest overall growth in employment between 2009 and 2021, out-of-town employment grew by 20% during the same period, and that after 2014 the "employment growth rate in out-of-town areas outpaced England and Wales average."[259] The statistics from ONS on increased non-urban economic growth shows these out-of-town areas can potentially be viable areas for rural and regional AAM markets.

Income and wealth are additional factors in urbanization can also drive demand for AAM operations. A survey of potential consumers conducted by Yedavalli & Mooberry found that survey participants in large regions with considerable traffic congestion and high levels of income and wealth, such as Los Angeles, were most receptive to using UAM.[260] Therefore, examining megacities with high income and wealth per capita while facing increasing congestion can help identify potential centres for successful urban air mobility adoption.[261] The Institute of Fiscal Studies show that high-net-worth individuals "have become more geographically concentrated in the last decade."[262] The ONS shows that the "median individual wealth was £157,000 higher in the South East than the North East of England and this regional disparity has increased over time."[263] These demographic trends specific to the UK may be useful when considering social drivers of AAM adoption and identify potential cities for UAM services.

5.2.4 Societal Drivers

Available literature suggests that demographic characteristics may drive AAM adoption. Therefore, area demographics are likely to drive initial AAM adoption, with further adoption occurring as the technology becomes more familiar, proven, and accessible. The characteristics of potential early adopters of AAM services resemble those of early adopters of electric and autonomous vehicle technologies, as individuals from certain demographic backgrounds (highly educated, high income) and with certain attitudes (environmental conscious and technology-oriented lifestyle)[264] are more likely to try new technologies.[265] Considering the UK,

Driver	Description
Demographic factors	Several demographic characteristics have been found to be associated with AAM adoption, and may drive initial demand as services are first introduced
Changing public attitudes to travel and residency	COVID-19 has encouraged remote working, and encouraged more individuals to move out of the city, leading to less frequent, longer commutes, driving demand for convenient travel options in and out of the city, and across regions. Further, consumers are increasingly valuing sustainable travel options, and are incorporating environmental impact into their willingness to pay
Regional disparity and policymaker attitudes	Several AAM use cases contribute to broader policymaker goals in terms of regional connectivity, local advancement, and environmental sustainability. This may drive continued support for AAM adoption amongst public officials

Societal drivers.

a YouGov technology survey suggests that 11% of Britain are early adopters and "make up a smaller portion ... than the global average," while 49% of consumers are "latecomers."[266]

Roland Berger, in considering regional air mobility, note changing public attitudes to air travel and residency as potential drivers of RAM. COVID-19 has caused more people to work remotely outside cities, with longer and less frequent commutes to work. Consumers are more willing to pay for environmentally friendly transport options, and options that are socially-distanced and less crowded. Lastly, the trend of staycations conceived during the pandemic is likely to persist.[267] All of these factors could come together to increase the attractiveness of regional air mobility and drive the market forward. In the longer term, as remote or autonomous operations are considered, Al Haddad et al. (2020) and Fu et al. (2019)[268] also suggest that perceived safety, trust, and affinity for automation[269] can be drivers that lead to adoption, with service reliability considered as a "highly influential" factor in the adoption of AAM and can lead to increased usage of AAM.

Societal factors can also encourage public officials to accept and encourage the adoption of AAM services. AAM can be considered a public signal of modernity and technological advancement, due to their novelty, which can drive city officials to integrate eVTOL operations at major events such as the Paris Olympics in 2024[270] and the Los Angeles Olympics in 2028.[271] Considering regional air mobility, Roland Berger identifies government desires to fulfil air service obligations and provide regional connectivity as a further driver. This could also arise as a driver in the UK, where regional air connectivity has been an ongoing topic of discussion, and the reduced costs and improved convenience regional AAM vehicles could provide once mature, may be attractive to governments. In the same spirit, public officials may be incentivised to support the adoption of various AAM use cases in pursuit of meeting their climate and pollution targets. For example, in the UK, adoption of AAM could contribute towards the government's Jet Zero strategy for sustainable aviation.

5.3 Market Barrier Review

Despite their potential benefits, the adoption and commercialization of AAM solutions face multiple barriers. In the early stages of AAM operations, flight volumes will be low and restricted to limited routes. Barriers during this stage notably include the development of regulations and certification standards, gaining public acceptance of AAM, and financial challenges associated with initial service and infrastructure developments. As the industry matures, manufacturing scale-up, societal acceptance, and infrastructure build-up will take place. The medium-to-late stages will see increased operating volumes, greater flexibility in travel routes, and the beginning of autonomous operations. During this period, barriers primarily relate to scaling infrastructure to enable the development of a larger network and the provision of increased services. Airspace management is identified as a barrier across all stages, with challenges evolving as the industry matures. For example, as technology matures, barriers regarding the integration of unmanned vehicles and autonomous operations will arise.

This section provides an overview of the general barriers identified throughout the literature review and identified during interviews with industry experts. Opinions on most significant barriers vary across the industry. While Morgan Stanley believes that social and regulatory barriers will be the primary challenge rather than technology,[272] Deloitte identifies ground infrastructure as "the biggest hurdle."[273]

Salient UK barriers and variables for these barriers are discussed in Section 6, Possible Government Interventions.

Table 5.9 summarises key market barriers, with further details provided below.

Barrier	Early Stage	Late Stage
Social	• Public acceptance and adoption of AAM • Privacy and noise concerns	• Trust in remote and autonomous flight
Technological	• Cybersecurity • Battery energy density, power and thermal management • Noise reduction • Technology maturity for detect & avoid, on-board sensors, GPS-denied environment operations	• Advanced air traffic management technologies and their integration into broader systems, to enable scaled operations, and, later, remote and autonomous flight • Maturation and integration of autonomous flight technology • Battery energy density, and maturation of hydrogen technologies
Infrastructural	• Insufficient availability of AAM passenger infrastructure, and potentially high investment costs associated with building up sufficient access points • Telecoms infrastructure needed for operations • Construction of vertiports and grid upgrades • Air traffic management infrastructure	• High investment requirement for construction of vertiports and other facilities (service centres, charging docks) or adaptation cost of existing infrastructure • Mass construction of vertiports required for on-demand models • Design and integration of locations to meet demand and convenience
Economic	• High development cost of vehicles, coupled with uncertainty in time-to-market • Cost of initial service • High investment costs for service providers • Unproven business cases	• Scaling of operations important to success, but only possible with suitable infrastructure, which requires a high level of investment and clearing of regulatory and local hurdles
Regulatory	• Policy, certification, regulation, and licensing • Local authority planning engagement • Coordinating with industry stakeholders	• Regulations keeping up with technological progress and operational needs
Operational	• Airspace systems and management • Integration and sharing of airspace • Competition for airspace usage • Poor and unanticipated weather conditions • Early-stage ATM challenges (increased workload for air traffic control)	• Integration of autonomous and remote flight with national air traffic management (ATM) or unmanned air traffic management (UTM) • Automation of air traffic management processes
Environmental	• Noise, impact to wildlife, land use, energy consumption and visual disruption	• Noise, impact to wildlife, land use, energy consumption and visual disruption

Table 5.9. Summary of AAM market barriers.

5.3.1 Social Barriers

Various organisations and industry entities regularly report on trust, automation, and service reliability barriers.[274,275,276] Users of AAM services need to feel safe using novel vehicles, since users' understanding of new technologies is a key factor to their comfort and willingness to fly. Survey participants have raised preferences for incorporating mitigations for failure modes, cybersecurity provisions, pilot incapacitation measures, and other aspects that would enhance users' safety in eVTOLs.[277] Survey results from multiple studies, including NASA-sponsored UAM market studies,[278] have found that respondents are uncomfortable and have a "negative view of automated cockpits."[279] Straubinger et al. suggest that "UAM is not yet tangible neither to the public nor to customers";[280] as 25% of survey participants state they would not use eVTOLs due to perception of safety.[281] Looking further into the future, Booz Allen Hamilton suggest that "drops in reliability" can "degrade trust in automated systems […] leading to decreased adoption."[282]

Participants in the UK Future Flight Challenge report expressed concerns over air collisions, airspace congestion, and disturbance, indicating some level of uncertainty over new technology implementation.[283] Safety was considered the most immediate concern for participants, with those from rural island or mountainous regions especially concerned about the safety risks of flying in adverse weather. Therefore, AAM service providers may need to extensively demonstrate vehicle safety records and reliability to improve public acceptance.

Barrier	Description
System safety	The general public is hesitant to use novel air systems with unproven safety records. Additionally, the risk exists that a high profile safety incident erodes public trust, and makes widespread adoption untenable
System vulnerability	Concerns exist among potential passengers regarding the susceptibility of AAM vehicles to hacking or sabotage
Distrust of automated systems	Notable proportions of the general public are distrustful of transport automation, particularly of aerial vehicles. This may prove a barrier to the rollout of automation of AAM vehicles for the purposes of cost and operational optimisation
Overhead flight: privacy and intrusion	Members of the public are concerned that overhead flights of delivery and passenger vehicles may invade their personal privacy. Equally, potential passengers of AAM vehicles have cited concerns that individuals on the ground would be able to look into the aircraft
Passenger privacy and safety	While ridesharing models for AAM vehicles seem to offer some commercial advantages compared to dedicated passenger operations, sections of the population are uncomfortable with ridesharing, citing safety and privacy concerns
Noise and environmental impact	Potential consumer surveys have further indicated that members of the public are concerned about the noise impact of AAM vehicles. Though tests indicate that vehicles could indeed operate within acceptable noise levels, community pushback, for example around take-off and landing sites, may hinder adoption. Additionally, consumers cite concerns around the environmental impacts of AAM, for example on bird populations. Visual pollution is also a concern

Social barriers.

Regarding cybersecurity, participants raised concerns around the potential for intentional damage caused by, or done to, future flight technologies. Additionally, participants expressed a preference for a piloted operations, noting suspicion around automated vehicles, and the perception that piloted operations remained superior with regards to "quick thinking" and "instinct."

NASA-sponsored AAM studies also suggest that "personal security and privacy"[284] were priorities for UAM passengers. Similar concerns exist for individuals living in areas of UAM operation. 47% of participants in the UK DfT Transport and Transport Technology Public Attitudes Tracker suggest privacy and intrusion as a potential disadvantage of UAM across all groups, while for uncrewed aerial drones, "concerns about privacy and intrusion were more strongly felt among older age groups and those living in rural areas."[285] In terms of personal security and safety, participants were the "least comfortable" sharing UAM taxi services with strangers.[286] However, it should be noted, that these concerns are not exclusive to AAM, but also present in rideshare car services. Additionally, Booz Allen Hamilton, McKinsey, and Crown Consulting all suggest another common concern raised by potential consumers, namely that aircraft windows can make users feel exposed, with perceptions that those on the ground would be able to see into the aircraft. Furthermore, those on the ground are uncomfortable with aircraft flying closely above them, citing concerns of privacy violations.[287] Therefore, most participants preferred limiting aircraft operations overnight in residential neighbourhoods and prohibitions on flights over residential areas.[288] Constraints on UAM operations, such as those to limit noise and address privacy concerns, may hinder the ability of air taxi services to serve networks within cities, limiting the reach of UAM operations.

> ***"There is a lot that needs to be done to explain AAM to the public, and help them understand its impacts. This is really hard to do when there is already bias of understanding regarding how these 'sci-fi future vehicles' will operate. There are already some barreirs to overcoming how the public perceives these services will be run."***
>
> – Senior manager of an AAM development programme

5.3.2 Technological Barriers

While undoubtedly a key enabler, battery performance and safety also remains a significant concern. Battery and electric propulsion technologies still face significant challenges in energy storage, energy density, and charge rates which can affect AAM mission ranges and service reliability. Deloitte suggests that energy management is "crucial" to determine how a vehicle would carry passengers or cargo, maintain a safety margin, and reload for subsequent trips.[289] HSBC suggests that eVTOL batteries require "extreme fast charging capabilities to achieve profitability for mass production and commercialization."[290] Straubinger et al. suggest that eVTOL

Barrier	Description
Battery technology	In the near term, battery safety may prove a major barrier, as manufacturers must balance making cell packages safe against weight and range constraints. Thermal management is a key consideration here. It also remains to be seen whether battery lifetimes and charging rates allow the business case to close. In the longer term, the introduction of longer-range use cases requires continued maturation of batteries with higher energy density, as well as, potentially hydrogen fuel cells
Cybersecurity	Given the safety impacts of a malicious cyber-attack against AAM vehicles or infrastructure, robust cybersecurity provisions are critical for AAM adoption. Improper provisions may hinder certification or licensing, or may result in a safety incident, grounding flights and eroding public trust
Air traffic management	Scaling of AAM operations to profitable levels requires their integration into a broader ATM environment that allows for high-volume, high-frequency flights at various levels of airspace. Insufficient progress on individual technologies, or their integration into a system of systems, would therefore serve as a barrier to AAM roll-out
Communciations, sensing, and navigation	As operations scale, and vehicles become more automated, high bandwidth, low latency communication systems, as well as robust navigation solutions will be required for safe operations. A lack of solutions, or inability to adapt networks to meet the requirements of AAM operators, will hinder roll-out

Technological barriers.

concepts face strict limits (~100 km) due to energy density of current batteries.[291] Morgan Stanley observes that "few" battery-powered drones currently exist that can carry over 10 pounds (~4.5 kg).[292] Shamiyeh et al. (2018) argues that energy management will be critical, since "as mission ranges decrease, transport energy efficiency reduces significantly."[293] HSBC further note that thermal management capability is a key factor in eVTOL safety as UAM batteries generate nine times the heat generated compared to an EV driving in highway conditions, and 100 times more when compared to city driving.[294] An MIT study indicated high risk severity of battery thermal runaway and battery energy uncertainty for multirotor and distributed electric propulsion aircraft.[295]

Further uncertainties remain about the maturity of AAM technology, which may slow its widespread adoption. Georgia Tech Aerospace Systems Design Lab and Al Haddad et al.[296] suggest potential technological barriers include cybersecurity and air traffic management.[297] Deloitte[298] and Straubinger et al. suggest that the safety of eVTOLs will depend on vehicle maturity, detect and avoid technology, and air traffic management systems. Therefore, failure to design a comprehensive ATM network or integrate AAM vehicles into national airspace may be a large barrier to implementing AAM operations nationally. Deloitte suggests that in a GPS-denied environment, AAM vehicles need on-board sensors, but gaps remain for these technologies to provide longer-range sensing and recognition capabilities required for autonomous flight.[299]

5.3.3 Infrastructural Barriers

Constructing vertiports will be necessary for the development of AAM and Straubinger et al. state that building AAM-dedicated infrastructure is a "challenge in regions where land is sparse and planning [application] durations for infrastructure are long and expensive."[300] While some existing infrastructure, such as existing airfields or heliports, can be used, these will still require retrofitting, and, more importantly, may not be sufficiently close to centres of demand to enable the business case of a particular route. Additionally, AAM rollout ideally requires that existing airspace users are not negatively impacted, and there is an open question whether some sites, in particular urban helipads, are suitable for accommodating additional airspace users in the form of AAM operators. Straubinger et al. and Deloitte note that extensive construction of vertiports and vertistops is required. Deloitte argues that designing and implementing the required ground infrastructure is "the biggest hurdle.[301] Straubinger et al. further adds that facilities, such as security checks, bathrooms, and recharging areas for electrical-powered vehicles, are likely to be needed to support AAM operations. They also note that there should be further studies conducted on the design of vertiports.[302]

For the most ambitious use cases of on-demand urban air taxis, the McKinsey[303] AAM market study suggests that the near-ubiquitous vertiports required may be prohibitively difficult to achieve, as dense infrastructure is required for 'door-to-door' on-demand service. The lack of sufficient infrastructure and space in

Barrier	Description
Land use and cost	Depending on the use case and geography, land for vertiports may be limited, and/or expensive
Construction costs	UAM in particular may require ubiquitous take off and landing infrastructure that is prohibitively expensive
Maintenance and operational costs	UAM use cases require substantial infrastructure for operations and maintenance, which may not allow the business case to close depending on use case and local conditions
Telecommunications infrastructure	High speed and ubiquitous telecommunications infrastructure will be required to support scaled AAM operations, posing a barrier in areas where telecommunications infrastructure is underdeveloped or not at a level that meets AAM requirements
Airspace management infrastructure	AAM-specific air traffic management infrastructure needs are expected to be substantial, with limited sectors beyond AAM players likely to offer investment
Charging infrastructure cost and availability	Broader transport electrification, especially the increased use of electric vehicles, is expected to increase energy needs, requiring an energy grid able to meet AAM needs. Further, at a local level, depending on operational requirements, local charging infrastructure costs may also be substantial

Infrastructure barriers.

some cities may make it challenging to establish vertiports to accommodate high levels of UAM operations. The ADS Urban Air Mobility Group further agrees that establishing successful business cases for UAM operations at scale necessitates substantial infrastructure for operation, maintenance, and charging.[304] While it is unlikely extensive construction will be required for early service and user adoption, it is crucial for scalability of AAM services. Within the UK, it may not be necessary to construct entirely new infrastructure, with established airfields offering opportunities for initial limited operations.

Straubinger et al. suggest telecommunication infrastructure also needs to be developed to accommodate UAM operations. According to Vascik et al., existing air traffic control operations may need to limit the amount of emerging AAM operations that take place in congested airspace because of limitations related to workload and radio frequencies.[305] KPMG's Air Taxi Readiness report suggests that UK infrastructure, primarily due to broadband and mobile connection speeds, falls behind other countries such as the US and China.[306] Therefore, infrastructure in the UK such as broadband and telecommunications require further development to support AAM operations.

Finally, Straubinger et al. state that UTM "cannot be expected to be driven by other markets."[307] This suggests that for the AAM industry to benefit from capable UTM infrastructure to support AAM operations, investment will need to come from the AAM industry itself, as other sectors simply do not have the requirements

"Without infrastructure the grid couldn't handle it. [...] If you don't build enough electrical infrastructure, this erodes the value proposition."

– Head of market development for UAM vehicle manufacturer

"There is currently a lack of national planning guidance. As the industry starts to take off, there has got to be some measure for local authorities to process what planning applications would look like."

– Senior manager for AAM vehicle operator

"There are questions about who will pay up front for [infrastructure] now. We need infrastructure builders but no one is sure how this demand will develop, therefore there is hesitation to build."

– UAM vehicle manufacturer representative

"Grid operators need to be able to guarantee supply of large amounts of electricity."

– Head of regulatory affairs at a UAM manufacturer

Figure 5.10. Interview quotes related to infrastructure barriers.

or knowledge to develop suitable infrastructure. Straubinger et al. suggest that UTM system design will "influence the economic exploitation of VTOL-based transportation" and indicate that AAM-related traffic management poses many unique problems for the sector.

Access to the power grid and issues relating to charging infrastructure may present additional technological challenges to UAM, as operations are "heavily dependent on battery charging and fast-charging capabilities."[308] Since AAM requires a significant amount of power to operate multiple missions, the current electrical grid infrastructure may not be capable of providing the required power to support a large fleet of UAM vehicles, which can lead to stress on the grid, long wait times and inefficient operations. Therefore, the long charging times may prevent high utilization of eVTOLs. A NASA study found that as EVs utilize more of the electrical grid, there would be less power capacity from the electrical grid for UAM uses and that the success of UAM depends on electricity availability.[309] In the UK, the electrification of cars is increasing with 4,500 vehicles registered every month, therefore, with the higher demand for energy and simultaneous charging of EVs and AAMs,[310] substantial investment in the national grid is needed to support the operations of a very large number of charging stations at vertiports. Investments in electrical infrastructure are therefore required from AAM stakeholders. Garrow et al. notes that the grid upgrades required to support UAM operations are "not trivial," with infrastructure costs ranging from \$100,000 (£72,710) for the installation of a 31 MW chargers[311] to \$80 million (£58.2 million) for a new substation bank to support 30 charges.

5.3.4 Economic Barriers

Affordability and the initial pricing of AAM services are considered barriers

Barrier	Description
Cost per passenger mile	Costs per passenger mile will be driven by a variety of factors, including vehicle costs and lifespans, pilot costs, infrastructure and maintenance costs, energy prices, etc. While costs are expected to be elevated initially, if costs cannot be optimised, and economies of scale established to a point where prices can be lowered and the market expanded, the investment viability of certain use cases may suffer
Equity of service availability	Even if desired pricing can be achieved, certain routes or networks may not exhibit the scale required to be financially viable. This may produce concerns around equitable service (as is the case with regional aviation today, where subsidies are sometimes introduced to keep routes open)
Scaling costs	While initial operations can be established, significant scaling is required thereafter in terms of vehicle count, service availability and operational frequency. The investment required is significant, and may pose an additional barrier if funding cannot be secured
Substitution risk	Certain AAM use cases may be at risk of substitution from alternative services. If terrestrial alternatives enter the market offering lower prices with minimal reduction in service quality, AAM market viability may be eroded. Examples include autonomous ground delivery robots for AAM goods delivery, and high speed rail lines that are already under construction for regional air mobility

Economic barriers.

to widespread adoption, with demand sensitive to price.

As also discussed within the context of market outlooks, ADS Advanced Air Mobility Group,[312] Georgia Tech,[313] and Al Haddad[314] suggest that AAM demand, and especially demand for UAM services, is likely to be highly price elastic. Goyal et al. modelled the sensitivity of demand by using various price points to find a price elasticity of demand (PED)>1 for all US urban areas they examined.[315] Such findings imply that it is a fairly constrictive barrier if industry cannot lower costs sufficiently to set viable service pricing.[316]

Participants in the UKRI Future Flight Challenge also expressed issues regarding unaffordability, unequal benefits to different groups, and emphasized the need to address inequality, and concerns that AAM technologies would be "too expensive for the majority of the public to benefit."[317] If costs per passenger mile cannot be brought down, and economies of scale established, therefore, the market viability of AAM passenger transport may be reduced. Additionally, since AAM infrastructure requires large spaces to land, participants were concerned that AAM may benefit those living in residential communities of single houses more than multi-unit living and flats.[318] Participants were also felt that genuinely affordable services would be less profitable, and therefore less likely to receive commercial investment. Further, concerns were raised that a shift to air travel may draw public funding away from already strained public services, such as rail and bus.[319]

The attractiveness of AAM for many passengers depends on users' willingness to pay for time savings against the higher prices of AAM services, which may not result in a compelling case if there are too few vertiports in urban settings. Furthermore, the ADS Advanced Air Mobility Group[320] suggests that since convenience is a key benefit for individuals, the viability of AAM may depend on high utilisation rate.

Business cases for AAM must also consider the investments required to scale AAM operations. Relevant costs include the capital cost of building aircraft, energy and battery costs, pilot salaries, at least in the early phase, and other maintenance costs, which represent roughly 70% of all costs.[321] The ADS Urban Air Mobility Group[322] thus suggest that AAM can only be economical at scale, however, scaling operations presents challenges in terms of building out necessary infrastructure, and overcoming technical and operational challenges in terms of airspace management. Further, vehicle manufacturers must move from engineering a certified vehicle, to large-scale, low-per-unit-cost production, which interviews suggested poses a formidable challenge.

Finally, Crown Consulting further finds that market substitutes may impact AAM market viability, including availability of autonomous ground vehicles (AGV) with lockers for cargo, and driverless cars for passenger transport. Specifically, if terrestrial alternatives become available that fulfil the same consumer needs as AAM (e.g., convenient fast passenger transport, or timely goods delivery), then the business case for certain AAM use cases may be eroded.[323]

5.3.5 Regulatory Barriers

The laws regarding urban activities vary across cities and nations, therefore a wide range of rules regarding drone zones and drone usage could impact AAM operations and profitability in numerous urban areas.

In order to facilitate the success of UAM while minimizing its potential negative impacts on nearby communities, regulators may need to regulate traffic density over residential areas and adjust current regulations governing low-level operations around vertiports.[324] Additionally, regulators need to consider how current regulations need to be applied to UAM. In the UK, the current design standards for aerodromes and heliports are not directly suitable for eVTOLs, given that these will "be able to perform manoeuvres during take-off and landing that would not be acceptable at heliports using existing rules," and will therefore need to be adapted, ahead of tailored design standards being introduced.[325]

According to Deloitte[326] and the ADS Urban Air Mobility Group[327] the lack of timely regulation for pilotless vehicles, airworthiness certification, and licensing requirements may pose a significant obstacle for AAM operations. Indeed, vehicle manufacturers have recently struggled to secure vehicle certification, and have shifted timelines for entry into service as a result.[328] Morgan Stanley suggests that regulations around safety will also be a key challenge for AAM services.[329] Both Morgan Stanley and Booz Allen Hamilton report regulatory barriers are unlikely to keep up with technological progress. Ascension Global suggests that integration of rules for crewed flights are

Barrier	Description
Infrastructure requirements and certification	Design standards for heliports are not directly suitable for eVTOLs, and will required adaptation at a minimum. For scaled operations, novel standards will need to be introduced. In order to not present as a barrier, infrastructure requirements and certification will need to maintain pace with industry developments
Vehicle certification and continued air worthiness	Given the novel technologies incorporated, certification and continued air worthiness of AAM aircraft poses considerable challenges and represents a significant active barrier. Balancing of certification timelines against ongoing funding represents an ongoing challenge
Flight rules and operational requirements	While flying under visual flight rules will be sufficient for initial operations, this will not be sufficient for regular, reliable, scaled AAM passenger operations. Scaled operations will require clear operating requirements in various environments, and may pose a bottleneck for service roll-out
Global regulatory alignment	Misalignments in certification standards, operating rules, pilot licensing, and other factors may result in a fragmented global market, that does not allow vehicle manufacturers and operators to expand, or may impose an additional burden if manufacturers are required to adapt their vehicles to different markets
Autonomous and remote operation standards & requirements	As vehicle manufacturers and operators begin to seek implementing remote and autonomous operations to bring down costs, a comprehensive regulatory framework will be required for certifying flight systems, ground segments, and operating rules. As with initial introduction, misalignments between industry and regulatory timelines may pose a barrier to rollout

Regulatory barriers.

"likely to be time consuming and labour-intensive", requiring "significant updates to many existing parts."[330] Though focused on the US, Crown Consulting produced a list of regulatory actions that would need to be taken to enable various AAM use cases, alongside expected timelines. These are substantial and see some regulatory items stretching 10+ years into the future, indicating that even if initial regulatory requirements can be met, the process of incorporating AAM regulation will be a long-term and ongoing process.[331]

In the UK context, the UK Air Mobility Consortium noted that current rules governing flights in instrument flight rules (IFR) "do not provide a viable framework to support the operations described in the use case" such as restrictions associated with altitude and separation minima.[332] Current AAM use cases seek to fly in Instrument Meteorological Conditions (IMC) with a large volume of traffic and at altitudes that can increase the risk of collisions, therefore, regulators need to consider how regulations can support the use case of UAM but also ensure safety when operations are scaled.[333]

In BryceTech's interview with industry stakeholders, concerns were raised concerning certification timelines. One aircraft manufacturer representative stated that the "greatest barrier to other markets is the lack of regulatory framework." Other aircraft manufacturer representatives suggest that existing aviation rules are "not always applicable [and] relied upon." Interviewees further stated that more industry engagement and enabling regulatory framework on ground infrastructure such as vertiport standards, vehicle design standards, battery charging stands, operating rules, and pilot licensing are needed. In addition, interviewees noted that the "lack of clarity on when standards will be adopted and the principles" provides uncertainty for operators.

Going forward, industry wants to see a level of alignment in vertiport design and regulations globally, and expressed concerns that the risk of different regulatory standards across the world could prevent manufacturers from selling or operating in other geographies, while too stringent regulations can "reduce competitiveness" of vehicles and increase the cost of production. An example of this can be seen in the People's Republic of China's certification of Ehang; while the two-seater EH216-S is expected to be certified, the Chinese process is unlikely to set a global standard, suggesting that Ehang may face delays to operate outside of China.[334] In the US, the FAA shift on how to type certify eVTOLs contributed to delays in Joby's JAS4-1's certification and pushed Joby's service into 2025.[335] Industry stakeholders further feel that adaptation and changes of regulation will take a long time to take place, and may affect operators' planned deployment timelines.

Therefore, it is important to ensure that certification standards regarding safety procedures, pilot licensing, and how AAM vehicles are certified are applicable across multiple countries. The UK can further align its regulatory standards by adopting EASA's practices and increase collaboration with key civil aviation authorities around the world interested in AAM operations. Global harmonisation and standardisation is also under active discussion within ICAO.[336]

"Greatest barrier compared to other markets is the lack of a regulatory framework."

– Head of market development for eVTOL manufacturer

"It would be good to have dedicated set of rules, for example which rules are applied relating to infrastructure, airspace integration regulations, and air operations rules. These are unknowns that should be clarified."

– Head of global regulatory for eVTOL manufacturer

"There is a lack of clarity on when standards will be adopted and what the principles will be… There is no regulatory roadmap for operations in the UK by the middle of the decade."

– Public affairs lead for eVTOL manufacturer

"Not helpful if the standards in different jurisdictions are majorly different. Why should a US vertiport look different to a vertiport in the EU? Currently it looks like regulators are taking dramatically different approaches in these areas… There needs to be alignment [across the world] for the good of safety, clients, and people. We would encourage more exchange and collaboration."

– eVTOL manufacturer regulatory representative

Figure 5.11. Interview quotes related to regulatory barriers.

5.3.6 Operational Barriers

Operational barriers to AAM services include concerns regarding the integration of AAM vehicles with other aircraft in congested airspace, and the potential changes to current air traffic management systems to accommodate autonomous aircraft. Furthermore, unfavourable weather or environmental conditions in some urban areas may reduce AAM service reliability and add safety concerns.

Airspace

Airspace integration of AAM vehicles is another concern related to AAM operations, with notable issues including the potential burden on ATC operators, and airspace capacity constraints.

Competition in lower airspace is highlighted by Straubinger et al. as a barrier, as airspace use during congested periods may be dependent on regulators' "ad hoc" decisions.[337] Sharing airspace is a concern outlined by Koparderkar,[338] as speed profiles, ascent and descent rates, and other metrics need to be "well represented" in ATM systems to "ensure predictability of conflicts" and support ATC operations.[339] In the UK context, it is likely there will likely be portions of airspace that are dynamically restricted, in events such as emergencies, and periodically require traditional airspace users to use airspace primarily used by UAM.[340] Therefore, operators and regulators need to consider where "integration and interoperability" is possible, and where "segregation" is "absolutely necessary" for aircraft.[341]

Barrier	Description
Airspace capacity constraints	Airspace, especially around cities and existing aerodromes, is already considerably congested. The introduction of a sizeable number of additional users poses a considerable challenge. If airspace cannot be made available for scaled AAM operations, without unduly affecting existing airspace users, it would pose a significant barrier
Airspace change processes	Current airspace change processes take considerable periods of time, and are resource intensive. AAM will require airspace changes to be implemented in a timely manner to enable initial operations. Beyond this, AAM use cases will increasingly require dynamic airspace change management. These both represent bottlenecks to AAM entry into service and scaling
ATC burden	An increase in the number of airspace users could impose burdens on air traffic controllers that may constrain the level of operations until processes can be automated and aggregated
Incorporation of uncrewed and autonomous sytems	Incorporation of autonomous and remotely piloted systems into existing airspace regime and systems represents a considerable challenge. Establishing a national UTM regime requires the integration of various systems and is expected to be difficult to achieve in the near-term

Airspace barriers.

The UK Air Mobility Consortium noted that "the regular and dynamic introduction of new UAM routes that will be necessary to scale operations will require quick changes to routes across large swathe of low airspace environment, where there are existing operations by other aircraft."[342] This report further notes that the proposed traffic levels in scaled UAM operators could create issues for ATC, as deconflicting traffic flow will require additional mitigation measures to "maintain the level of risk of incidents and accidents." HSBC notes that as AAM operations scale, ATC issues such as where aircraft are permitted to land and where drones are allowed to fly will become important.[343] The complexity of evolving airspace architecture therefore needs to be efficiently mapped and coordinated by all relevant parties.

Since fully autonomous aircraft are not expected to be introduced in the early stages of the sector's development, workload for air traffic controllers may gradually increase over time. While this at least avoids a sudden influx of workload, it may nonetheless lead to safety concerns. Additional air traffic concerns include uncertainties in how ATC communicate with remote pilots, single pilots, and autonomous systems, as well as the potential delay in communications during risky conditions and emergencies which can heighten safety risks.[344] Furthermore, voice-to-text technology "must reach high maturity" to be utilised safely in aviation, however it currently remains in research and development.[345]

Koparderkar suggests that understanding the level of service expected from ATC systems by autonomous aircraft is required. Koparderkar highlights many services to be considered, however notes that "depending on the level of autonomy and size, weight, and available power of the aircraft, the support needed from the air traffic management system may vary."[346] Moreover, there are also operational concerns regarding the responsibilities and handling of events such as emergencies,

> ***"On demand travel is in the back of everyone's minds. That dynamic travel can only be accommodated if the system allows more dynamic changing of routes. It can't take 3 years to get airspace changes. Right now you need much higher predictability to allow that to happen. The airspace policy and airspace change process does not allow for that dynamism."***
>
> – Air traffic management expert
>
> ***"Digitising and managing high volumes of flight within a low level and segregated air space will be very challenging at first."***
>
> – Senior manager for AAM infrastructure developer
>
> ***"The whole of the ecosystem needs to be brought together. It is not enough for two trial airports to be speaking. When we design routes, we need to be designing for the whole transport network."***
>
> – Air traffic management expert

Figure 5.12. Interview quotes related to operational barriers.

managing large-scale disturbances, and collision avoidance. Straubinger et al.[347] and Koparderkar suggest that the near-term introduction of unmanned air traffic management (UTM) is "questionable" due to the difficulties of integrating multiple systems in early operations. UTM systems may be hard to integrate given the already "limited capacities of airspace" for crewed aviation and will have to transit through uncontrolled and controlled airspace, depending on the flight destination.

Operational Safety and Security

High-tempo operations at low attitudes in cities may increase risk of mechanical turbulence from tall buildings, and temporary obstructions to UAM flight path such as construction cranes needs to be considered.[348] Close proximity aircraft operations introduce risks of damage to nearby aircraft, especially in cases where loose items such as charging cables or maintenance equipment are nearby.[349] Furthermore, the downwash characteristics of eVTOLs needs to be examined, including considerations on their impact of vertiport designs, and how the safety of daily on-demand operations

Barrier	Description
Urban environment risks	Environmental interactions with buildings in an urban environment may pose risks to aircraft safety. Additionally, urban environments produce temporary obstructions (e.g. cranes set up on building sites) that also pose a safety risk. If these cannot be overcome they pose a barrier to service introduction
Take off and landing risks	Downwash, especially in congested aerodromes, poses a safety risks, and may constrain levels of operations
Security screening requirements	The potential need for security screenings in vertiports and airports (if AAM vehicles share airport infrastructure) may produce transport bottlenecks which erode the value proposition of quick convenient travel, and may pose as a barrier for scaling of operations

Operational safety and security barriers.

may be affected. Potential issues with downwash in dense urban areas may lead to unanticipated dangers for maintenance workers at vertiports and for passengers. Additionally, persistent downwash can affect take-off and landing for other aircraft, which can not only lead to an uncomfortable ride for passengers, but also increase the risk of accidents occurring. A recent UK study noted the current lack of existing research into the downwash profiles of novel vehicle designs.[350] Operators must therefore consider vehicle spacing, take-off and landing time allocations, and ensure surrounding infrastructure are suitable to accommodate downwash.[351]

Additionally, interviewees noted that, in terms of security, mitigating the risks of hijackings and terrorism may necessitate implementing security screening measures to ensure the safety of all passengers. It is currently uncertain whether UAM and RAM vehicles can share landing pads in airports, or whether landing zones will be located outside of the airport's vicinity. Should vehicles be permitted to share airport landing zones with airline passengers, achieving the level of security screening to that of large airports at small vertiports would require extensive investment and monitoring. Additionally, undergoing security checks for an intra-city trip could prove to be a time-consuming process for passengers. Alternatively, if the level of vertiport security is less stringent than of airports, passengers may be required to undergo additional screenings at the airport, which could result in longer wait times, increased total travel duration, and diminish the time saving benefits UAM could provide.

Weather

Barrier	Description
Impacts on service availability	Service availability may be reduced by weather in unfavourable operating environments, eroding the value proposition of certain use cases
Impacts on operating ranges	Real-time changes to flight plans will practically reduce operating ranges, constraining viable routes
Impacts on vehicle performance	Weather conditions, particularly humidity and temperature, may directly affect vehicle performance, e.g. increasing maintenance requirements, potentially eroding profit margins or constraining viable routes

Weather barriers.

Booz Allen Hamilton[352,353] and ADS Urban Air Mobility Group[354] further highlight weather as a potential limiting factor to AAM operations, service supply, passenger comfort and traffic management. Reiche et al. (n.d.)[355] suggests conditions such as high winds, visibility, and ice may affect UAM operations. Locations with weather characteristics such as "high temperatures, strong winds and thunderstorms" are seen as unfavourable for UAM operations, and may significantly constrain service availability. Findings from studying US cities show that it is important to factor weather characteristics and the impact on ride quality and service reliability, when determining where UAM services can take place.

An exploratory study by Uber Elevate (2016)[356] notes that cities such as London may have weather constraints[357] and that commercial airlines in London are "restricted due to atmospheric constraints," mostly "due to thunderstorms, low clouds, fog and icing," which can delay operations. The

Connected Places Catapult's Droneport Framework suggests that smaller drones may face "greater sensitivity to weather" and "flying drones in adverse weather can result in loss of situational awareness ... and loss of aircraft."[358] Some weather concerns relevant in the UK context include icing, rain, snow, humidity and changes in precipitation states which may increase risk of inflight icing, electrical failures, reduced visibility, fouling of rotors, and damaging UAS electronics not sealed to water.[359] The report suggests facilities should consider engaging with meteorological services during planning stages to identify challenges in the UK weather.[360] When accounting for the impact of weather avoidance on AAM operations, the UK Air Mobility Consortium notes that "consideration will need to be given to the ability of UAM operations to respond to real-time changes to flight plan and specifically deviations which elongate flying time/distance outside of the vehicle's endurance limits."[361]

"Certain technology components can degrade faster [in hot and humid conditions]."

– Assistant director of non-UK civil aviation authority

Figure 5.13. Interview quote related to weather barriers.

5.3.7 Environmental Barriers

While the reduction of emissions is considered a driver to AAM adoption, other potentially negative environmental impacts such as noise pollution, energy usage, and visual disruption have been cited as concerns for AAM operations by McKinsey, Crown, and Booz Allen Hamilton.

Barrier	Description
Noise and visual pollution	If noise and visual pollution of AAM operations exceed thresholds acceptable to the public, viable operating domains may be considerably constrained
Wildlife impacts	AAM operations, especially at scale, may have adverse impacts on wildlife and livestock, for example on bird populations through in-air collisions. This may constrain operating volumes or routes
Raw materials and supply chain	Sourcing of lithium and other raw materials for AAM may have adverse environmental impacts, as may the disposal or recycling of batteries

Environmental barriers.

McKinsey suggests that environmental threats such as noise, impact to wildlife, energy usage and battery waste will impact public acceptance for AAM services, while Crown Consulting outline noise as a main environmental challenge. Booz Allen Hamilton agrees that visual pollution and noise impacts will challenge AAM adoption. Visual disruption due to aerial traffic was cited as a potential concern by survey participants in the McKinsey AAM Market report, although not as significantly compared to environmental impacts such as noise.[362] The ADS Urban Air Mobility Group[363] and surveys such as the McKinsey AAM study[364] and Crown Consulting passenger acceptance survey, reveal that noise footprint and environmental impacts all contribute to passengers' willingness to use AAM services.[365] Participants in the NASA-sponsored study discussed issues of multirotor and wingtip speed noise,[366] indicating that these are "leading concerns" for eVTOLs.[367] Participants in the UKRI Future Flight Report also noted concerns of noise in rural areas.[368] A Booz Allen Hamilton study also found that noise concerns could pose a "notable obstacle" in the future.[369]

Other environmental concerns include land usage and emissions resulting from construction given the scale of infrastructure required for AAM operations. Environmental sustainability and balancing aspects of ecology, emissions, and noise with large AAM operations will be crucial for AAM operators. Participants in the Future Flight Challenge Public Dialogue Report expressed concern regarding the impact on biodiversity, bird habitats, and livestock, and raised the need for monitoring activities to assess wildlife impacts.[370] In addition, participants raised issues regarding visual disruption and protecting areas of natural beauty (AONB), such as Snowdonia, with rural areas raised during the discussion of no-fly zones.

Finally, the concerns raised regarding raw materials and supply chains for electric vehicles likely also apply to AAM vehicles. The sourcing of lithium, and other raw materials for batteries is a point of environmental contention, as is the environmental impact of battery use and recycling. The environmental impact of AAM along the supply chain may therefore pose a further barrier.

Almost all reports (Roland Berger, Deloitte, Booz Allen Hamilton, Straubinger et al.) emphasize that social acceptance is a prerequisite for the widespread UAM adoption, and that environmental concerns play a critical role in shaping public attitudes towards this emerging technology.

5.4 Future UK Market Viability

As studies suggest, AAM operations in the UK may be economically viable and there is potential demand for AAM services. Regional air mobility seems particularly viable, offering cost-competitive alternatives to existing rail and road routes, as well as offering the potential to create new routes, improving interregional connectivity and convenience, faster, and at reduced capital cost. Economic, environmental, and time-saving drivers may contribute to AAM adoption, as AAM vehicles are generally expected to be less carbon intensive than internal combustion engine automobiles and aircraft, and can provide faster trip times. Technological progress in software applications will enable on-demand AAM operations, while developments in hardware will enable the scaled production of vehicles, increasing supply of AAM services, and a potential decrease in end user pricing.

However, the scale of each AAM use case is still uncertain and large challenges remain. Future routes that are not currently travelled are difficult to quantify in terms of demand and economic impact. Furthermore, consumer perception remains a big barrier; distrust in automation and new technology may mean it could take a long time before users are willing to try AAM services, feel comfortable to integrate AAM into their daily commute, and feel acclimatized to seeing AAM in operation. Technology barriers remain in how to integrate AAM operations into airspace safely and will continue to be a challenge when remote and autonomous operations are introduced. Assessing the right price, and how to adapt pricing to demand, will be another challenge to market viability; it is important that operators can determine a viable price point that can capture demand but also enable steady revenue growth.

Secondly, while regulatory progress has been made, industry stakeholders are uncertain regarding many elements such as certification, pilot licencing, safety standards, operating rules, timelines, and the stringency of design and production standards. However, it is important that the UK jointly work with EASA and other international stakeholders to develop a translatable set of rules, operating framework, and licensing standards so that UK-based manufacturers and operators feel empowered to expand AAM operations abroad and international providers see the UK as an attractive market to invest in.

Should barriers be overcome, some of the more optimistic market outlooks explored in this section may well come to pass. What could prevent the realisation of projected market potential, in the UK and globally, therefore? Fundamentally, this question rests on the time taken to reach profitable unit economics, and AAM companies' financing runway.

A worst case scenario would see some of the most pressing barriers explored in this chapter resulting in untenable delays to revenue generation and profitable flights. Aircraft certification could uncover unforeseen issues, and take longer than expected. Operators could take flight, but struggle to secure desired airspace changes and expand their operations. Companies could face difficulties in scaling their aircraft production and reaching competitive pricing levels. Currently, certification appears to be the most pressing issue, however, infrastructure and airspace availability, as well as public perceptions, were also raised as amongst the most urgent barriers in interviews. In an unfortunate scenario, these circumstances could couple with an unfavourable macroeconomic and funding environment to result in bankruptcies and cessation of operations. This need not mean the end of the industry, as intellectual property would be acquired, not lost, and could be built on. Regulatory lessons learned would also prevail. However, such a scenario would see progress, and therefore the realisation of market potential, delayed by years. Many other factors and events could result in similar outcomes. A major safety incident, for example, could set the sector back decades.

The barriers discussed in this chapter are multifaceted in nature, and cannot be addressed by any single stakeholder group. A path likely exists to navigate the barriers that exist for AAM, and realising the market potential that many have forecast. However, this will require a collaborative, iterative, and responsive approach to market building. This should involve safety-conscious, transparent, frequent testing of vehicles in order to gather the technical and operational data required to inject certainty into decision making. Government has a part to play in supporting industry towards an economically viable market. Potential initial interventions that could be taken in the UK are discussed in the next chapter.

6 Possible Government Interventions

This section explores possible government interventions that could be taken in the UK to further strengthen the AAM ecosystem. BryceTech explored salient barriers in the UK to the introduction and scaling of AAM by speaking to multiple industry and government representatives, and referencing literature. These conversations revealed that the availability of vertiport infrastructure is viewed as a considerable barrier to scaling UAM services to become affordable, and that public acceptance of AAM is critically important for adoption. Interviewees also discussed optimisations that could be made to the UK's policy and regulatory system to ensure a continued position of global market prominence. Finally, several interviewees discussed the importance of building an airspace system compatible with profitable AAM operations.

Based on the barriers identified in interviews, comments regarding their root causes, and available literature, BryceTech identified barrier drivers. Informed by these drivers, recommendations made by interviewees, and long-listing of policy options, longlists of possible government interventions were drafted for each barrier category. These were filtered according to several critical success factors, but, importantly, agnostic of resource constraints, in order to provide a shortlisted portfolio of government interventions. This shortlist of interventions was qualitatively assessed for their costs and benefits. Finally, a recommended list of high-impact, low-cost interventions were proposed, which could be implemented in the near-term to have tangible impact at minimum cost. In addition, further interventions were drawn out for consideration, with higher expected costs, but nonetheless high expected benefits.

It is important to note that whilst this evidence review was being conducted, the UK government co-launched the Future of Flight Industry Group (FFIG) with industry partners. This is co-chaired by Baroness Vere, the minister responsible for aviation, and Duncan Walker, CEO of Skyports. The intention of the FFIG is to jointly draft and publish a UK strategy referred to as the Future of Flight Action Plan, which will include the AAM sector. Since the launch of the FFIG occurred following the conclusion

Key Findings

The challenges facing the AAM sector are highly interlinked, and therefore, it is expected that implementing interventions in one area may well reduce frictions in other areas, further helping the AAM market to grow and develop. Four key barriers were identified based on the findings presented throughout this evidence review. Within each barrier, a low cost and more resource-intensive intervention was identified and recommended based on the results of a a shortlisting process.

Availability of AAM Passenger Infrastructure

- Low cost: Issue a national policy statement, setting out the government's position on the prioritisation, nature and roll-out of AAM infrastructure in the UK
- Resource-intensive: Conduct an information campaign to local planning bodies on AAM impact, infrastructure, and planning

Public Acceptance and Adoption of AAM

- Low cost: Actively facilitate the conduct of demonstration flights of AAM vehicles for commercial use in areas accessible to, and viewable by, the public
- Resource-intensive: Provide funding for provision of AAM use cases where public value is clearly visible, such as patient transport and medical goods delivery

Policy, Certification, Regulation, and Licensing

- Low cost: Publish a strategic regulatory action plan for AAM in the UK, laying out envisioned timelines of AAM roll-out and regulatory milestones to be reached at each stage, clear assignment of responsibility, as well as perceived opportunities and risks of AAM in the UK
- Resource-intensive: Increase CAA resourcing, particularly within design and certification teams, and assess pay scales for key roles to ensure the attraction and retention of necessary labour

Airspace Systems and Management

- Low cost: Enable rolling airspace trials in order to enable initial operations and trial of AAM flights in the UK
- Resource-intensive: Provide continued challenge funding for the development and fielding of technologies require for scaled AAM operations

of interviews, some comments in this section may not reflect this activity. At the time of publication, the work of the FFIG is well-established, with the drafting of the Future of Flight Action Plan underway. The points raised throughout the interviews held as part of this review, along with the wider body of evidence, are being considered and will inform the direction of the Future of Flight Action Plan.

6.1 Approach

BryceTech first conducted a review of the international context in terms of government interventions, identifying and summarising government actions taken in other nations. BryceTech also produced a summary of existing interventions to date in the UK.

With these reviews as context, BryceTech took a six-stage approach to identify and down-select potential UK government interventions, informed by Green Book[371] and Magenta Book[372] guidance.

1. **Current UK Interventions and the International Context.** Examined to draw a base case if no action were taken, and put UK actions in a global context

2. **Salient UK Barriers.** Identified using targeted industry interviews, and drawing from the literature review of market barriers
3. **Intervention Options.** Identified to produce a long-list of possible interventions, which were then scored in order to create barrier-specific shortlists
4. **Shortlisted Intervention Appraisal.** Conducted by qualitatively assessing costs and benefits of shortlisted interventions
5. **Recommended Interventions.** Identified by barrier category, and their intervention rationale and theory of change described

6.2 UK Advanced Air Mobility Policy Context

This section outlines existing Advanced Air Mobility (AAM) UK policy context to help define the counterfactual and build a case for change for any possible additional government interventions.

The Department for Transport (DfT) is the UK Government department responsible for delivering the following priority outcomes:[373]

Improving connectivity across the UK and growing the economy by enhancing the transport network, on time and on budget

- Building confidence in the transport network as the country recovers from COVID-19 and improving transport users' experience, ensuring that the network is safe, reliable, and inclusive
- Tackling climate change and improving air quality by decarbonising transport
- Increasing the global impact of the UK, boosting its influence and maximising trade

DfT leads UK strategy and policy for the aviation sector and has a range of possible levers for government intervention, including stakeholder engagement and consultations, communications, legislation, regulation and spending.

The Civil Aviation Authority (CAA) is the UK's independent specialist aviation regulator sponsored by DfT whose mandate is set by Parliament. UK Government requires that the CAA's costs are met entirely from charges to those they provide a service to or regulate. The CAA works so that:

- The aviation industry meets the highest safety standards
- Consumers have choice, value for money, are protected and treated fairly when they fly
- Through efficient use of airspace, the environmental impact of aviation on local communities is effectively managed and CO_2 emissions are reduced
- The aviation industry manages security risks effectively

Most aviation regulation and policy is harmonised across the world to ensure consistent levels of safety and consumer protection. Worldwide civil aviation safety and security regulations are set by the International Civil Aviation Organisation (ICAO).

DfT's *Flightpath to the Future*[374] sets out a ten-point plan for aviation focusing on four key themes:

- Enhancing global impact for a sustainable recovery
- Embracing innovation for a sustainable future
- Realising benefits for the UK
- Delivering for users
- Embracing innovation for a sustainable future includes drones and new aircraft such as electrical vertical take-off and landing aircraft (eVTOLs)

Enabling the introduction of these new types of aircraft is key to the future of aviation and achieving the UK Government's and Department for Transport's objectives. As set out in this report, AAM presents opportunities for low carbon local and regional air mobility for goods and people. These opportunities also feed into the UK's Jet Zero strategy of achieving net zero aviation by 2050.

Alongside the potential opportunities AAM presents, there are a number of barriers as set out in this report. It is crucial that the market is developed in the right way with proportionate government interventions. To help build any necessary case for change, examples of recent AAM and AAM-related projects and government interventions can be found in Appendix A3.

6.3 International Context

A selection of the most prominent international interventions taken, in addition to the public investments previously described, were reviewed in order to further inform the process of intervention selection (which can be found in Appendix A4). Several countries, including the US and Japan, are working towards establishing a firm regulatory framework for AAM vehicles that will act as a first step in their plans to stimulate development. Promotional efforts such as public events and campaigns were also common amongst the interventions, with many countries focusing on the social acceptance of AAM as a mode of transport and delivery. Multiple countries have also been engaged in roadmapping activities, as well as active facilitation in trials, securing operational data and enabling optimisation of related operating rules and regulations.

6.4 Salient UK Barriers

To understand UK specific barriers and their component elements, the study team conducted interviews with experts and stakeholders, and referenced relevant literature. Of the general barriers in Table 5.9, the following barriers were viewed as particularly relevant to the UK:

- Insufficient availability of AAM passenger infrastructure
- Public acceptance and adoption of AAM
- Policy, certification, regulation, and licensing
- Airspace systems and management

Of these barriers, driver trees were produced to better demonstrate the factors that feed into the barriers themselves.

6.4.1 Insufficient Availability of AAM Passenger Infrastructure

Multiple interviewees raised the availability of vertiport infrastructure as a notable barrier to the commercial scaling of AAM passenger travel in the UK. Of the vehicle integrators and operators interviewed for the study, all raised concerns that the vertiport and airfield infrastructure needed for commercially viable operations may not be developed in time to unlock the value of novel routes in a reasonable timeframe.

Several reasons for these concerns were provided. Firstly, concerns were raised that uncertainty surrounding vehicle certification timelines and airspace modernisation would translate to the investment case for take-off and landing facilities. This would reduce investor willingness to finance these projects until greater clarity on operating conditions and greater certainty regarding profitable operation could be obtained.

Secondly, multiple interviewees raised concerns that the UK planning system is ill-equipped to build out the necessary take-off and landing infrastructure to fully realise the potential economic value of AAM. The difficulties and timelines of obtaining planning permission were raised, as well as a perceived poor integration of planning processes with other required developments such as airspace change.

Lastly, some interviewees noted that, even where existing infrastructure could be used, difficulties remained in the adequate outfitting of facilities to accommodate AAM passenger travel. Again, airspace amendment was noted as an issue, as was the current lack of sufficient electrical infrastructure in airfields to allow the accommodation of necessary charging infrastructure for electric aerial vehicles.

6.4.2 Public Acceptance and Adoption of AAM

Several interviewees raised concerns around public acceptance of AAM operations. Interviewees expressed that there may be public doubts around pricing and accessibility in the early phases of AAM implementation. Further, it was stressed that it was extremely important for public confidence in vehicle safety, as well as cybersecurity considerations, to be upheld.

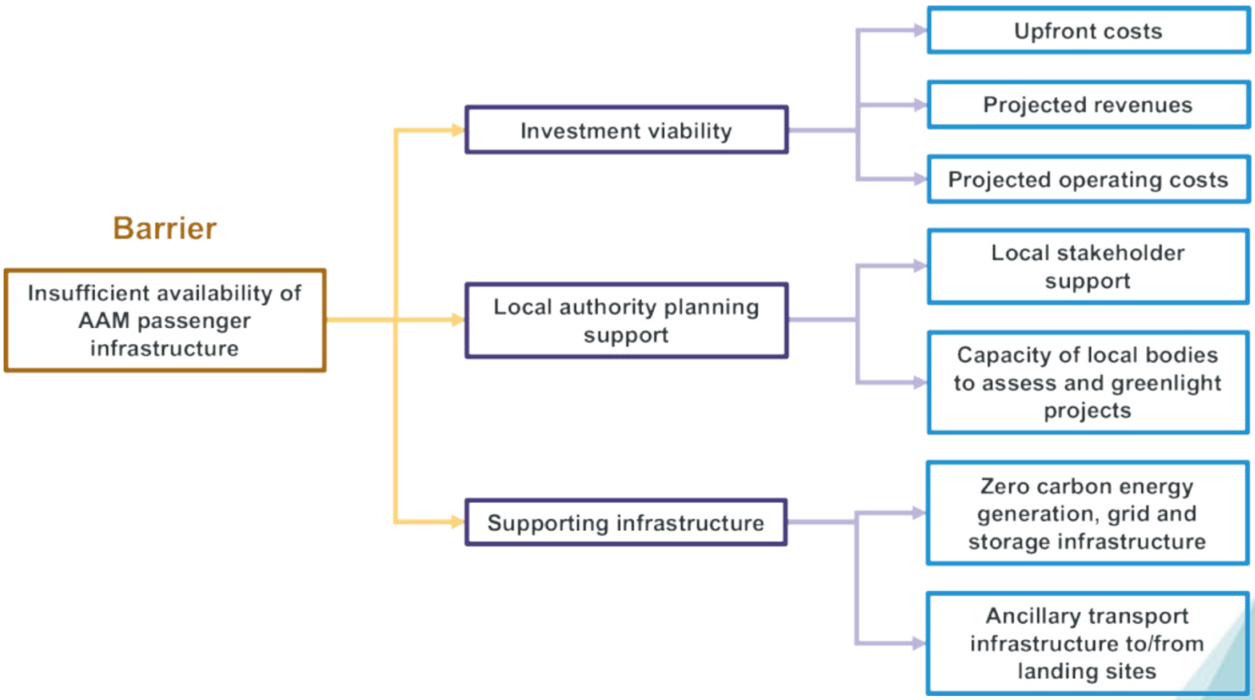


Figure 6.1. Driver tree of infrastructure availability barrier.

Interviewees also raised concerns that, despite the expected lower noise output of vehicles, preconceptions formed by alternative aerial transport options such as helicopters would create a pre-emptive backlash against operational deployment. Several interviewees also noted having observed public concern around the impact of AAM on the natural environment, particularly on birds.

Finally, and in part feeding into the prior elements of public concern, several interviewees expressed concern that if the public does not have opportunities for direct experience with AAM, it may remain an abstract concept that people attach with their preconceptions and concerns.

6.4.3 Policy, Certification, Regulation, and Licensing

Most interviewees noted issues in the development of a regulatory system for AAM as a barrier. It was universally recognised that clear regulations, standards, processes and guidance for vehicle certification, pilot and vertiport licensing, security, and operations, were fundamentally necessary conditions for the success of the ecosystem.

However, most comments made around certification, regulation and licensing were not on the implementation of these measures themselves, but on the nature in which they are being implemented, and whether their content would match industry needs. Interviewees generally did not doubt that regulatory measures in key fields would be introduced at some point. Rather, they expressed concerns that the manner and timing by which this was done, and a lack of adequate industry consultation, may inhibit UK industry and put the UK at a competitive disadvantage. As such many factors within this barrier category are not government failures per se, but rather opportunities for optimised policy delivery that, if implemented, would reduce frictions for industry and allow eased roll-out and innovation.

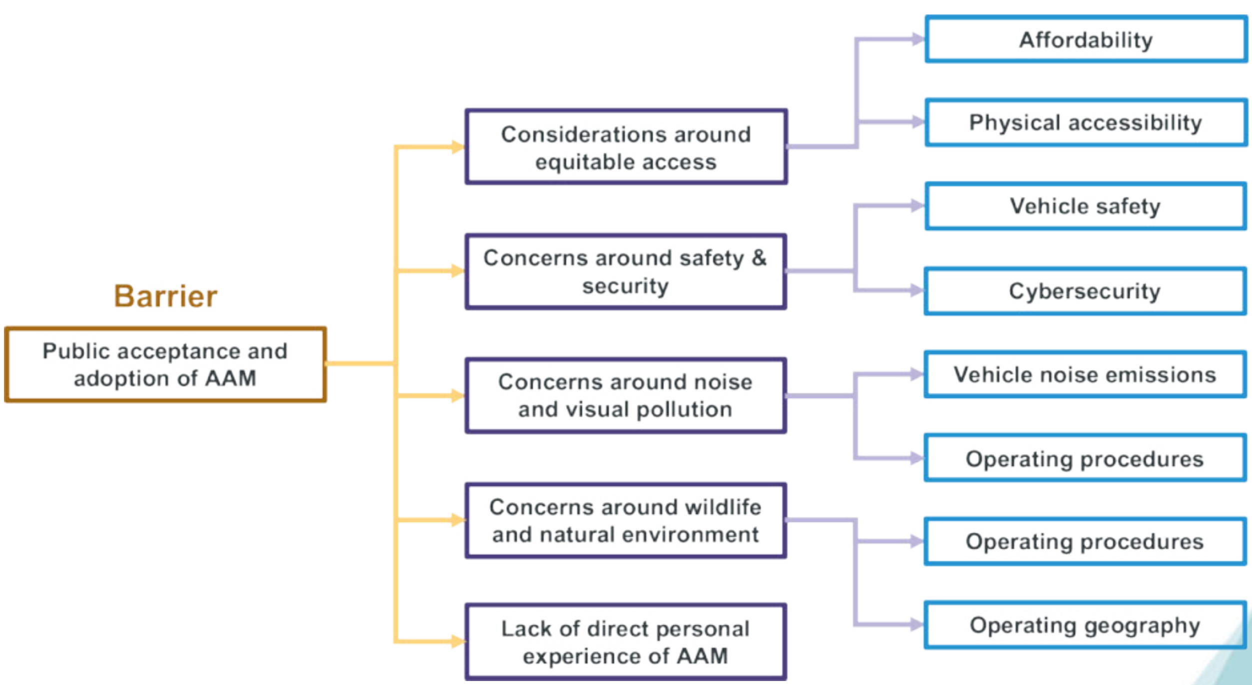


Figure 6.2. Driver tree of public acceptance barrier.

In particular, concerns were expressed that no clear regulatory action plan currently existed for the commencement of AAM operations by the middle of the decade. Some interviewees were concerned that a regulatory framework was not clear, and would not be available in a timeframe that would allow for limited initial commercial operations to take place. Further, interviewees expressed a clear desire for a marked increase in the level of industry engagement in the formulation of emerging rules, regulation and policy. Interviewees also made clear that government prioritisation and positioning in terms of the use cases, benefits and roll-out of AAM was critical. One interviewee noted that, whilst other nations, had publicly recognised the benefits of AAM and voiced these at ministerial level, no such public recognition had been observed in the UK. Some interviewees also expressed concerns that regulatory and certification bodies were insufficiently resourced to implement necessary measures at a pace that matched other leading geographies such as the EU and US. While this issue is recognised by relevant entities in the UK, it is nevertheless a matter that requires attention. Finally, some interviewees reported inconsistent messaging between government departments on AAM, as well as between different levels within the same department. Closer interdepartmental coordination on key positions, and the dissemination of these positions throughout different levels of departments, was urged.

In the time since interviews took place, the FFIG has been considering the evidence above through the development of the Future of Flight Action Plan. In addition, significant structural changes at the CAA

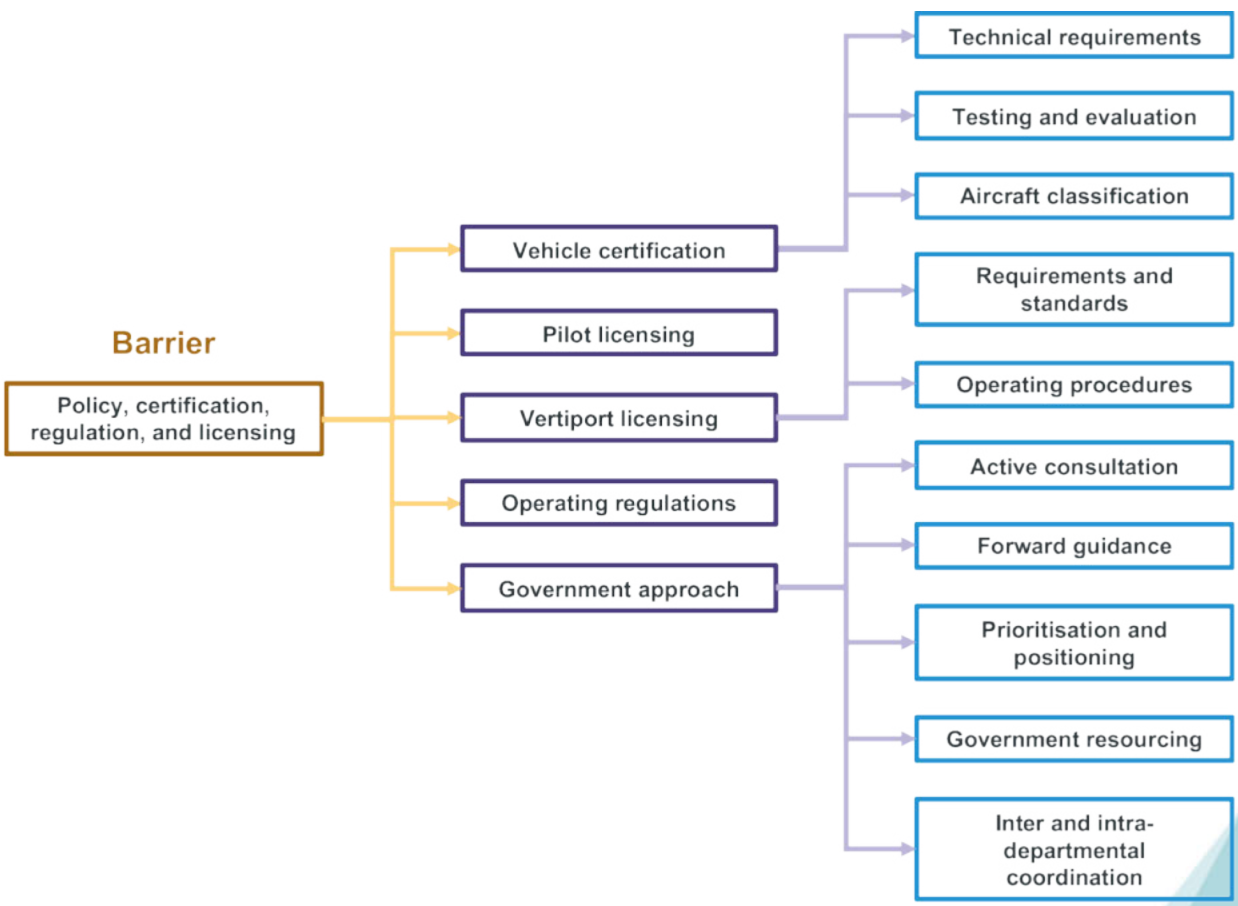


Figure 6.3. Issue driver tree of certification, regulation, and licensing.

have taken place in order to more effectively support new, innovative technologies.

6.4.4 Airspace Systems and Management

Several interviewees indicated that scaling AAM operations to a profitable level would be challenging under the UK's existing airspace regime. While most interviewees believed that the current regime was sufficient to allow for early-stage trials and initial low-volume operations, it was unanimously agreed that the sector would not be able to scale under current arrangements. Work on achieving this is ongoing, with the publication of the UK's Airspace Modernisation Strategy (AMS), which explicitly calls out the need to accommodate AAM vehicles, and sets a path forward for future airspace change and management.[375] This said, practical elements that could be addressed in complement to ongoing work under the AMS were identified by interviewees.

While initially, AAM flights can be conducted under visual flight rules, operations under IFR will be required for scaled and predictable operations. One interviewee hypothesised that, if original equipment manufacturers (OEMs) did not see a clear path to IFR, they may consider transitioning to a different national jurisdiction.

The changes in the UK's airspace structure and change process were also raised as potential hurdles to overcome. One interviewee noted the uncertainty, given lack of operational data, regarding the most appropriate airspace structure to accommodate AAM vehicles. Another interviewee noted the need for, and challenges to, ensuring that changes to airspace are not exclusive, and do not impede the operations of other airspace users already present in an increasingly congested airspace environment.

The airspace change process, and its modification, was also raised as a potential barrier. The current CAP1616 process was described as being unsuitable for the increasing dynamism required for AAM as it scales, in particular, as on-demand models are explored and rolled out. Currently, airspace change consultations can take years, and require considerable stakeholder engagement. It was noted that this would be complicated further by

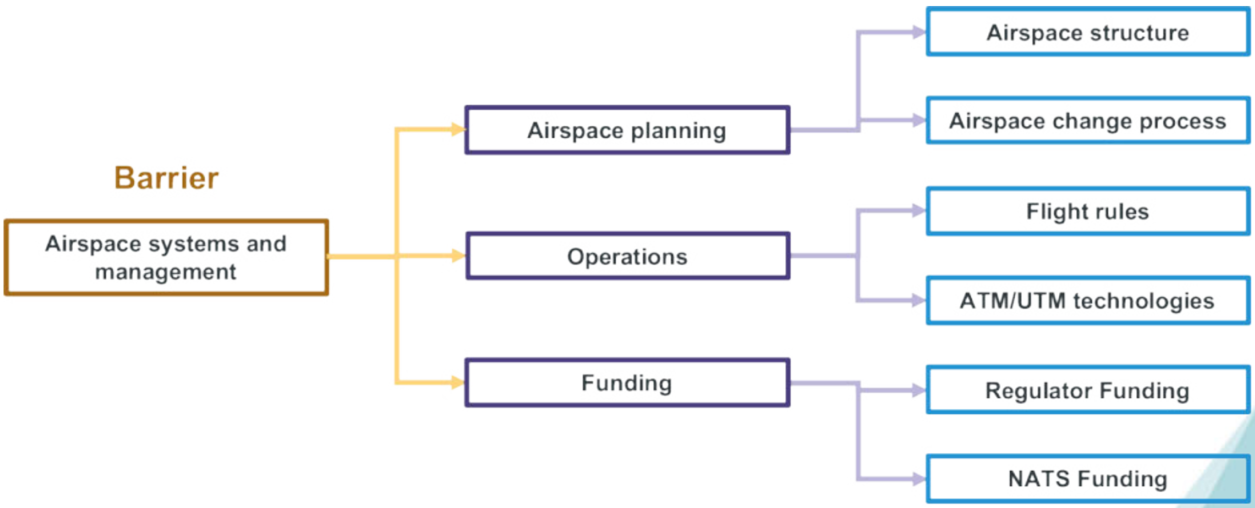


Figure 6.4. Issue driver tree of airspace barrier.

the fact that the introduction of vertiports, especially in built-up urban areas, would involve a considerably higher number of stakeholders than is usually seen in traditional consultations.

It was noted by several interviewees that the accommodation of a large number of AAM vehicles, especially if these begin to adopt remote or autonomous piloting models, would necessitate considerable technology shifts in air traffic control systems, which would also need to shift to a more autonomous model. Interviewees envisioned the role of human air traffic controllers shifting from technical control to strategic planning, in order to accommodate a higher volume of flights. This represents a significant shift from current operating models, one that will require considerable trials and investment to achieve effectively.

Funding the required air traffic management changes was raised as a currently unresolved issue, though consultation is ongoing. Currently, traditional airlines fund a notable portion of NATS' work. It is considered infeasible to ask airlines to effectively subsidise AAM-related activities. However, a challenge exists in AAM developers and operators funding the processes and changes required to enable their operations before they are operational, and, even when operational, before they are generating revenues and profits at a meaningful scale. One interviewee noted that, while the Future of Flight Challenge could serve as a well-suited model for proving out and maturing the required technological and operational shifts to air traffic management (as well as other, less mature technologies required for scaled operation) in the lead-up to roll-out, it is currently set to end in 2024, with no follow-on publicly announced.

It should be noted that these airspace challenges are not exhaustive, given the complexity involved in the domain, and are those that were highlighted by interviewees. Further, it should be recognised that, in the UK, these issues are largely already under active consultation. Nevertheless, airspace was listed among priority areas to "get right" by several interviewees in order to enable the AAM business case. If these areas are resolved in good time, and in a manner that fully unlocks the value proposition, they may well never manifest themselves as barriers. However, should progress on vehicles, vertiport infrastructure and consumer demand outpace the required changes in airspace, these issues will act as barriers to further growth and scaling.

6.5 Recommended Interventions

Under each barrier category, a number of potential interventions were identified, which could address the barrier and facilitate the development of AAM in the UK. The approach used was shaped by Green Book guidance, and a full description including intervention summaries and refining methodology can be found in Appendix A5.

For each barrier category, a low-cost intervention option was identified, which poses the lowest barriers to implementation. Additionally, a relatively more resource intensive intervention was identified for each category, that was also expected to deliver high impact.

Figure 6.5. Terminal outcomes for identified interventions.

The theory of change for each option was visualised to communicate causal pathways and indicate underlying assumptions, while also noting market/governance failures. Each identified intervention contributes to one or more terminal outcomes as shown in Figure 6.5.

6.5.1 Insufficient Availability of AAM Passenger Infrastructure

Low-Cost Intervention

Issuance of a national policy statement laying out the government's position on the prioritisation, nature, and roll-out of AAM infrastructure in the UK

Issuing a national policy statement (NPS) laying out the government's position on AAM infrastructure with the intention to increase clarity for local planning authorities on the implementation of AAM infrastructure. The intervention seeks to resolve a perceived government failure of a lack of information amongst the actors involved in the planning system, whose informed participation and consent is required for the effective and timely rollout of AAM infrastructure. The intervention, representing a high-profile statement of intent from government, and a vote of confidence in the future rollout of AAM infrastructure, is also intended to directly build investor confidence, further improving the investment viability of AAM infrastructure. The intervention is supported by interview evidence, with improvements to planning processes as applied to AAM advocated for. Vertical Aerospace also proposed a similar intervention in its 2021 White Paper.

The theory of change for this intervention is shown in Figure 6.6. It assumes that the clarity produced for planning bodies through the release of an NPS would tangibly result in a smoother and expedited planning process for AAM infrastructure. It further assumes that investors would indeed perceive the issuance of an NPS in a manner that increases confidence in the future financial viability of AAM infrastructure projects. Finally, in contributing to terminal outcomes, the theory assumes that AAM vehicles perform close to expectations, and are able to provide time saving and productivity benefits to segments of the population.

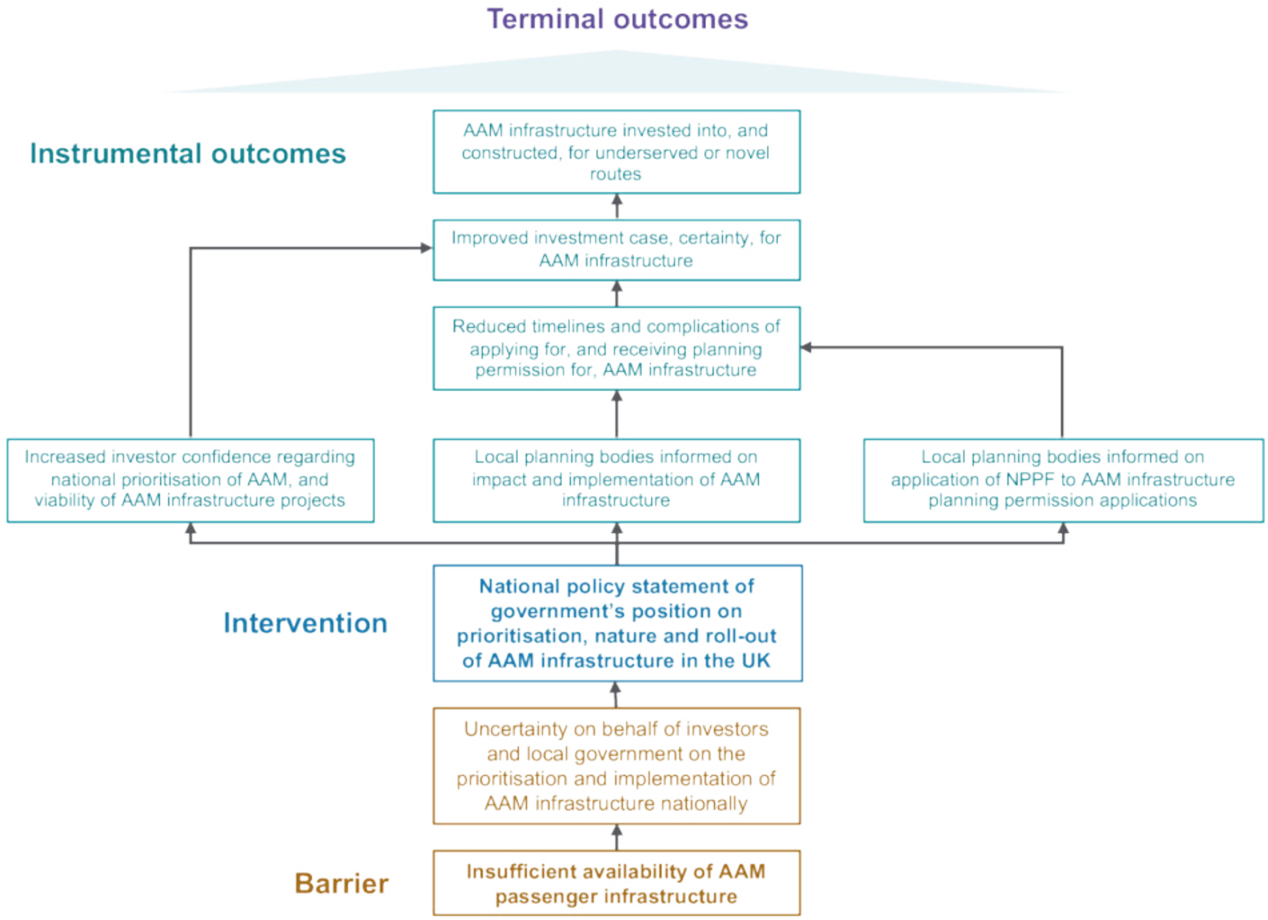


Figure 6.6. Outcomes pathway of the proposed low-cost infrastructure intervention.

More Resource Intensive Intervention

Information campaign to aid local planning bodies in the revision of local procedures and plans to account for vertiport construction, and to inform on the opportunities and risks of AAM across the UK

An information campaign, for example in the form of a white paper and associated dissemination, is also intended to increase clarity for local planning authorities on the implementation of AAM infrastructure. Again, this intervention similarly seeks to address a lack of information amongst the actors involved in the planning system. This is in itself driven by the extremely novel nature of the sector. It is currently unclear, for example, how the National Planning Policy Framework (NPPF) should be applied in the assessment of AAM infrastructure planning applications. This intervention is supported by interview evidence, with one interviewee putting forward a similar proposal, and several interviews relating to infrastructure highlighting expected difficulties in proceeding with infrastructure build-out due to complications in the planning process as a major concern.

The outcomes pathway, representing the theory of change of the intervention, is shown in Figure 6.7. The theory of change assumes that, alongside greater clarity on how to assess planning proposals for AAM infrastructure, planning bodies would also be more confident greenlighting such projects.

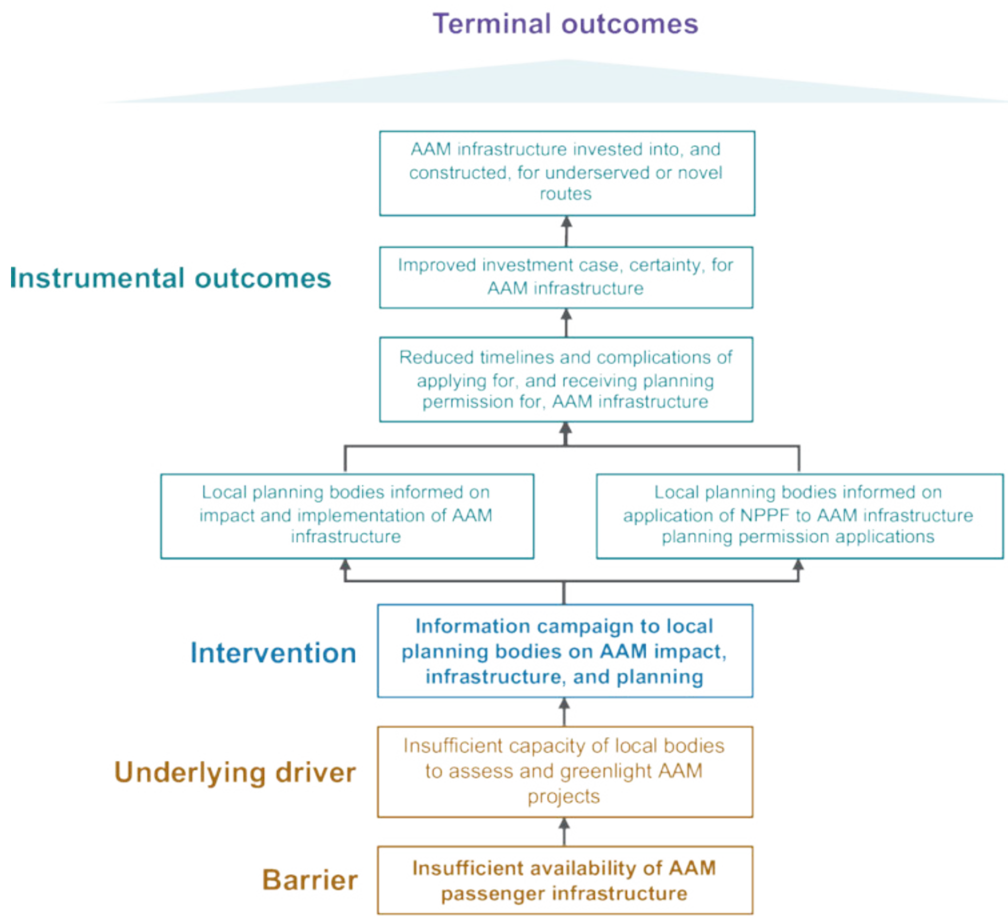


Figure 6.7. Outcomes pathway of the proposed more resource intensive infrastructure intervention.

It further assumes that greater information availability on the part of planning bodies would translate to expedited and improved planning outcomes for AAM infrastructure projects. Finally, it assumes that improved planning prospects for infrastructure projects would result in increased investor confidence and willingness to commit to investment in AAM-related infrastructure.

6.5.2 Public Acceptance and Adoption of AAM

Low-Cost Intervention

Actively facilitate demonstration flights of AAM vehicles for commercial use in areas accessible to, and viewable by, the public

The primary benefits of this intervention were considered to be the immediate effect on the general public, allowing individuals to experience and form their own opinions on AAM, as well as the opportunities generated for such flights to feed into regulatory efforts. Interview findings support this intervention, with vehicle manufacturers, infrastructure developers and other stakeholders alike seeming to agree that being able to see and experience AAM vehicles in person would be more effective in building public acceptance than more abstract communications campaigns. The matter of public acceptance is partially an issue of a market failure relating to information asymmetry, with industry participants holding far more data regarding vehicle performance and safety than members of the public.

The primary causal pathway of this intervention is therefore through the building of familiarity, trust in technology, creation of opportunities for public feed-in, and opportunities for government to inform regulation. The outcomes pathway, representing the theory of change of the intervention, is shown in Figure 6.8. It assumes that vehicle performance parameters, particularly around noise and safety, are as currently stated, otherwise public trials could have the opposite of the intended effect. It further assumes that operational data generated through trials would be made available to relevant government bodies. It further assumes that reduced public concern around AAM would tangibly feed into public consultation processes relating to planning and airspace change. Finally, it assumes that positive public consultation processes tangibly affect investor sentiment in future projects, and hence increases the prospects for future AAM projects to be invested into and developed.

This intervention would be complementary to, and build on, work done under the Future of Flight Challenge. The Advanced Mobility Ecosystem Consortium, for example, involving Vertical Aerospace, Virgin Atlantic and others, seeks to conduct physical flights between Bristol Airport and South West England, and between London Heathrow Airport and the Living Lab vertiport.[376]

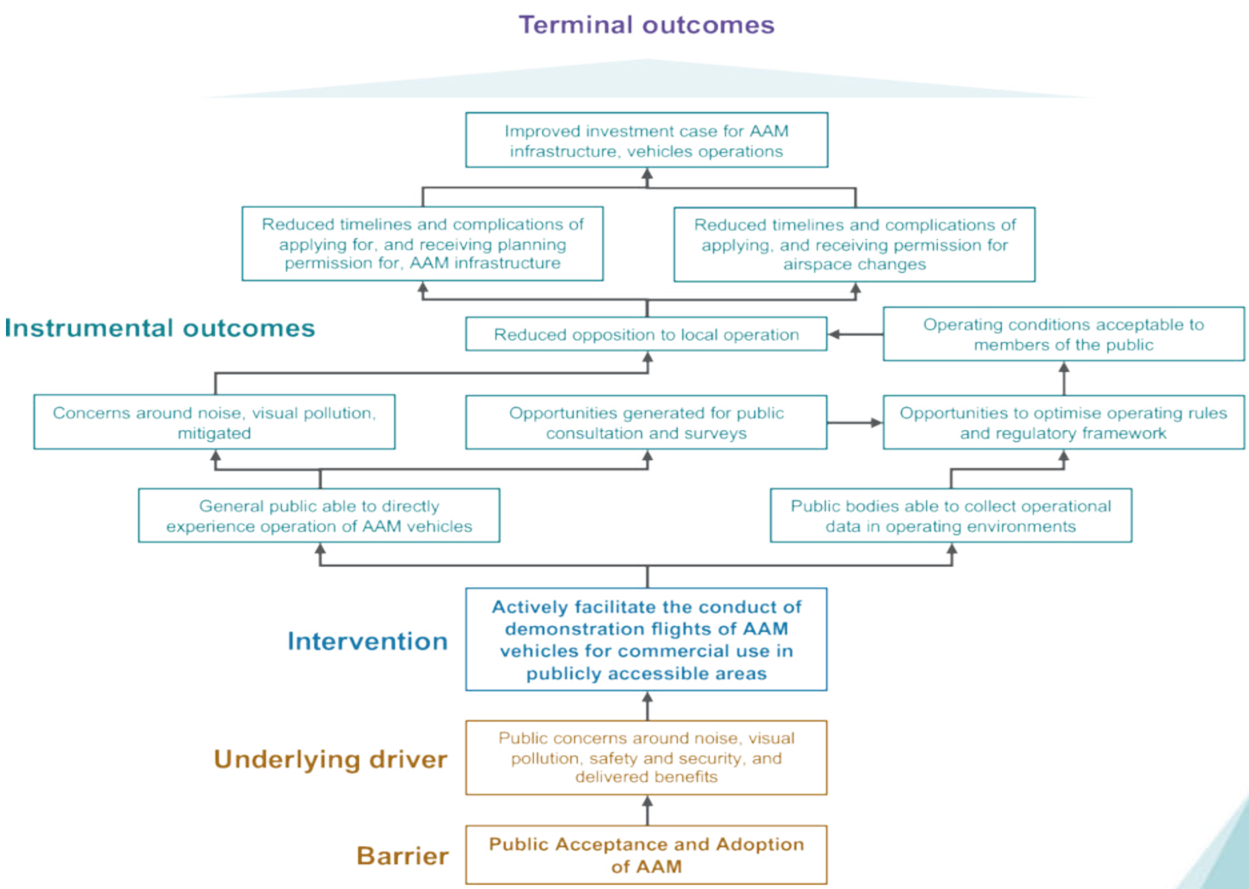


Figure 6.8. Outcomes pathway of the low-cost public acceptance intervention.

More Resource Intensive Intervention

Provide funding to actively facilitate the launch of pilot programmes in the provision of services in use cases where public value is clearly visible, such as patient transport and medical goods delivery

Similarly to the prior intervention, the provision of funding to support AAM use cases with clear public value seeks to increase public familiarity and trust in AAM technologies, while making clear the benefits systems can deliver. The intervention seeks to support visible use cases which are unambiguously "good," for example the use of AAM vehicles to airlift patients. The intervention also seeks to support the rollout of systems in the provision of public services where appropriate, in order to release the benefits such systems could provide. This direction is supported by other studies. For example, EASA suggests "Gradually introducing use cases with the highest benefit for the general public, e.g., transporting medical goods with manned eVTOLs could also reinforce societal acceptance."[377] As with the prior intervention, the intervention seeks to address a perceived market failure of information asymmetry, with industry participants holding far more data regarding vehicle performance and safety than members of the public. The intervention seeks to produce familiarity and greater knowledge of performance characteristics of vehicles for the public through direct exposure. Furthermore, this intervention could well produce additional positive impacts in the form of reduced emissions, and subsequently improve public health outcomes. Additionally, it seeks to ease institutional inertia in the rollout of AAM technologies in public services.

The causal pathway for the intervention is indicated in Figure 6.9. The primary assumption made in this theory of change is that vehicles perform as intended. Especially in the provision of critical public services, safety and reliability will be critical. The intervention is therefore also intended to be implemented in phases, with funding dedicated to carefully controlled trials prior to further roll-out. As with prior interventions, the theory of change also assumes that increased public familiarity reduces regulatory and institutional barriers to implementing AAM technologies, and that this, in turn, improves the investment case for further AAM roll-out.

6.5.3 Policy, Certification, Regulation, and Licensing

Low-Cost Intervention

Publish a strategic regulatory action plan for AAM in the UK, laying out envisioned timelines of AAM roll-out and regulatory action to be taken at each stage, clear assignment of responsibility, as well as perceived opportunities and risks of AAM in the UK

In the case of certification, regulation and licensing, the publication of a strategic regulatory action plan for AAM in the UK was chosen as the most beneficial low-cost intervention. This would provide an initial regulatory framework under which

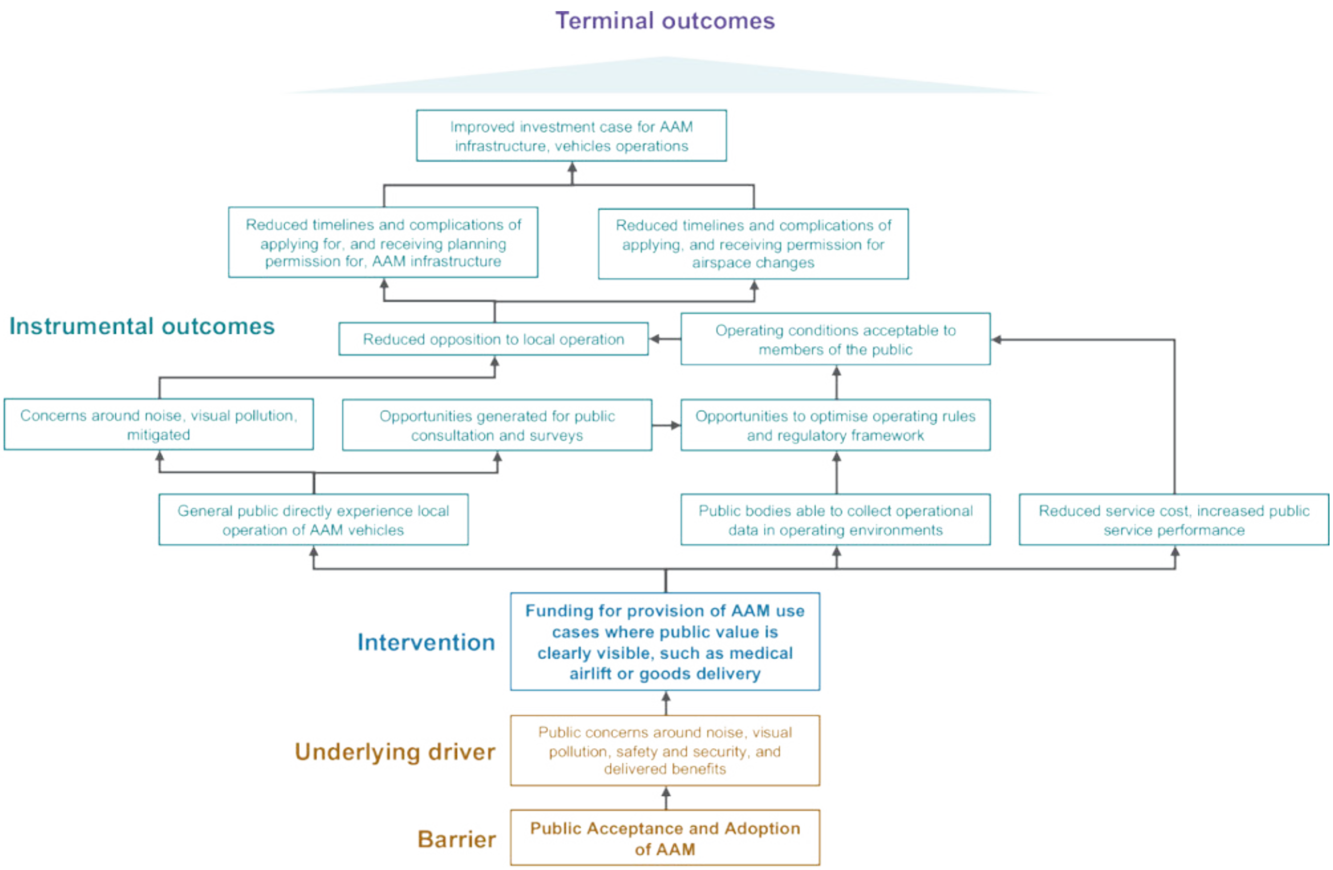


Figure 6.9. Outcomes pathway of the more resource intensive public acceptance intervention.

early-stage commercial operations could take place, likely building on existing legislation in most cases. It would also set out envisioned timelines for the sector to commence operations, scale, expand, and what actions would be taken to achieve this. The primary benefit of this intervention was perceived to be the effect it was expected to have on industry and investor confidence. Again, this intervention was also supported by interview evidence, with a majority of interviewees expressing a lack of government clarity, transparency and vision as a concern. The primary causal pathway of this intervention is through the building of industry and investor confidence, opportunities for consultation, and improvements in the regulatory process. The primary issue it seeks to address is one of consistency and availability of information, with clear and well defined timelines and milestones required in order to support the development of the market.

The outcomes pathway, representing the theory of change of the intervention, is shown in Figure 6.10. It assumes that the existence of an AAM action plan would indeed facilitate cross-government coordination and consistency. Further, it assumes that industry will trust that the action plan will be followed over time, and that this, in turn, will provide sufficient confidence to contribute meaningfully to investment decisions.

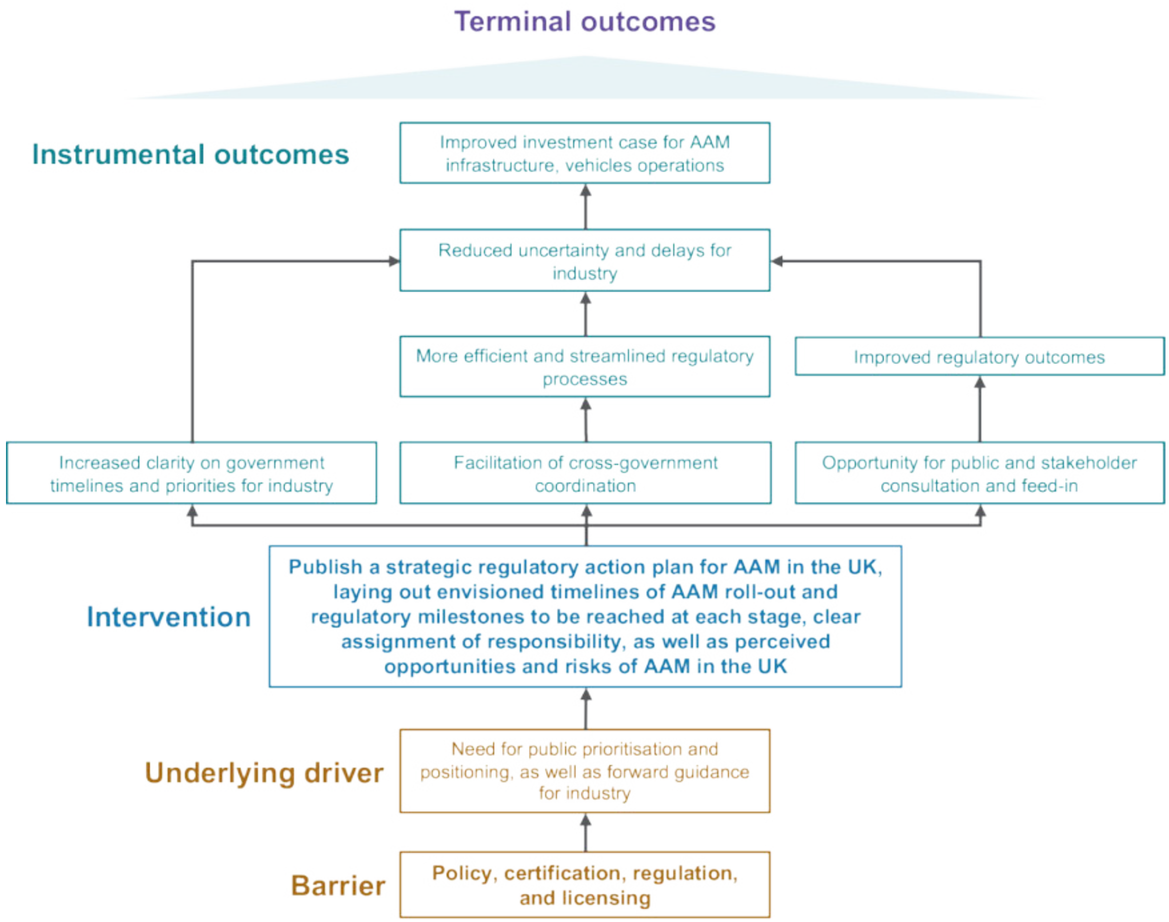


Figure 6.10. Outcomes pathway of the low-cost certification, regulation, and licensing intervention.

More Resource Intensive Intervention

Increase CAA resourcing, particularly within design and certification teams, and assess pay scales for key roles to ensure the attraction and retention of necessary labour

Type certifying new aircraft is in itself a difficult and time-consuming process. In the case of AAM, this task is made more difficult still by the fact that the proposed systems are fundamentally different to anything seen previously by regulators. Further, the scaling of AAM not only requires certifying aircraft, but also designing entirely new systems relating to ground infrastructure, operating rules, airspace management, and other factors.

The CAA's primary responsibility, until recently, was as a safety, security and consumer regulator. Post-Brexit, the regulator has now assumed a far greater portfolio of responsibilities, including but not limited to design and certification responsibilities. The CAA is now tasked with successfully delivering on this expanded portfolio, as well as engaging sufficiently with industry in the regulation process to ensure that the UK's regulatory arrangements are responsive and world-class. This requires considerable human resource in very particular skills areas. Interviews indicated a sentiment that existing resources are not at the level required to fulfil the UK's potential. This may indicate a government failure in the form of inefficiency of resource and skills allocation to the regulation and support of a novel industry (and existing industries).

This intervention seeks to address this issue directly, therefore, through the greater resource allocation to the CAA, and a re-evaluation of how required talent is attracted and retained. The theory of change shown in Figure 6.11 primarily assume that there are no major institutional or organisational inefficiencies that would prevent the realisation of more efficient and streamlined regulatory processes despite the greater availability of resources. Further, it assumes that industry is able to meet the regulatory standards set by CAA, i.e., that there are not major technical issues that would prevent the certification of vehicles regardless of greater regulator capacity.

6.5.4 Airspace Systems and Management

Low-Cost Intervention

Enable rolling airspace trials in lieu of timely airspace changes in order to enable initial operations and trial of AAM flights in the UK

The roll-out of AAM will require phased introduction, and the creation and trial of hypotheses regarding operating rules as services expand. Initial trials and commercial operations will require appropriate airspace arrangements. However, the CAP1616 process, depending on the airspace change required, can take anything between two and eight years. This opens the possibility for AAM vehicles to be ready for initial operations by the middle of the decade, but the required airspace infrastructure not yet being present to allow

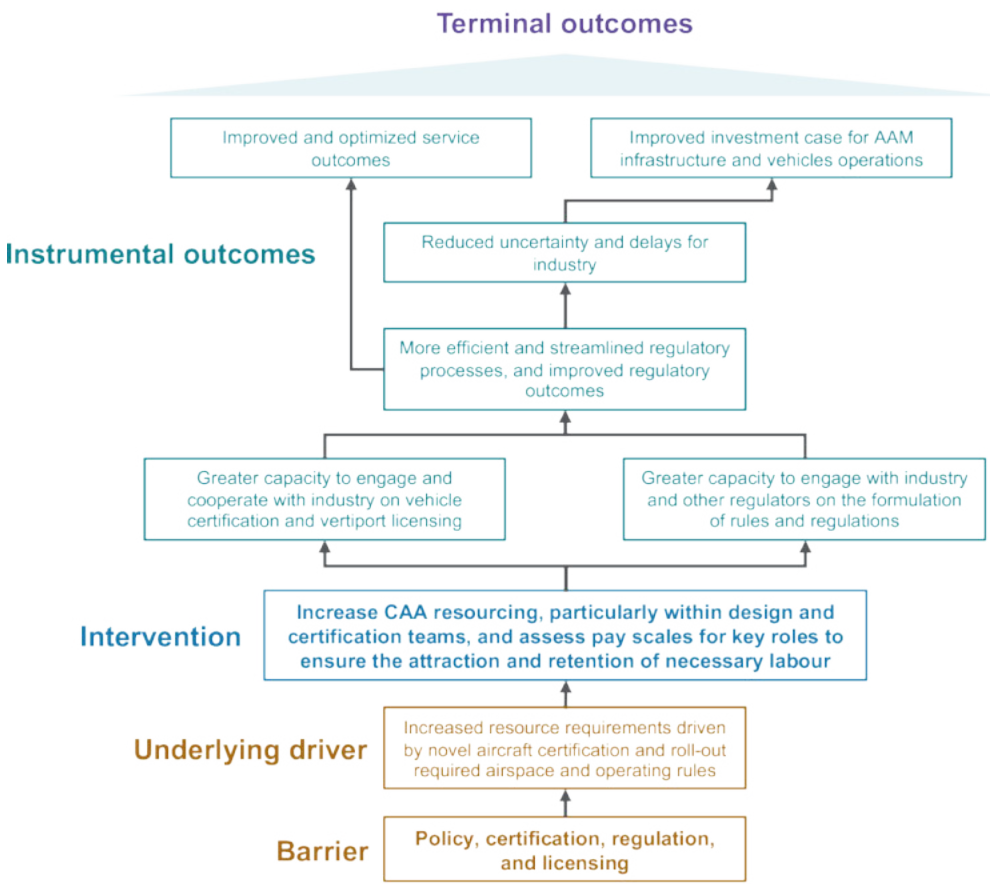


Figure 6.11. Outcomes pathway of the more resource intensive certification, regulation, and licensing intervention.

expanded trial flights and initial commercial operation. Longer-term modifications to the airspace change process are under consideration as part of broader efforts relating to the AMS. However, in the nearer term, enabling airspace trial arrangements would allow initial operations to take place, while CAP1616 processes are undergone, and longer-term modifications to the airspace change process are made. This approach is also raised as a possibility by the UK Air Mobility Consortium in their UAM CONOPS report, prepared for CAA.[378] While current timelines of the airspace change process cannot be categorised as a government failure per se, this intervention does address a potential discrepancy between market needs, existing regulatory arrangements, and the timelines needed for reform.

The intervention is intended to realise benefits through three primary pathways. Firstly, it is intended to increase vehicle manufacturer and investor confidence that vehicles will be able to promptly begin operations. Secondly, it is intended to increase opportunities for members of the general public to experience AAM services, aiding in the public perception domain. Finally, the intervention is intended to increase opportunities for authorities to gather operational data and optimise regulatory and operational frameworks. The outcome pathway in Figure 6.12 assumes that vehicles will largely operate when, and as, intended. Additionally, similar assumptions as made for prior interventions regarding public and investor sentiments also apply.

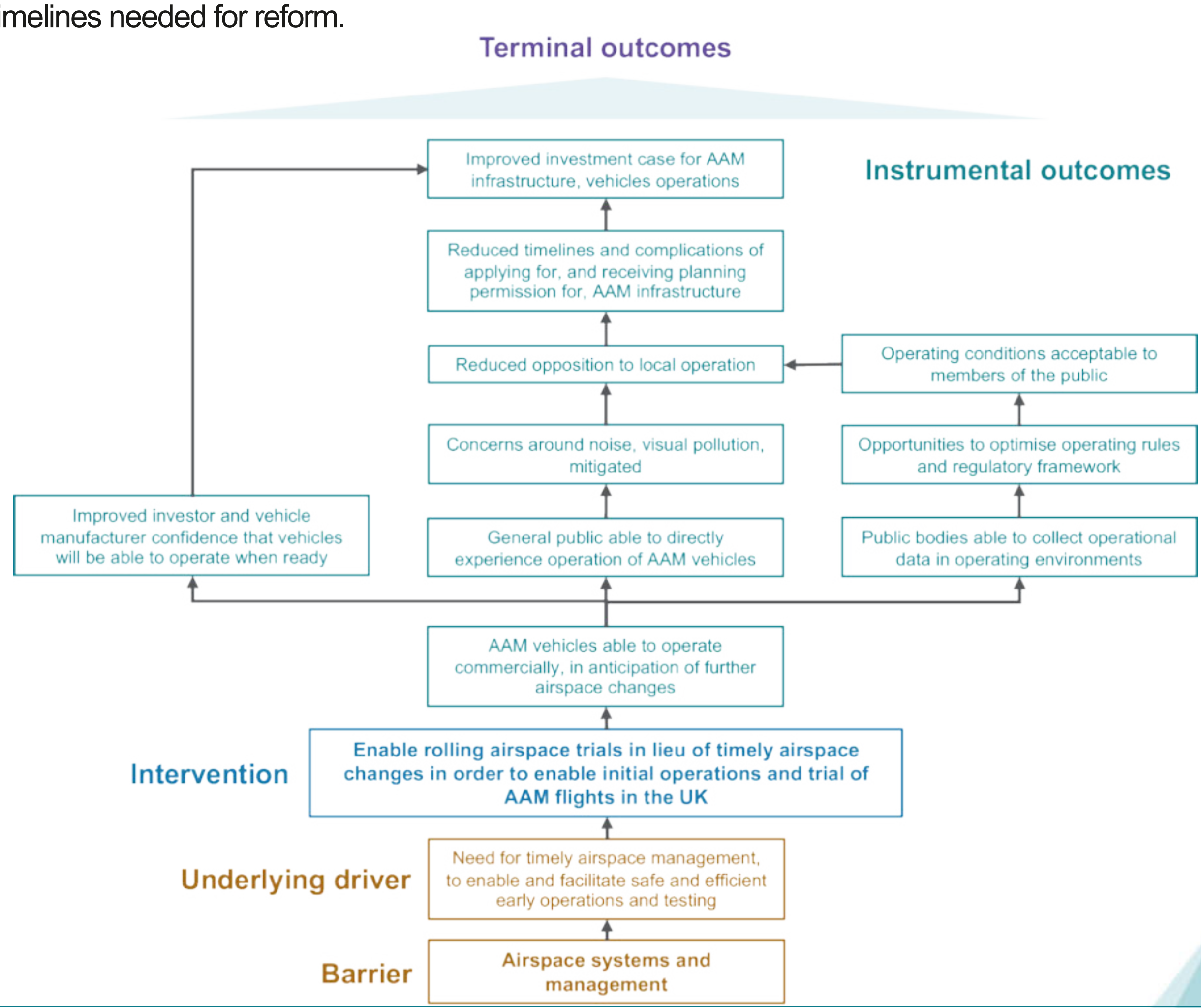


Figure 6.12. Outcomes pathway of the low-cost airspace systems and management intervention.

More Resource Intensive Intervention

Provide continued challenge funding to support the development of technologies required for scaled AAM operations

The Future of Flight Challenge has successfully provided support to demonstration projects of AAM technologies, among others. This said, the challenge ends in 2024, with no clear successor program, and the timeline of AAM roll-out from initial operations to operation at scale is expected to reach into the early 2030s. As discussed in the UK salient airspace barriers segment, technology will play a key role in enabling operations at scale, and as automation in the air and on the ground is phased in. As discussed in the technological readiness section of the report, there are still several enabling technology categories, particularly relating to air traffic management and autonomous and remote operations, that are relatively immature. This represents a potential market failure in the form of a funding gap for technology implementation that could offer public benefit but may still be considered too risky to be fully financed in an imperfect information environment. This intervention need not be purely for the development of airspace management technologies, and could also benefit other areas, for example, advanced manufacturing for scaled AAM vehicle production.

This intervention seeks to address this by reducing the cost and risk associated with further technology development and roll-out. Additionally, the intervention is intended to boost industry confidence and provide further opportunities for government to gather operational data. A key assumption implicit in the theory of change shown in Figure 6.13, beyond assumptions concerning investor confidence and useful operational data gathered, is that a meaningful number of projects funded are successful, and lead to solutions that can be implemented at scale. Further, the theory of change assumes that demand is sufficient to warrant expanded AAM services to the scale where these technologies are required.

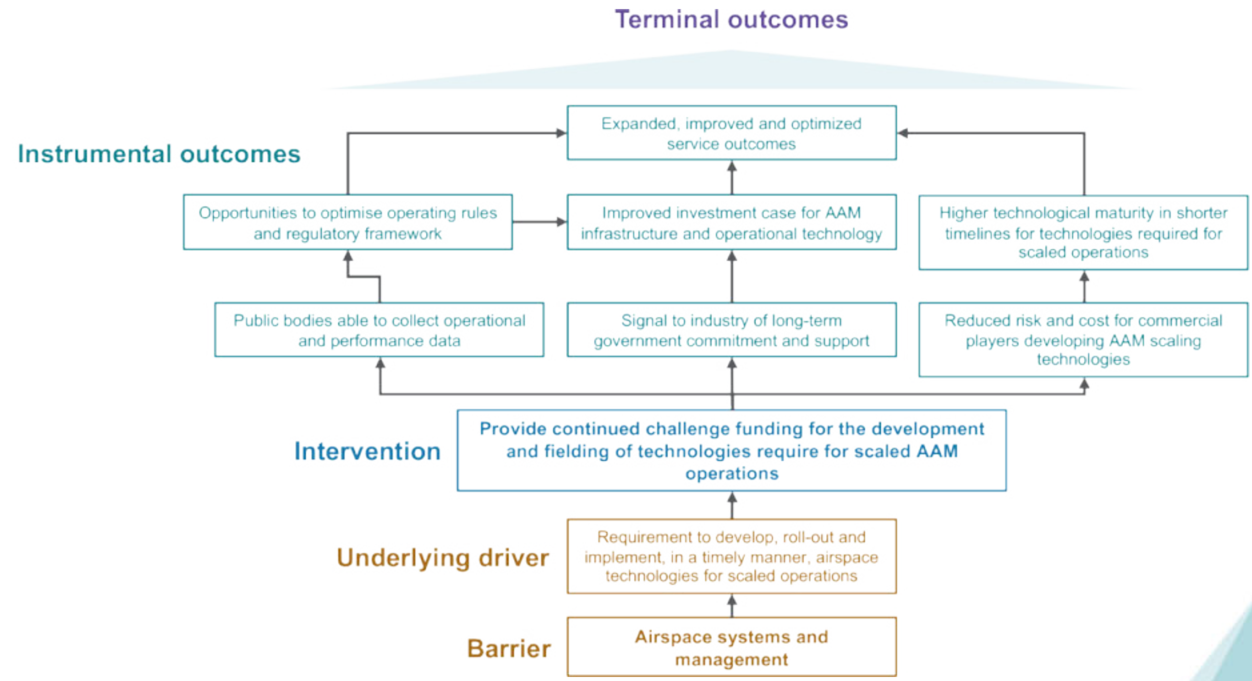


Figure 6.13. Outcomes pathway of the more resource-intensive certification, regulation and licensing intervention.

7 Conclusion

Advanced Air Mobility holds great promise. This said, the sector exhibits the inevitable uncertainties of a novel technology class, particularly around the scale, nature, and timing of the benefits it will bring. As observed by some of the reports examined through this study, predictions made around the scale and impact of the automobile, powered flight, or the mobile phone were all inaccurate. Careful monitoring, and flexible, agile, governance will be needed to shepherd the AAM sector to commercial success and optimised impact.

The AAM sector already represents a substantive presence in the UK, and this is prior to any form of meaningful commercial operation. Current annual revenues of approximately £70 million, reflecting B2B sales, and employment of over 1,000 individuals should be seen as the starting point of a technological adoption process, with accelerating growth as the technology is commercialised and scaled. As the sector develops, it promises to bring with it jobs, direct benefits to passengers, and unlocked economic growth through productivity gains. Market outlook studies focused on the UK seemingly indicate promising market potential, particularly in the field of regional mobility, where notable productivity gains could be unlocked through marked time savings, and the development of new routes that are poorly, or not at all, served by existing infrastructure. Further, AAM passenger vehicles and cargo drones can benefit public service provision, improving service quality and speed, and delivering social benefit. This said, not all AAM use cases will be commercially viable in the UK, and continued market research, and monitoring, of the sector will be required.

While potential benefits exist for the UK, the AAM sector faces undeniable barriers. Vehicle manufacturers will need to prove to regulators, and the public, that their vehicles are safe, quiet, and affordable. The idiosyncrasies of the UK's planning system mean it may prove challenging to build the infrastructure required to address demand. Similarly, integrating a new class of vehicles into the UK's airspace whilst protecting the interests of existing airspace users, and upholding general safety, means that airspace planning and management will prove a challenge. Public acceptance and enthusiasm are crucial to the adoption of AAM technologies, and the public must be actively informed and involved in the development of the sector by both industry and government. Regulation and policy can be the tools that shepherd and unlock the potential of the AAM sector in the UK, or they could become a factor that render it uncompetitive in a global market with formidable competition, and plenty of alternative promising markets.

Further, barriers to the sector's development will not cease upon the introduction of commercial services. Vehicle developers will need to manufacture vehicles at scale and commercially viable costs. Technological innovation surrounding remote and autonomous operations promise to make AAM services more affordable and available. However, these same innovations will prove formidable regulatory challenges, and strong engagement with both the public, and industry, will be crucial in the future development of the sector.

BryceTech has formulated and proposed several potential interventions, that may help alleviate some of the barriers outlined. Four low-cost, and four more resource-intensive interventions were shortlisted.

The high-impact, low-cost interventions were:

- Issue a national policy statement, setting out the government's position on the prioritisation, nature and roll-out of AAM infrastructure in the UK
- Publish a strategic regulatory action plan for AAM in the UK, laying out envisioned timelines of AAM roll-out and regulatory milestones to be reached at each stage, clear assignment of responsibility, as well as perceived opportunities and risks of AAM in the UK
- Actively facilitate the conduct of demonstration flights of AAM vehicles for commercial use in publicly accessible areas
- Enable rolling airspace trials in order to enable initial operations and trial of AAM flights in the UK

The high-impact, more resource-intensive interventions were:

- Conduct an information campaign to local planning bodies on AAM impact, infrastructure, and planning
- Increase CAA resourcing, particularly within design and certification teams, and assess pay scales for key roles to ensure the attraction and retention of necessary labour
- Provide funding for provision of AAM use cases where public value is clearly visible, such as patient transport and medical goods delivery
- Provide continued challenge funding for the development and fielding of technologies require for scaled AAM operations

These interventions could go some way to support the development of the AAM industry in the UK. Beyond the shortlisted interventions, continued review of the intervention long-list, as well as exploration of further intervention options that may arise, would be prudent as the industry develops further.

A number of the additional interventions identified offer the potential for meaningful impacts on the AAM industry, and include options such as securing ministerial sponsorship, that ensures the governmental backing of viable AAM use cases in the UK are publicly recognised. Whilst this example is low in cost, it is crucial that government further engages with industry to determine whether more widespread or resource intensive interventions are merited. For example, while the technologies for initial commercial operations are fairly mature, a plethora of technologies that promise to unlock further AAM potential are still in development, and government could play a role in the ongoing funding of technological innovation and commercialisation in these fields beyond the end of the Future of Flight Challenge in 2024. Other fiscal measures or more wide-reaching regulatory and policy measures than those put forward may be merited, and further study of potential interventions is recommended. The longlist of interventions presented in this report vary in both scope and scale, and may aid in this effort.

Ultimately, evidence suggests that AAM promises sufficient benefit, and costs that are sufficiently mitigatable, to warrant increased governmental confidence and support of the AAM sector in the UK. Of course, risks and timeline uncertainties remain. However, ongoing development and regulatory efforts are continuously addressing these concerns, paving the way for safe, reliable AAM operations. AAM therefore offers a promising avenue for the future of mobility in the UK, as well as an opportunity for novel export opportunities in vehicles, underlying technologies, and services.

A1 Econometric Analysis Methodology

The wider economic impacts of the identified AAM-related activity are quantified using Cambridge Econometrics' UK impact model. The model, calibrated to the 2018 UK Input-Output (I-O) Tables, estimates the wider impacts based on identified flows of products and services between sectors and different agents in the UK economy.

The process for calculating multipliers from I-O tables has been established for many years. Type I multipliers show the additional demand that results through supply chains from producing outputs of a particular good or service. Type 1 multipliers are calculated by:

- Converting the monetary flows between sectors in the I-O table into a table of coefficients showing the proportion of output of a good that comes in the form of inputs of different goods and services (compensation of employees producing the good)
- Deriving Type I Leontief Inverse (matrix of multipliers) as (I-A)-1 where A is defined as the matrix of intermediate demand coefficients, and I is the identity matrix.

The Type II multipliers (which additionally includes the effects from the spending from the incomes associated with the additional employment through the supply chain) is calculated in an equivalent way, but with the matrix A being augmented with the compensation of employees coefficients (i.e., the share of compensation in output) as an additional row at the bottom of the A matrix, and household expenditure coefficients (i.e., household spending as a share of total resources) as an additional column appended to the right.

The value-added and employment multipliers are calculated from the Leontief Inverse by taking into account the ratio of GVA/employment to output:

- For the GVA multiplier, it is the ratio of GVA to output
- For employment, it is the ratio of full-time equivalent (FTE) employment to output

The calculation of employment multipliers requires FTE employment for each sector identified in the input-output analysis. Such employment data are not readily available from official sources. As such, estimates are constructed from Cambridge Econometrics' in-house databanks of jobs by sector, which are consistent with official data (published at lower sectoral disaggregation). These data are counts of people in different types of job. In estimating FTEs, it is assumed that part-time jobs count as half a full-time job. Where the Cambridge Econometric data needs further disaggregation to map to the Input-Output table sectoral detail, the disaggregation is based on the shares of compensation of employees reported in the Input-Output tables.

Assumptions

The assumptions for the current scale of activity that is directly AAM-related have been developed by BryceTech. The firm level data underpinning these assumptions includes activities/firms where employment has been identified but no value has been attributed to their activities. For this reason the productivity implied by the assumptions is probably an under-estimate and is likely to result in a relatively lower employment multiplier compared to output multipliers calculated.

A2 Methodology to Estimate AAM Market in Competitor Countries

1. The number of firms engaged in four sectors was estimated for 11 countries: UK, US, China, South Korea, Japan, Germany, France, Canada, Brazil, Australia, and Singapore.

2. Four industries were selected as proxies considered the most appropriate to be utilised when estimating the AAM market in the 11 countries: automotive, aerospace, total manufacturing, and advanced technology, with these believed to provide the closest approximation to AAM, including the value chain utilised in the production of AAM vehicles and other elements. These 11 countries comprised the 'total market' assessed, with each country's proportion of the total calculated.

3. Country by country analysis was performed with data acquired from official and reputable unofficial sources on the number of firms participating in the selected industries.

4. UK data utilised figures from BryceTech's AAM database for revenue, employees, and the number of participating companies, acquired from a bottom-up analysis of the UK AAM market.

5. The advanced technology, automotive, and aerospace industries were not utilised further as the results showed considerable polarisation with a limited number of countries accounting for the majority of activity. The manufacturing industry, along with data on the number of AAM vehicle integrators in each country was utilised in combination to better reflect the estimation of AAM activity in each country.

6. The total market size for the 11 countries was defined using the sourced data and the segmentation of the individual proportion for each country calculated with the 11 countries representing the 'total market.'

7. The three UK anchor data points for revenue, employees, and number of participating companies, were utilised to define the total market size for these three metrics, utilising the UK proportion of the industries' total.

8. The segmentation of market share calculated for each country was utilised against the scaled up totals (revenue, employees, firm numbers) to define the AAM market size for each country.

9. This assessment comprises a top-down approach, driven by the inherent difficulty in defining the emerging AAM market, and therefore represents a high-level comparative assessment.

10. The start-up and formative nature of the AAM sector in 2021 results in considerable movement at present including a lack of clarity on regulations related to AAM, hesitation by some funders to participate further or at all, and other factors related to the supply chain, intellectual property, amongst others. The results are approximate and indicative and also provide a relative scale within the region of the three metrics assessed.

A3 Recent UK AAM and AAM-related Projects and Government Interventions

Government body/ Organisation(s)	Intervention Type(s)	Intervention(s)
CAA	Regulation	Independent delivery of regulation for the aviation sector, including drones[379] and AAM e.g., eVTOL safety activities.[380]
Connected Places Catapult (CPC)	Communications; Research & Development	Future Air Mobility Innovation centre, including Future of Air Mobility Accelerator[381] (2021[382] and 2022[383] cohorts) which provides funding to small and medium-sized enterprises with innovation solutions for the aviation industry.
DfT	Communications; Consultations; Strategy	Consultation on the safe use of drones in the UK in 2016,[384] Future of drones in the UK consultation in 2019[385] and Future of Transport Regulatory Review consultation in 2021,[386] including Future of Flight. Flightpath to the Future published in 2022.[387] Future of Flight Industry Group (FFIG) established in 2023 to work with industry and the CAA to bring together stakeholders from across these different technologies to address shared challenges in a coordinated way to develop, publish and implement a Flight Action Plan, with set milestones and targets for achieving routine beyond visual line of sight (BVLOS) drone operations and AAM trials.
DfT	Legislation	Air Navigation Order (ANO) amendments, including for drone airspace restrictions, registration and pilot competency, and Air Traffic Management and Unmanned Aircraft Act (ATMUA) 2021.
DfT	Research & Development	Funding for research into Future of Flight technologies, including drones and AAM, such as £28.75M Solent Future Transport Zone[388] and other desk-based research.
DfT/CAA	Communications; Consultations; Data; Funding; Strategy	Funding to help scale up CAA support to innovators, including CAA Innovation Team,[389] AAM[390] and BVLOS[391] challenges, regulatory sandboxes,[392] regulatory toolkit[393] for innovators and guidance,[394] case studies[395] and improvements to the Drones and Model Aircraft Registration and Education Scheme (DMARES).[396] Airspace Modernisation Strategy (AMS)[397] published in 2023 following consultations, including Future Aviation Strategy Implementation (FASI) initiative coordinated by the independent Airspace Change Organising Group and with £5.5M funding in 2021 and a further £3.7M funding in 2022 temporarily from government.

Government body/ Organisation(s)	Intervention Type(s)	Intervention(s)
DfT/CPC	Communications; SME support; Research & Development	Drones Pathfinder Programme, including Drones Technology Research and Innovaiton Grants (D-TRIG) and case studies including ATOMICUS drone project,[398] Unmanned Aircraft Systems Authentication System (UASAS) project,[399] Airspace of the Future project,[400] Drones for COVID Response.[401] Zero Emission Flight Infrastructure (ZEFI) £3 million R&D project announced[402] in the UK Government's The Ten Point Plan for a Green Industrial Revolution[403] in 2020 with additional funding from the 2021 Spending Review. Future of Freight Plan and Future Innovation Fund[404] Future Aviation Skills project
DfT/Department for Science, Innovation and Technology (DSIT)/ Drone Industry Action Group (DIAG)	Strategy; Stakeholder Engagement; Communications	Drones Ambition Statement[405] published in 2022 outlines how government and the drone sector will work together to achieve a vision for commercial drones will be commonplace in the UK by 2030, in a way that benefits the economy and wider society, delivering new capabilities, boosting productivity, and reducing emissions and risk to life, while sharing airspace equitably and safely with other users.
Department for Business and Trade (DBT)/ Aerospace Technology Institute (ATI)	Strategy; Research & Development; Communications	Aerospace Technology Institute (ATI) £3.2B industry-match funded programme, including £1.6B grants awarded to UK organisations across 343 projects. ATI creates the technology strategy for UK aerospace, which builds on the UK's strengths and responds to the challenges faced by the UK civil aerospace sector. It provides a roadmap of the innovation necessary to keep the UK competitive in the global aerospace market, and complements the broader strategy for the sector created by the Aerospace Growth Partnership (AGP). Projects funded through the ATI Programme must align with the technology strategy Destination Zero.
DSIT; UK Research & Innovation (UKRI); InnovateUK	Research & Development	Future Flight Challenge (FFC) £125M government funded programme[406] from 2019 to 2024 convening the emerging industry and supporting businesses to develop technologies that support the operation of drones, advanced air mobility and electric aircraft, with case studies including Advanced Mobility Ecosystem Consortium,[407] Coventry Urban-Air Port,[408] NHS[409] and Project CAELUS[410] drone delivery projects, and the Altitude Angel drone 'superhighway' project.[411] FFC has created initial national roadmaps and is leading workstreams on Community Integration, Safety, Market Analysis, social research and Industrialisation.
OFCOM	Regulation	UAS operator radio licence to authorise the use of radio equipment on drones.[412] The authorisation of this equipment is an enabler for drones to be operated beyond visual line of sight (BVLOS). The licence authorises a range of equipment that an operator may choose to use or be required to carry by the Civil Aviation Authority (CAA). This licence does not replace the current licence exemption regime for low power 2.4 GHz and 5 GHz equipment which most drones on the market currently fall under.

A4 International Government Interventions

Country	Government Agency	Intervention Type	Intervention
United States	FAA	Regulatory	07/12/2022: FAA proposed regulatory changes to support advanced air mobility commercial operations. A notice of proposed rulemaking (NPRM) was issued, marking the first of multiple anticipated rulemakings to align regulations with the FAA's earlier decision to change course on the certification of eVTOL aircraft.
		Industry Support	26/06/2020: FAA developed and shared the UAM concept of operations (ConOps) with both internal and external stakeholders to describe the envisioned operational environment that supports the expected growth of flight operations in and around urban areas.
	FAA and NASA	Promotion	12/04/2020: FAA collaborated with NASA on their Advanced Air Mobility National Campaign to promote public confidence and accelerate the realisation of emerging aviation markets.
Canada	NRC (forming CAAM)	Industry Support	28/10/2020: Canadian Air Mobility and National Research Council of Canada (NRC) launched Vancouver-based Canadian Advanced Air Mobility Consortium (CAAM), a multi-stakeholder group with more than 20 partners to streamline research, development and commercial operations in the AAM sector. Objectives included creating an AAM innovation hub to help SMEs grow from low TRL to commercialisation, and building sector connections.
	CAAM	Roadmapping	April 2021: CAAM launched an ongoing $1 million CAD project to develop a 20-year AAM master plan for Canada with regional implementation strategies.
		Roadmapping	April 2021: CAAM launched and completed a 12-month, $350,000 CAD project to assemble a cluster of aerospace and automotive leaders to collaborate on a supply chain roadmap for the AAM industry in Canada.
		Roadmapping	April 2021: CAAM launched a $500,000 CAD regional project in Ontario to produce a white paper on the feasibility of AAM in the Greater Toronto Area.
		Roadmapping	March 2022: CAAM launched a $300,000 CAD regional project to produce a white paper on the feasibility of AAM in Manitoba.
		Infrastructure Development	06/05/2021: CAAM contracted D3 Technologies to define and implement air traffic management infrastructure to support eVTOL aircraft and drone operations.

Country	Government Agency	Intervention Type	Intervention
Brazil	ANAC, DECEA	Roadmapping	30/08/2021: Embraer spinoff Eve Urban Air Mobility (“Eve”) led a new working group, building a concept of operations to integrate urban air mobility into Brazilian airspace, starting with Rio de Janeiro. The initiative included more than 50 institutional members and was supported by Brazil’s National Civil Aviation Agency and the Department of Airspace Control.
China	CAAC	Roadmapping	08/06/2022: CAAC released its “14th Five-Year Plan for General Aviation Development.” It detailed a roadmap focusing on the development of UAM and autonomous drone operations.
		Trial enablement	03/08/2017: The Civil Aviation Administration of China granted EHang AS9100C certification and approved clearance for test flights.
		Trial enablement	21/05/2020: CAAC announced China’s first Unmanned Civil Aviation Zones, providing structure for initial eVTOL aircraft flight trials.
Japan	Tokyo Metropolitan Government	Infrastructure Development	08/08/2022: A joint proposal from Japan Airlines, Mitsubishi Estate and Kanematsu Corporation to establish AAM services was accepted by the Tokyo Metropolitan Government. The project for the implementation of AAM services in Tokyo to run until spring 2025, is to explore a variety of business models based on AAM in the metropolitan area.
	METI	Roadmapping	21/05/2021: METI (Ministry of Economy, Trade and Industry) releases its 2021 AAM roadmap. The Japanese government and the private sector worked together to develop a new market and clarify the regulatory framework.
Germany	BMDV	Roadmapping	15/12/2022: The Federal Ministry for Digital and Transport (BMDV) published a U-space Strategy aimed at improving the integration of drone traffic into the existing airspace. The strategy provides the basis for the first U-space act, which is due to be developed in 2023.
		Infrastructure Development	28/06/2021: Andreas Scheuer, Germany’s Federal Minister for Transport and Digital Infrastructure, signed a memorandum on cooperation with the four German UAM model cities and regions of Aachen, Ingolstadt, Hamburg and North Hesse to start a new innovation network for the use of drones in Germany.
France	Directorate General for Civil Aviation (DGAC)	Trial enablement	25/03/2021: Bordeaux and Toulouse hosted trials for UAM operations in the spring and summer of 2022. France’s DGAC and the city governments of Toulouse and Bordeaux supported the initiative.
	DGAC	Regulatory	02/03/2023: The French DGAC published Version 1.5 of its guide to operations of unmanned aerial systems (UAS) in the specific category in France. The guide presents the main safety principles and rules for operating an aircraft (UAS) in the specific category introduced by the European regulations and applies to professional use of these aircraft in France.
	Choose Paris Region	Trial enablement	01/10/2020: Choose Paris Region (a governmental agency), Groupe ADP, and RATP Group launch the “Re.Invent Air Mobility” initiative for the safe, sustainable, and state-of-the-art integration of urban air mobility in Paris Region. The 30 winners conducted experiments in the test area at the Pontoise-Cormeilles-en-Vexin airfield.

A5 Intervention Down-selection

Intervention Options

Intervention long-lists were drafted for each of the four categories identified as salient UK barriers:

- Insufficient availability of AAM passenger infrastructure
- Public acceptance and adoption of AAM
- Policy, certification, regulation and licensing
- Airspace systems and management

Potential interventions were produced by taking into consideration the scope, solution, delivery implementation and funding options of interventions. Combinations of the intervention options, as shown in Table A5.1, were considered in turn to produce a longlist of intervention options for each barrier category. These were further complemented by suggestions made by interviewees.

	Scope	Solution	Delivery	Implementation	Funding
Definition	*Intervention target*	*Intervention type*	*Intervention entity*	*When and in what form intervention should be implemented*	*Funding model*
Options	Local government and planning bodies General public Investors Vehicle manufacturers Vehicle operators Infrastructure developers	Revised regulation, policy or plan Grants or subsidies Loans Consultation initiative Public information initiative Investment	Direct public sector provision Public private partnership Private provider Public sector provision with private input	Immediate implementation Phased implementation Implementation upon entry into service of vehicles	Private finance Public finance Mixed funding model

Table A5.1. Intervention options along five options choices dimensions.

The longlists generated from the option choices model were supplemented with additional interventions that focus on refining existing initiatives. These interventions were derived from interview insights and measures implemented in other nations, focused on improving existing measures.

Intervention Appraisal and Shortlisting

Critical Success Factor Assessment

Each intervention was rated according to how well they were deemed to score against a sub-set of standard critical success factors (CSF) listed in the Green Book. Interventions were placed in a high, medium, or low category according to whether they fell into the bottom, middle or top third of scores assigned by a panel of BryceTech team members across all interventions. Costing factors were not considered, in order to allow for a flexible approach agnostic of budget, given future budgets are still under consideration. The critical success factors considered were:

- **Strategic fit and meets business needs:** Holistic fit and synergy with other strategies, programmes, and projects
- **Potential value for money:** Optimisation of social value (social, economic, and environmental)
- **Supplier capacity and capability:** Ability of potential suppliers to deliver the required services
- **Supplier capacity and capability:** Appeal to the supply side
- **Potential affordability:** Alignment with sourcing constraints
- **Potential achievability:** Likelihood to be delivered given an organisation's ability to respond to the changes required
- **Potential achievability:** Match with the level of available skills required for successful delivery

A shortlist of potential interventions was identified where the CSF rating achieved either a medium or high rating.

Cost Benefit Assessment

For each shortlisted intervention, an initial assessment of relevant costs and benefits was conducted. This process was conducted qualitatively in proportionality to project scope and resource. All shortlisted interventions are envisioned to be conducted in close cooperation, and, in some cases, through joint funding with industry, in order to maximise intervention-market fit and ensure value-for-money.

Each intervention was assigned a rating of costs to HMG based on an assessment of how much each intervention was expected to cost. Low ratings corresponded with interventions deemed to be possible with existing full-time equivalent resources (£). The medium rating was split to correspond to interventions estimated to cost in the millions (££) or tens of millions (£££) to deliver. Finally, the high rating indicates interventions expected to cost one-hundred million pounds or more (££££).

Each intervention was also assigned a benefit score by a panel of BryceTech team members. Interventions were placed in a high, medium, or low category according to whether they fell into the bottom, middle or top third of scores assigned by the panel. Interventions were assigned one point for each of the following benefit categories they were perceived to fulfil. These benefit categories were derived from a combination of evidence reviewed and UK-specific priorities put forward in interviews.

1. Research, Development, and Testing: opportunities for HMG to gain operational and performance data
2. Clear Market Data: opportunities for HMG to gain market and financial data
3. Informed Public Acceptance: ability of an intervention to enable informed decisions about AAM roll-out
4. Maximised Social Benefit: ability of an intervention to induce clear social benefit, including to local communities and other stakeholders
5. Appropriate Regulatory Framework: ability of an intervention to contribute to regulations that enable safe enablement of AAM in the medium term and beyond
6. Secure Supply Chain: ability of an intervention to contribute towards an integrated and resilient domestic supply and manufacturing chain
7. Realised Economic Potential: ability of an intervention to contribute towards new markets, jobs, value-add manufacturing, and new forms of connectivity
8. Global Leadership: contribution towards an internationally-active UK that leads in technology development, regulation, and certification
9. Proactive Communication: contribution towards communication from government regarding strategy, plans and work on the horizon, through public outreach and deep industry engagement

For each barrier category, a low-cost intervention option was identified, which poses the lowest barriers to implementation. Additionally, a relatively more resource intensive intervention was identified for each category, that was also expected to deliver high impact.

Results

The following tables present the identified interventions across the four barrier categories, along with the assessed critical success factor ratings and levels of relative costs and benefits. The high, medium, and low categories aligned with the following scores.

	Low	Medium		High
CSF Rating	< 4.8	4.8 - < 5.8		5.8 - 7
HMG Cost Rating	£ £FTE	££ £FTE - £10M	£££ £10 – £100M	££££ £100M+
Benefits	< 3	3 - < 5		5 - 9

Table A5.2. Category scoring.

Insufficient Availability of AAM Passenger Infrastructure

For the infrastructure barrier, a longlist of eight potential government interventions was formulated. Three interventions were not carried forward, as these were generally rated lower on critical success factors relating to likelihood of delivery and availability of skills required for successful delivery.

Intervention	CSF Rating (Max 7)	HMG Cost Rating	Benefit Rating (Max 9)
Local infrastructure planning campaign: Information campaign to aid local planning bodies in the revision of local procedures and plans to account for vertiport construction, and to inform regarding the opportunities and risks of AAM across the UK	High (6.6)	Medium (££)	Medium (4)
Local AAM benefits campaign: Information campaign from local government to inform local population about benefits and risks of AAM, incorporating private input	High (6.5)	Medium (££)	Low (1.5)
Investors and developers campaign: Information campaign to investors and/or infrastructure developers, making clear government priorities for AAM infrastructure, incorporating private input	High (6.6)	Medium (££)	Low (2)
Subsidies to infrastructure developers: Subsidies to infrastructure developers for the development of AAM infrastructure, for phased implementation as entry into service becomes imminent, in order to improve investment case	Low (3.8)		
Revised NPPF: Revision of National Planning Policy Framework to account for possibility of novel forms of transport infrastructure, for the benefit of local government and planning bodies seeking to make decisions regarding the implementation of AAM infrastructure	Medium (5.4)	Medium (££)	Medium (3.5)
Investment into vertiports: Direct investment into one or more vertiport / airfield projects by government, for operation under a public-private partnership arrangement upon entry-into-service	Low (4.4)		
National policy statement: Issuance of a national policy statement laying out the government's position on the prioritisation, nature and roll-out of AAM infrastructure in the UK	High (6)	Low (£)	Medium (4)
Infrastructure development loans: Provision of government loans to infrastructure developers for the development of AAM infrastructure, for phased implementation alongside entry into service, in order to improve investment case	Low (4.2)		

Table A5.3. Appraisal of insufficient availability of AAM passenger infrastructure interventions.

Public Acceptance and Adoption of AAM

For the public acceptance barrier, a longlist of six logically consistent potential government interventions were formulated. One intervention was not carried forward as, again, it was rated lower on critical success factors relating to likelihood of delivery and availability of skills required for successful delivery.

Intervention	CSF Rating (Max 7)	HMG Cost Rating	Benefit Rating (Max 9)
Operating subsidies: Operating subsidies to vehicle operators upon entry into service of vehicles, to lower costs of AAM services in the near-term	Low (4.1)		
AAM Centre of Excellence: Provide grants and operating funding, under a mixed public-private funding model, for the establishment of an AAM Centre of Excellence, to allow public engagement and industry sandboxing	Medium (5.0)	Medium (££)	High (5.5)
Local information campaigns: Information campaign to local government bodies, to aid in the engagement and informing of local residents regarding the use cases, benefits, risks (and their mitigations) of AAM	High (6.3)	Medium (££)	Low (1.0)
Information campaign to public: Information campaign directly to the general public regarding the use cases, benefits, risks (and their mitigations) of AAM	High (6.0)	Medium (££)	Low (1.5)
Commercial test flights: Actively facilitate the conduct of test flights of AAM vehicles for commercial use in areas accessible to, and viewable by, the public	High (6.0)	Medium (££)	High (6.0)
Public benefit test flights: Provide funding to actively facilitate the launch of pilot programmes in the provision of services in use cases where public value is clearly visible, such as patient transport and medical goods delivery	High (6.4)	Medium (£££)	High (7.0)

Table A5.4. Appraisal of public acceptance and adoption of AAM interventions.

Policy, Certification, Regulation, and Licensing

For the policy, certification, regulation and licensing barrier, a longlist of seven potential government interventions was formulated. All interventions were carried forward for further consideration.

Intervention	CSF Rating (Max 7)	HMG Cost Rating	Benefit Rating (Max 9)
Strategic regulatory action plan: Publish a strategic regulatory action plan for AAM in the UK, laying out envisioned timelines of AAM roll-out and regulatory milestones to be reached at each stage, clear assignment of responsibility, as well as perceived opportunities and risks of AAM in the UK	High (6.8)	Low (£)	High (6.5)
Industry consultation: Increase the frequency and depth of industry consultation and feed-in to the formulation of policy, regulation, and rules, including accelerating implementation of the Future of Flight Industry Group	High (6.4)	Low (£)	Medium (4.5)
CAA resourcing: Increase CAA resourcing, particularly within design and certification teams, and assess pay scales for key roles to ensure the attraction and retention of necessary labour	High (5.9)	Medium (£££)*	Medium (4.0)
Cross-government coordination: Deepen cross-government coordination, accelerating the activities of the FFIG and cross-Whitehall working group, and considering the establishment of an AAM sub-committee or dedicated cross-governmental AAM working group	High (6.4)	Low (£)	Medium (3.0)
Foreign engagement: Ensure multi-actor engagement with foreign regulators, assuring that DfT, CAA, NATS, and other systemic stakeholders in the UK are speaking with one voice	High (6.3)	Low (£)	Low (2.5)
Flexible regulatory approach: Where practical, ensure flexibility in regulation while maintaining safety standards, particularly while operational data and characteristics are still outstanding, and ensure this flexibility is made clear and acted upon across departments	High (5.9)	Low (£)	Medium (3.0)
Ministerial Sponsorship: Secure ministerial sponsorship, and ensure that governmental backing of viable AAM use cases in the UK are publicly recognised at a ministerial level through speeches, information campaigns or issued statements	High (6.6)	Low (£)	Medium (4.0)

** Cost could be varied depending on scale of requirements, and benefits may also scale with costs.*

Table A5.5. Appraisal of policy, certification, regulation and licensing interventions.

Airspace Systems and Management

Five longlist options were identified to address issues identified by interviewees regarding airspace systems and management. All five were carried forward for further consideration.

Intervention	CSF Rating (Max 7)	HMG Cost Rating	Benefit Rating (Max 9)
Amend NATS funding: Review and reform NATS funding model through CAA support in order to enable sufficient funding of AAM-related airspace management activities	Medium (5.1)	Low (£)	Medium (3.0)
Review IFR: Review and reform the use of instrument flight rules in urban areas for AAM vehicles	Medium (5.5)	Medium (££)	Medium (3.5)
Amend airspace change process: Amend and optimise existing air space change processes to expedite airspace impact assessments and stakeholder consultations	Medium (5.3)	Medium (££)	Medium (3.5)
Airspace trials: Enable rolling airspace trials in lieu of timely airspace changes in order to enable initial operations and trial of AAM flights in the UK	High (6.2)	Low (£)	High (5.5)
Continued development funding: Provide continued challenge funding to support the development of technologies required for scaled AAM operations	High (6.1)	High (££££)*	Medium (4.0)

** Cost could be varied depending on scale of requirements, and benefits may also scale with costs.*

Table A5.6. Appraisal of airspace barrier interventions.

A6 Glossary

AAIM	Advanced Aviation Infrastructure Modernization
AAM	Advanced Air Mobility
AFWERX	Air Force Work Project
AGP	Aerospace Growth Partnership
AGS	Aberdeen, Glasgow and Southampton
AGV	Autonomous Ground Vehicles
AMI	Air Mobility Initiative
AMS	Airspace Modernisation Strategy
ANO	Air Navigation Order
AONB	Area of Natural Beauty
ARC	Ames Research Center
ARI	AAM Reality Index
ATC	Air Traffic Control
ATI	Aerospace Technology Institute
ATMUA	Air Traffic Management and Unmanned Aircraft Act
ATRI	Air Taxi Readiness Index
BEIS	Department for Business, Energy & Industrial Strategy
BEV	Battery Electric Vehicle
BMDV	The German Federal Ministry for Transport and Digital Infrastructure
BMZ	The German Ministry for Economic Cooperation and Development
BNDES	Brazil’s National Development Bank
BVLOS	Beyond Visual Line of Sight
CAA	Civil Aviation Authority
CAAM	Canadian Advanced Air Mobility Consortium
CAELUS	Care & Equity – Healthcare Logistics UAS Scotland
CCTV	Closed Circuit Television
CEO	Chief Executive Officer
CIVATA	Civic Air Transport Association
CSF	Critical Success Factors
CTOL	Conventional Take-off and landing
DBT	Department for Business and Trade
DEP	Distributed Electric Propulsion
DfT	Department for Transport
DGAC	The French Directorate General for Civil Aviation
DMARES	Drones and Model Aircraft Registration and Education Scheme
DOE	Department of Energy
DSIT	Department for Science, Innovation and Technology
D-TRIG	Drones Technology Research and Innovation Grants

EASA	European Union Aviation Safety Agency	NASA	National Aeronautics and Space Administration
EIS	Entry into Service	NATS	National Air Traffic Services
EU	European Union	NHS	National Health Service
EV	Electric Vehicles	NPPF	National Planning Policy Framework
eVTOL	Electric Vertical Take-off and Landing	NPRM	Notice of Proposed Rulemaking
FAA	Federal Aviation Administration	NPS	National Policy Statement
FASI	Future Aviation Strategy Implementation	NRC	Canadian Air Mobility and National Research Council of Canada
FFC	Future Flight Challenge	NTRS	NASA Technical Reports Server
FFIG	Future of Flight Industry Group	ODAM	On-Demand Air Mobility
FYE	Financial Year End	OECD	Organisation for Economic Co-operation and Development
GDP	Gross Domestic Product	OEM	Original Equipment Manufacturers
GHG	Greenhouse Gas	ONS	Office for National Statistics
GPS	Global Positioning System	PED	Price Elasticity of Demand
GVA	Gross Value Added	PSO	Public Service Obligations
HMG	His Majesty's Government	PwC	PricewaterhouseCoopers
HSBC	Hongkong and Shanghai Banking Corporation	QA	Quality Assurance
ICAO	International Civil Aviation Organisation	RAM	Regional Air Mobility
ICEV	Internal Combustion Engine Vehicle	RNLI	Royal National Lifeboat Institution
IMC	Instrument Meteorological Conditions	RPAS	Remotely Piloted Aircraft System
IOAT	Input-output Analytical Table	SAF	Sustainable Aviation Fuel
IPO	Initial Public Offering	SIF	Strategic Innovation Fund
KPMG	Klynveld Peat Marwick Goerdeler	SME	Small and Medium-Sized Enterprises
LAX	Los Angeles Airport	STOL	Short Take-off and Landing
LEK	Lawrence Evans Koch	TAM	Total Addressable Market
LEO	Low Earth Orbit	TRL	Technology Readiness Level
MENA	Middle East and North Africa	UAM	Urban Air Mobility
METI	Ministry of Economy, Trade and Industry	UAS	Uncrewed Aerial System

UK	United Kingdom
URKI	UK Research and Innovation
US	United States
USA	United States of America
USAF	United States Air Force
UTM	Unmanned Aircraft Traffic Management
VTOL	Vertical Take-off and Landing
VTTS	Value of Travel Time Saving
WHO	World Health Organisation
WSP	Williams Sale Partnership
WTP	Willingness To Pay
ZEFI	Zero Emission Flight Infrastructure

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Friary Court, 13-21 High Street
Guildford, Surrey
United Kingdom, GU1 3DL
info@brycetech.com

brycetech.com