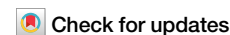


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Navigating the low-altitude economy: stakeholder perceptions and ecosystem implications of UAM in China

Ruikai Sun¹, Tiansheng Yang²✉ & Ahmad Jamal³

Urban Air Mobility (UAM), particularly passenger-oriented electric vertical take-off and landing services, is increasingly promoted as part of future urban transport, but its adoption depends on coordination among regulators, engineers, operators, investors and researchers. This study develops an ecosystem-oriented framework integrating socio-technical transition theory, innovation ecosystem theory and a flying electric Mobility-as-a-Service perspective. A PESTLE-based survey of 149 stakeholders in Jiangsu Province, China, was analysed using K-modes clustering and exploratory factor analysis. The results show limited baseline familiarity with UAM and substantial heterogeneity in perceived drivers and barriers. Four attitudinal profiles were identified: proactive supporters, highly cautious stakeholders, policy-trusting stakeholders and technologically neutral stakeholders. Factor analysis revealed four underlying dimensions: technological performance and system safety, policy guidance and economic incentives, public acceptance and market awareness, and environmental sustainability. Stakeholder roles were associated with different priorities, with governance actors placing greater emphasis on policy support and technical stakeholders expressing stronger implementation concerns. The findings indicate that scalable UAM deployment requires predictable governance, transparent safety assurance, evidence-based decision support and user-centred service integration. This study provides quantitative evidence on stakeholder heterogeneity and coordination needs for UAM adoption in China.

Urban Air Mobility (UAM) is emerging as a potential component of future urban passenger transport systems, although most applications remain in pilot and early commercialisation stages globally. In this study, UAM refers specifically to passenger-oriented electric vertical take-off and landing services (eVTOL), such as air taxis and flying cars, operating within urban or peri-urban low-altitude transport systems. This focus is adopted because passenger-oriented eVTOL services directly connect aviation technology with everyday urban mobility, requiring not only aircraft safety and operational reliability, but also public trust, service accessibility, fare acceptability and integration with existing transport networks. This scope distinguishes UAM from the broader low-altitude economy and Advanced Air Mobility (AAM), which also include freight delivery, emergency response, aerial inspection and regional air services. Its development responds to growing road congestion, increasing sustainability requirements and the broader integration of multimodal transport. UAM is viewed not only as a technical innovation but also as a new form of transport service shaped by regulatory, infrastructural, social, economic and environmental

conditions within complex urban mobility systems^{1,2}. Although advances in technologies have made early deployment feasible, large-scale adoption is still constrained by institutional uncertainty, infrastructure readiness, regulatory developments and public acceptance. These constraints are interdependent and distributed across multiple actors, including regulators, operators, engineers, investors and researchers. Recent studies suggest that the central question is no longer whether the aircraft can fly but whether the system can operate reliably in real urban environments^{3,4}. This shift highlights the need for coordination among a range of stakeholders whose expectations, incentives and responsibilities may differ.

In China, UAM has developed within the broader national agenda of the low-altitude economy. This policy agenda covers a wide range of applications, including logistics, emergency services, urban governance, tourism and passenger mobility. However, passenger-oriented eVTOL services occupy a distinctive position within this agenda because they require the simultaneous alignment of aircraft certification, low-altitude airspace governance, vertiport planning, urban transport integration, public

¹Liverpool Logistics, Offshore and Marine Research Institute, Liverpool John Moores University, Liverpool, UK. ²University of South Wales, Cardiff, UK. ³Cardiff University, Cardiff Business School, Cardiff, UK. ✉e-mail: tiansheng.yang1@southwales.ac.uk

acceptance and commercial service design. Mission-oriented policy implementation and public-private collaboration have encouraged city governments as well as leading firms to participate in low-altitude experimentation and industrial development, as illustrated by Shenzhen's low-altitude economy and cases involving SF Express, Meituan and Heli-Eastern⁵. The transition from demonstration activities to scalable passenger UAM services remains uncertain. Also, there is limited empirical evidence on whether stakeholders in this emerging system, such as government authorities, researchers, investors, engineers and operators, share similar expectations or hold diverging views^{6,7}. Existing UAM research has paid substantial attention to technical feasibility, operational concepts, infrastructure planning and conceptual system design, while empirical studies comparing the perceptions of multiple stakeholder groups remain relatively limited^{8,9}. This gap is particularly evident in China, where institutional, cultural and market conditions differ substantially from those in the United States and Europe. Although China's low-altitude economy is being actively promoted through policy support, industrial development and demonstration projects¹⁰, empirical evidence on stakeholder perceptions and coordination needs remains limited^{8,11}.

To address this gap, this study adopts an integrated theoretical perspective that combines socio-technical transition theory, innovation ecosystem theory, and emerging views, such as treating flying electric Mobility-as-a-Service (feMaaS) as a case. This approach allows UAM to be understood as more than a niche technology. It is also a service ecosystem in which policy support, market incentives, technological maturity, regulatory legitimacy and public trust must be aligned. Under this framework, stakeholder coordination is more important than technology alone in determining whether UAM can move beyond pilot projects and become a stable component of urban transport. This study examines two research questions.

RQ1. How do different stakeholder groups perceive the key drivers and barriers shaping their interactions and influencing the systemic adoption of Urban Air Mobility in Chinese cities?

RQ2. What forms of stakeholder coordination are required to address these barriers and enable Urban Air Mobility to be effectively integrated into future urban mobility systems?

This study contributes to the literature on UAM adoption in two ways. It develops a comprehensive analytical framework that brings together socio-technical transition theory, ecosystem thinking, and a Political, Economic, Social, Technological, Legal and Environmental (PESTLE)-based empirical model to examine how policy, technology, markets, and social acceptance jointly influence adoption. It also provides rare quantitative evidence using stakeholder perception data analysed through clustering and factor analysis. The results reveal apparent differences among stakeholder groups, showing distinct attitudinal profiles and identifying areas of alignment and divergence within the emerging ecosystem. These findings help improve our understanding of how governance, technological readiness and public acceptance interact, and they offer practical insights for designing coordination mechanisms that can help UAM evolve from experimental pilots to scalable transport services.

The remainder of this paper is organised as follows. Literature Review section reviews the policy context, market landscape, and key UAM technologies to establish the institutional and industrial foundations relevant to China. Methodology section outlines the research design, including the stakeholder survey, data sources and the PESTLE-based empirical approach. Results section presents the results of the clustering and factor analyses, identifying the attitudinal groups and underlying cognitive structures. Discussion section discusses the implications for firms, managers and policymakers, and suggests ways to strengthen coordination within the ecosystem. The conclusion section concludes the paper, summarises the main contributions and identifies directions for future research.

Literature review

Overview of UAM research

UAM has been proposed as a way to ease road congestion, improve urban accessibility and support a shift towards more sustainable modes of

passenger travel². In this study, UAM is understood as passenger-oriented eVTOL operating within urban or peri-urban low-altitude transport systems. This definition is consistent with established views of UAM as an urban or metropolitan air transport system enabled by eVTOL technologies^{12,13}. UAM can be regarded as a passenger-focused subset of AAM, which covers a broader range of regional, rural and cargo-related air mobility services¹⁴. UAM is narrower than the low-altitude economy, which includes freight delivery, emergency response, aerial inspection, regional air services and other non-passenger applications. Compared with conventional airport infrastructure, UAM may offer greater flexibility in ground infrastructure because vertiports can be located at ground level or on building rooftops. However, such land requirements may depend on the number of vertipads, parking spaces, passenger processing facilities, safety buffers, charging infrastructure and local regulatory requirements^{15,16}. The combination of electrification, automation, and digital control has increased its commercial potential and enabled new service concepts, such as air taxis and short-distance commuter routes⁹.

Early studies focused mainly on engineering-related issues such as vehicle design, propulsion systems and safety performance^{14,17}. More recent work has examined topics including airspace management, noise control, and energy efficiency¹⁸. As infrastructure has become more important, researchers have also begun to study the planning of vertiports, energy supply networks, and the integration of UAM with ground transport¹⁹. However, technical feasibility alone cannot ensure widespread adoption among the general public. Certification, safety assurance, regulatory governance and public trust remain significant challenges. Recent studies show that UAM research has expanded beyond vehicle-level feasibility towards broader adoption conditions, including legal and regulatory barriers, infrastructure integration, stakeholder coordination and social acceptance^{20,21}. This direction aligns with the broader Mobility-as-a-Service literature, which emphasises platform integration and coordination among actors during mobility transitions²².

Although the field has advanced, empirical evidence on the drivers and barriers to UAM adoption remains limited. Engineering-oriented studies⁹ provide valuable technical insights but often overlook governance and behavioural aspects. Qualitative studies and stakeholder workshops reveal differences in perceptions but usually lack statistical robustness or generalisability. From a theoretical perspective, scholars increasingly agree that adoption depends on system-level interactions, yet the empirical tools available to quantify such interactions remain limited. Current quantitative research often relies on small samples or stated-preference surveys and typically uses structural equation modelling^{23–27}. These studies improve our understanding of behavioural intentions but are usually based on hypothetical scenarios and therefore struggle to capture subtle resistance, evolving attitudes or long-term behavioural change. Technical modelling also remains incomplete, particularly in relation to vertiport networks, traffic management, and aircraft performance, while legal and regulatory studies are even scarcer^{9,28}. Current regulatory frameworks remain underdeveloped, and progress varies widely across regions, with marked gaps outside high-income countries^{8,29}.

Few studies adopt interdisciplinary or participatory approaches that combine technical, social, economic and legal perspectives^{30,31}. Most focus on a single dimension or a specific stakeholder group. Geographically, research remains concentrated in the United States and Europe, and systematic empirical evidence from developing countries, including China, remains limited^{16,14}. Over time, academic attention has expanded from vehicle design and airspace safety to governance, regulatory practices, infrastructure location and social acceptance. The central question has therefore shifted from whether the aircraft can fly to whether the broader system can operate effectively within cities. Certification, interoperability and public trust have become essential considerations. The literature on Mobility-as-a-Service echoes this shift, showing that mobility transitions depend on coordinated action across multiple actors rather than on progress within a single mode. This idea informs the ecosystem framework adopted in this study.

Policy, legal and market issues in China

China's push for a low-altitude economy has created a clean policy-led environment for UAM development. Milestones include the 2021 national transport plan, strategic designation in 2023, and the world's first eVTOL production certificate in 2024. Such achievements have encouraged city-level pilot projects, industrial investment and regional clustering, while also promoting low-altitude manufacturing, eVTOL research and development, digital infrastructure, logistics applications, emergency response and urban public-service scenarios.

Within this broader policy-led agenda, UAM is particularly relevant to urban transport research because it requires coordination between aviation regulation and everyday urban mobility systems²¹. Its deployment depends not only on aircraft certification, but also on airspace access, vertiport networks, multimodal integration, fare structures, safety communication and public acceptance of this new mobility mode³². The key challenge is, therefore, no longer limited to whether eVTOL aircraft can be certified or demonstrated, but whether UAM can become a reliable, affordable and publicly trusted component of urban transport.

The legal architecture remains incomplete: definitions of eVTOL operations and licensing are evolving; approvals remain case-specific; airspace coordination is fragmented; and provisions on liability, privacy, and data security are being clarified³³. These conditions suggest that the transition from demonstration projects to scalable and commercially viable UAM operations depends on more predictable, performance-based approval procedures, together with clearer arrangements for data governance and liability allocation.

Stakeholder and theoretical perspectives on UAM adoption

The development of UAM involves a vast constellation of stakeholders, including government bodies, engineers, operators, investors, and researchers. Their expectations, resources and constraints jointly influence both the direction and the speed of adoption. However, existing studies often examine these actors in isolation and tend to overlook the coordination challenges that arise when groups with different responsibilities and risk exposures must contribute to the same emerging system^{7,23,26}. Research from related fields such as autonomous driving and shared mobility has repeatedly shown that when stakeholders hold misaligned expectations, the diffusion of new technologies can be significantly delayed^{22,34}. Understanding how coordination can be achieved across multiple groups is, therefore, a fundamental requirement for the sustainable development of UAM.

To analyse these interactions, this study employs socio-technical transition theory³⁵ and ecosystem theory³⁶, which together provide a structured explanation of how new mobility systems evolve. Socio-technical transition theory, developed initially within sustainability and innovation studies^{35,37}, explains how technologies, infrastructures and social practices evolve within complex systems such as transport, energy and mobility. It views transitions as the outcome of interactions across three analytical levels: the landscape, the regime, and niche innovations. From this perspective, UAM can be understood as a niche innovation that challenges established urban mobility systems³⁸. Its development is shaped by landscape-level forces such as sustainability objectives, electrification and the integration of urban transport systems. These forces may create opportunities for the niche to expand. However, the extent of actual embedding within the regime depends on whether stakeholders can align their expectations, coordinate their resources, and adapt their institutional roles.

Ecosystem theory provides a complementary perspective by focusing on how coordination and value creation occur among interdependent actors at the organisational and meso levels, including industry-level coordination and cross-sector collaboration^{36,39}. In the UAM ecosystem, engineers supply technological solutions, governments shape certification and airspace governance, researchers provide decision-making support, investors contribute financial resources, and operators ensure service reliability. Successful adoption relies on the alignment of incentives, capabilities and governance arrangements among these actors. Fragmented coordination or inconsistent

expectations create systemic frictions that can impede UAM development even when supportive policy signals are present.

Several UAM studies already adopt an ecosystem lens grounded in strategy scholarship^{36,39}. Cohen, Shaheen and Farrar¹⁴ map the UAM 'ecosystem' across manufacturers, operators, ANSPs, cities and platform providers, highlighting complementarity bottlenecks such as vertiport capacity and digital integration. NASA's UAM Market Study likewise frames adoption as a multi-actor service system, tracing value flows and orchestration tasks along the chain⁷. European programme work in ASSURED-UAM operationalises this view by linking certification, airspace management, and municipal planning through coordinated roles and shared standards³¹. Systems-level assessments from DLR and stakeholder mapping studies reach the same conclusion: misaligned complementarities, not isolated technical hurdles, pose the main risk to diffusion^{8,29}.

The current study proposes to integrate these two theoretical lenses, as this enables a more comprehensive understanding of UAM as a combined socio-technical transition and an emerging innovation ecosystem. The socio-technical framework clarifies the structural and temporal pressures shaping adoption at a macro level, while ecosystem theory highlights the coordination mechanisms required at organisational and operational levels. Together, they can illustrate how technological, institutional and social dimensions evolve alongside one another.

Moreover, scholars increasingly argue that new aerial modes should be understood as elements of a user-oriented, platform-based mobility system rather than as independent aviation technologies^{22,34}. Building on this view, the concept of feMaaS positions UAM as one interconnected component within a larger multimodal, electric and on-demand mobility ecosystem. Within such a configuration, UAM is expected to link with public transport, ride-hailing services, payment systems and real-time data platforms, enabling integrated planning, pricing and customer experience. This perspective extends both stakeholder and institutional theories by emphasising complementarities among manufacturers, regulators, operators, platform providers, and users, as well as the importance of governance arrangements for data sharing, service quality, and safety.

Two additional ideas further strengthen this integrated framework. The first is stakeholder salience, which refers to the power, legitimacy and urgency associated with different actors and helps explain whose expectations tend to dominate system priorities⁴⁰. The second is institutional pressure, which includes coercive, normative and mimetic influences that shape organisational behaviour and account for variations in adoption pathways across contexts⁴¹. Together with the feMaaS perspective, these ideas situate UAM within a broader transition in which coordinated action among actors is an important condition for translating technological capability into feasible, trusted and scalable urban mobility services.

Research gaps

The discussion points to four related gaps in the current literature. First, existing UAM studies rarely compare multiple stakeholder groups and therefore provide limited evidence on how perceptions, responsibilities and coordination challenges differ across the emerging UAM ecosystem. Second, although ecosystem theory and socio-technical transition theory^{35,36} have been used to discuss UAM development, fewer studies have integrated these perspectives empirically to examine UAM as a system-wide adoption process. Third, empirical evidence from China remains scarce, particularly in relation to how institutional, cultural and market conditions shape stakeholder perceptions of UAM adoption. Fourth, existing studies remain largely qualitative or focus on single stakeholder groups, while quantitative evidence on multi-stakeholder perception patterns is still limited. This study responds to these gaps by developing a quantitative, ecosystem-oriented framework. PESTLE analysis is first used to select and organise questionnaire variables across political, economic, social, technological, legal and environmental dimensions, while clustering and exploratory factor analysis are applied to identify stakeholder profiles and the latent perception dimensions underlying their attitudes towards UAM adoption.

Conceptual framing of UAM adoption as an ecosystem coordination problem

This study conceptualises UAM adoption as an ecosystem coordination problem shaped by political, economic, social, technological, legal and environmental conditions. UAM adoption cannot be determined by a single dominant driver. Prior studies show that its development depends on the interaction of multiple conditions, including technical readiness, regulatory arrangements, infrastructure provision, public acceptance, market viability and coordination among ecosystem actors^{8,14}. One recurring mechanism concerns the translation of technical credibility into social legitimacy. Prior studies^{30,42} indicate that advances in safety performance, system maturity, and operational capability do not automatically lead to acceptance among regulators, users, or the public unless assurance practices are transparent and intelligible beyond expert communities. A second mechanism relates to the role of policy predictability in enabling investment and operational commitment^{1,43}. While policy ambition can accelerate early experimentation, stable and performance-based regulatory pathways are more critical for reducing uncertainty and encouraging stakeholders to move beyond pilot projects towards scaled deployment. A third mechanism concerns environmental credibility and its alignment with urban governance priorities^{7,44,45}. Verified reductions in emissions and noise are increasingly important for securing public support and procurement opportunities in climate-constrained cities, particularly where UAM must compete with alternative low-carbon transport investments.

Together, these mechanisms highlight that UAM adoption is conditioned by the alignment of expectations across safety assurance, regulatory stability and environmental performance, rather than by technological readiness alone. This perspective informs the empirical strategy adopted in this study. By combining a PESTLE-based measurement framework with clustering and exploratory factor analysis, this study does not aim to test causal hypotheses at this stage. Instead, it seeks to identify how stakeholder groups differ in their perceptions of UAM adoption drivers and barriers, where their expectations are aligned or misaligned, and which areas may require stronger coordination to support the transition from pilot projects to scalable UAM services. The resulting patterns of attitudinal clustering and latent factor structures provide an exploratory basis for understanding how technical, institutional and environmental considerations jointly shape stakeholder positions, and they offer guidance for future research designs that may explicitly test causal pathways using longitudinal data or structural equation modelling.

Methods

This study employs a multi-step approach to collect and analyse data. Firstly, the authors conducted a PESTLE analysis to identify drivers and barriers, and to capture the systemic interactions that determine whether UAM can move from a niche innovation to an integrated element of the broader urban mobility ecosystem. This perspective emphasises that adoption is a collective outcome of cross-domain alignment, policy push, market pull, social trust, technological readiness, regulatory legitimacy, and environmental responsibility.

The second step involved using a quantitative survey method to investigate the drivers and barriers of stakeholder acceptance of UAM. The use of a structured questionnaire supports comparability across respondents and provides a consistent format for collecting stakeholder perceptions, which facilitates subsequent clustering and exploratory factor analysis. The questionnaire was organised into four sections. Section 1 consisted of questions about respondents' travel behaviour. Sections 2 and 3 contained questions about perceptions related to the drivers and barriers of UAM. Section 4 asked questions to capture demographic information.

PESTLE factors affecting UAM adoption

To operationalise the drivers and barriers affecting UAM adoption, this study used PESTLE analysis as a structured framework for questionnaire variable selection. PESTLE has been applied in transport research to organise external political, economic, social, technological, legal and

environmental factors affecting transport systems and mobility services. For example, Leviäkangas⁴⁶ used PESTLE analysis to assess the policy and strategic coverage of digitalisation impacts in Finland's transport sector, while Sobhani et al.⁴⁷ used PESTLE to organise factors and sub-factors influencing unconventional transport modes in a developing city context. Drawing on these applications, this study uses PESTLE not as a causal model, but as a framework for identifying and organising survey variables related to UAM adoption.

As shown in Table 1, the political dimension encompasses factors such as production, purchase, use, infrastructure, technology-support incentive policies, advertising, and broader macro policies. The economic dimension covers investment costs, market demand, recoverable costs, energy prices, supplier reliability, and the development of local manufacturers. Social factors capture public perceptions of cost, safety, comfort, pilot mode, travel time, expected benefits, awareness of UAM technology and environmental protection, stakeholder collaboration, and the development of other future mobility modes. Technical factors are divided into vehicle-related (e.g., travel range, battery performance, safety, capacity, automation), operational (e.g., fleet maintenance, pilot training, ride matching, airspace and ground operations), and infrastructure-related aspects (e.g., vertiport design, location, throughput, energy supply, and security). Legal factors include industry management, safety, air traffic control, and cybersecurity regulations, while environmental factors focus on emission reduction, noise pollution, and battery recycling. These variables were derived from prior literature on emerging mobility innovations (e.g., eVTOL, car sharing, autonomous vehicles) and adapted to the UAM context.

Based on these factors, the survey assessed respondents' core perceptions in two parts. In the second section, respondents were asked to classify each factor as either a barrier or a driver. The question was worded as follows, 'The following Table lists the impact factors affecting the progress of Urban Air Mobility (UAM). Do you consider the following impact factors as barriers or as driver factors?' For each factor, respondents selected either 'barrier' or 'driver', which were coded as 1 and 2, respectively. In the third section, respondents evaluated the perceived importance of each factor. The question asked, 'How much do you think the following impact factors as barriers/driven factors affect the adoption of Urban Air Mobility (UAM)?' Respondents rated each factor using a five-point Likert scale ranging from 1, 'very unimportant', to 5, 'very important'. This two-step design enabled the survey to distinguish between the perceived direction of each factor and its perceived importance for UAM adoption. All respondents evaluated the same list of factors derived from the PESTLE analysis, which ensured comparability across stakeholder groups.

While each PESTLE dimension can be examined independently, adopting an ecosystem perspective allows us to conceptualise these factors not as isolated categories but as interdependent conditions that jointly shape stakeholder coordination. In this view, PESTLE factors are embedded within a multi-actor ecosystem, where decisions, constraints or actions associated with one stakeholder group may influence other actors and shape conditions in related political, economic, social, technological, legal or environmental domains. For instance, political incentives influence financial institutions' willingness to provide funding (economic). At the same time, technological maturity shapes public trust and acceptance (social), which, in turn, pressures regulators to update safety standards (legal).

Stakeholder groups within the UAM ecosystem

PESTLE analysis also helped identify five role-based stakeholder groups using support from ecosystem theory^{36,39}, that reflect functional positions within the emerging UAM ecosystem. These five groups are not defined by attitudinal tendencies but by their institutional responsibilities and the type of value they contribute to the system, as shown in Table 2.

The Governance and Regulation (GovR) group provides institutional legitimacy and sets policy signals, regulatory requirements and safety standards. The Technical Systems and Safety (TechS) group forms the technological and operational backbone, including system design, certification activities, safety assurance and maintenance responsibilities. The

Table 1 | The Impact Factors of the Study

Impact factor Category	Impact factor	Reference
Political	Availability of raw materials for UAM industry	64–69
	UAM production incentives policy	
	UAM purchase incentives policy	
	UAM usage incentives policy	
	UAM infrastructure incentives policy	
	UAM technology support policies	
	UAM advertisement policy	
	Macroscopic policies	
Economic	Initial UAM investment cost	66,70–74
	Initial UAM infrastructure investment cost	
	UAM recoverable cost	
	UAM market demand	
	UAM operation and maintenance cost	
	Clean energy price	
	Reliability of UAM components suppliers	
	Development of local UAM manufacturers	
Social	Public perception of UAM travel cost	2,7,25,70,74,75
	Public perception of UAM safety and reliability	
	Public perception of UAM travel comfort	
	Public perception of UAM pilot mode	
	Public perception of UAM travel time	
	Public perception of UAM expected benefits	
	Public awareness of UAM technology	
	Public awareness of environmental protection	
	Development of other future mobility	
	Collaboration between stakeholders	
	Public perceptions of UAM market mode	
Technical (Vehicle)	Travel time of UAM	7,25,76–78
	Connection time of UAM	
	Travel Range of UAM	
	Battery performance of UAM	
	Travel Comfort of UAM	
	Safety of UAM	
	Propulsion system of UAM	
	Capacity of UAM	
	Automated UAM	
Technical (Operational)	UAM fleet maintenance	16,74,77
	UAM pilot training plan	
	Ride matching	

Table 1 (continued) | The Impact Factors of the Study

Impact factor Category	Impact factor	Reference
Technical (Infrastructure)	Airspace operation	16,72,76,79
	Ground operations	
	Infrastructure of maintenance, service, and repair	
	Vertiport Design	
	Location and network of Vertiport	
	Throughput and capacity of Vertiport	
	Security of Vertiport	
	Energy supply	
Law	UAM industry management regulation	7,31,74,77
	UAM Safety regulations	
	UAM Air traffic control regulations	
	UAM cybersecurity regulations	
Environmental	Wastage and recycling of battery	74,77,80
	Emission Reduction	
	Noise pollution	

Strategic and Investment (StratInv) group contributes to commercialisation through strategic planning, investment decisions and partnership development. The Operational Execution (OpsExec) group is responsible for day-to-day service delivery, standard operating procedures and direct interactions with end users. The Knowledge and Evidence (KnowEv) group plays a cross-cutting role by synthesising evidence, modelling demand and system impacts, and supporting decision-making.

In the questionnaire, respondents were asked to report their occupation and work role. Based on this information, they were assigned to one of five stakeholder groups. Respondents from government agencies involved in low altitude management, transport governance, emergency management, public safety or related regulatory functions were classified into the Governance and Regulation group. Engineers, software specialists and technical staff from government agencies or enterprises were classified into the Technical Systems and Safety group. Staff from government agencies, industry associations, company management teams and investment departments were classified into the Strategic and Investment group. Staff involved in company operations, service delivery and market functions were classified into the Operational Execution group. Researchers from universities and research institutions were classified into the Knowledge and Evidence group. These role-based groups are used to interpret heterogeneity in perceptions revealed by clustering and factor analysis, allowing the results to be examined through the lens of ecosystem coordination rather than simple organisational labels. Table 2 summarises their scope and ecosystem functions.

Quantitative data collection

From March to September 2025, an online survey was conducted in Jiangsu Province, China, to collect empirical data. Jiangsu was selected as the study area because it represents one of China's active regions in promoting low-altitude economy and UAM-related development. The province has issued policy measures to accelerate the high-quality development of the low-altitude economy and to strengthen low-altitude manufacturing, including unmanned aircraft, eVTOL, low-altitude information infrastructure, and related industrial chains^{48,49}. In addition, several Jiangsu cities have begun to develop low-altitude application scenarios in logistics, emergency response, urban governance, and public services. Therefore, Jiangsu provides an appropriate empirical context for examining stakeholder perceptions of UAM adoption in China. The questionnaire was distributed to stakeholders

Table 2 | Stakeholder Group Summary (Source: This Study)

Stakeholder Group Name	Group Scope	Ecosystem Role	Occupation and Role
Governance and Regulation Group (GovR)	Policy design, regulation, standards, public oversight	Provides institutional legitimacy and sets the regulatory framework shaping adoption	Policymakers and regulatory staff in government agencies
Technical Systems and Safety Group (TechS)	System design, certification, operations safety, maintenance	Acts as safety gatekeepers, ensuring technical feasibility and reliability	Engineers, software specialists and technical staff in government agencies or firms
Strategic and Investment Group (StratInv)	Strategic planning, budgeting, partnerships, commercialisation	Functions as strategic orchestrators, aligning resources and market entry strategies	Management teams and investment departments staff from government agencies, industry associations, company
Operational Execution Group (OpsExec)	Day-to-day operations, SOPs, customer interface, service delivery	Ensures service reliability, translating plans into operational practice	Staff from company operations, service delivery and market departments
Knowledge and Evidence Group (KnowEv)	Evidence synthesis, modelling, evaluation, horizon scanning	Serves as knowledge brokers, generating insights and informing decision-making	Researchers from universities and research institutions

involved in, or related to, UAM and the low-altitude economy. These included government agencies responsible for low altitude management, transport governance, emergency management, public safety and related regulatory functions. Respondent organisations also included UAM manufacturers, UAM service companies, public transport companies, airports, banks, insurance companies, technology companies, industry associations, universities and research institutions. This sampling strategy was designed to collect views from actors with different degrees of direct and indirect involvement in the emerging UAM ecosystem. The study protocol was reviewed and approved by the University of South Wales Faculty of Business and Creative Industries Faculty Ethics Committee (reference number FBCE040). The research was conducted in accordance with the principles of the Declaration of Helsinki. All participants received information about the purpose of the study and provided written informed consent before completing the questionnaire. Participants also received a brief and neutral description of the technology considered in this study. The description stated that UAM refers to passenger-oriented air taxi or flying car services within the context of urban air mobility and the low-altitude economy. It did not provide detailed technical specifications, operating ranges, fare assumptions, safety claims or deployment scenarios. This design was intended to capture respondents' existing perceptions and baseline familiarity with UAM.

The recruitment yielded a total of 234 responses, of which 149 were retained as valid responses after data screening. Responses were deemed invalid and excluded if respondents selected the same answer for all perception items. This criterion was used to identify straight-line response patterns, which are commonly treated as an indicator of careless or insufficient-effort responding in survey research^{50,51}. Because identical responses across all perception items provide limited information for distinguishing stakeholder attitudes, excluding these cases helped improve the reliability of the clustering and exploratory factor analyses. The demographic characteristics of the respondents are shown in Table 3. The survey gathered responses from a diverse pool of participants with relevant driving and mobility experience. A large majority (89.93%) held a valid driver's licence, and 79.19% reported owning a car. Among car owners, petrol-powered cars were the most prevalent (81.88%), followed by electric vehicles (20.81%), hybrid cars (8.72%), and diesel vehicles (4.03%), while no respondents reported owning CNG-powered vehicles (0.00%). These variables were included as background mobility indicators rather than core explanatory variables. They provide information on respondents' exposure to personal travel behaviour and current reliance on private mobility, which may shape how they interpret UAM as a potential alternative or complementary mode within future urban transport systems. In terms of gender distribution, the sample was predominantly male (74.50%), with female participants accounting for 25.50% (0.00% reporting other genders). The age profile skewed towards middle-aged individuals, with 40.27% aged 36–45, followed by 20.13% aged 26–35 and 20.13% aged 46–55. Younger respondents aged 15–25 accounted for 14.09%, and 5.37% were aged 55 or

older. Regarding educational attainment, 50.34% of participants held an undergraduate degree, and 20.81% held a postgraduate degree. Other educational qualifications included college/intermediate/A-levels (17.45%), matriculations/O-levels (6.71%) and professional qualifications (2.01%). Smaller proportions held a doctorate degree (1.34%), reported primary school or below (0.67%) or selected other qualifications (0.67%). Personal annual income varied across the sample. The largest group (20.13%) reported earning less than 10,000 CNY per year, though this category may include respondents unwilling to disclose their income. Other income brackets included 50,000–100,000 CNY (16.78%), 100,000–200,000 CNY (14.09%), 30,000–50,000 CNY (10.07%), and smaller proportions across higher and lower ranges. In terms of occupation, participants represented a broad spectrum of professional roles. The largest group was OpsExec (32.89%), followed by StratInv (26.85%), KnowEv (18.79%), TechS (14.77%), and GovR (6.71%).

Data analysis techniques

Two complementary analytical techniques were employed to analyse questionnaire data. The first technique was an unsupervised clustering algorithm, K-modes⁵², which aimed to capture heterogeneity in stakeholder perceptions. This method was selected because the survey collected respondents' categorical judgements of 54 impact factors as either barriers or drivers. Unlike K-means clustering, which is designed for continuous numerical variables, K-modes uses matching dissimilarity and model values to group respondents with similar categorical response patterns. It was therefore suitable for identifying stakeholder groups with similar attitudinal profiles towards UAM adoption. Unlike descriptive statistics, which provided only aggregate tendencies, clustering analysis enables the identification of latent, unobserved sub-populations within the sample^{53,54}. Since the number of clusters was not known, an optimisation procedure was undertaken to evaluate alternative solutions and determine the most appropriate number of clusters, thereby ensuring both statistical validity and interpretive relevance of the derived groupings.

The second technique was introduced to address the dataset's dimensional complexity. Given the considerable overlap and potential interdependencies among the 54 impact factors across the six PESTLE categories, Exploratory Factor Analysis (EFA) was performed. EFA is particularly suited to examining underlying correlation structures, as it extracts shared variance among observed variables and condenses them into fewer latent constructs⁵⁵. In this study, EFA helped move the analysis beyond individual survey items and the original PESTLE categories by identifying broader dimensions that structure stakeholder perceptions, such as technological performance, policy support, public acceptance and environmental sustainability. This not only enhances simplicity but also facilitates a more robust interpretation of the data by identifying broader conceptual dimensions that structure stakeholder perceptions⁵⁶.

The application of clustering and factor analysis provides a more comprehensive analytical framework. While clustering delineates groups of

Table 3 | Overview of respondents (N = 149)

Demographics		Sample percentage
Driver license	Yes	89.93%
	No	10.07%
Car ownership	Yes	79.19%
	No	20.81%
Fuel of car	Diesel	4.03%
	Petrol	81.88%
	Hybrid	8.72%
	CNG	0.00%
	Electric	20.81%
Gender	Male	74.50%
	Female	25.50%
	Other	0.00%
Age	15–25	14.09%
	26–35	20.13%
	36–45	40.27%
	46–55	20.13%
	Above 55	5.37%
Education level	Primary School or below	0.67%
	Matriculations/O-Levels	6.71%
	College/Intermediate/A-Levels	17.45%
	Professional Qualification	2.01%
	Undergraduate Degree	50.34%
	Postgraduate Degree	20.81%
	Doctorate Degree	1.34%
	Other	0.67%
Personal annual income	less than 10,000 CNY	20.13%
	10,000–20,000 CNY	9.40%
	20,000–30,000 CNY	6.04%
	30,000–50,000 CNY	10.07%
	50,000–100,000 CNY	16.78%
	100,000–200,000 CNY	14.09%
	200,000–300,000 CNY	7.38%
	300,000–500,000 CNY	9.40%
Occupation category	Above 500,000 CNY	6.71%
	KnowEv	18.79%
	TechS	14.77%
	GovR	6.71%
	OpsExec	32.89%
	StratInv	26.85%

Note: The fuel type of the car is a multiple-response question. Therefore, the percentages for fuel type may sum to more than 100%.

stakeholders with distinct attitudinal orientations, factor analysis synthesises many correlated variables into interpretable dimensions. The combination of these approaches thereby yields complementary insights into both the diversity of stakeholder perspectives and the latent structures underpinning the drivers and barriers of UAM adoption.

Results

Respondents' clusters gathering by attitude

After completing data collection and cleaning, the analysis begins by examining stakeholders' baseline familiarity with UAM, which provides

essential context for interpreting their subsequent perceptions of drivers and barriers. Figure 1 presents familiarity levels with UAM across different stakeholder groups. Overall, baseline familiarity was limited. Only 22% of respondents reported being either 'very familiar' or 'familiar' with UAM, whereas 31% selected 'unfamiliar' and 17% selected 'very unfamiliar'. Taken together, nearly half of the respondents reported low familiarity with UAM.

This pattern should be interpreted in relation to Jiangsu's development stage. Although Jiangsu is an active region for low-altitude economy development and eVTOL-related testing, UAM has not yet become a routine urban transport service. Current activities remain concentrated on policy planning, industrial testing, demonstration scenarios and early technical development, rather than regular passenger service operations. Therefore, stakeholders may be familiar with the broader low-altitude economy while still having limited direct exposure to UAM as an operational service. This distinction is important because the familiarity measure captures self-reported prior familiarity with UAM, rather than objective technical knowledge of eVTOL systems.

Stakeholder differences further support this interpretation. GovR respondents reported relatively higher familiarity, although this should be interpreted cautiously due to the small group size. KnowEv and StratInv respondents also showed moderate familiarity, possibly reflecting their exposure to research, policy analysis, market assessment and strategic planning. By contrast, TechS respondents showed the lowest level of familiarity, with only 9.1% selecting 'very familiar' or 'familiar' and 54.5% selecting 'unfamiliar' or 'very unfamiliar'. OpsExec respondents also reported relatively low familiarity, with 49.0% falling into the two unfamiliar categories. This should not be read as a lack of technical or operational capability. It suggests that regular UAM services have not required extensive direct involvement from many technical and operational professionals in areas such as passenger eVTOL certification, maintenance, vertiport operation, airspace integration and service-level system design. This provides useful context for interpreting the subsequent clustering results.

Based on the survey responses regarding perceptions of 54 impact factors, the K-Modes clustering algorithm was applied to categorise participants into distinct attitude-based groups. K-Modes is a variant of the K-means family of clustering algorithms designed for categorical data. It replaces numerical distances with a simple matching distance and replaces means with modes when updating cluster centroids. As K-Modes is an unsupervised machine learning method, determining the optimal number of clusters was necessary. Figure 2 presents the results of the Elbow Method, where the x-axis represents the number of clusters and the y-axis indicates the clustering cost (dissimilarity). In the K-modes analysis, the number of clusters was determined by comparing clustering solutions from $k = 1$ to $k = 10$ and calculating the total within-cluster dissimilarity cost. The elbow plot showed a sharp decline in cost when the number of clusters increased from one to two, followed by a continued decrease up to $k = 4$. After $k = 4$, the curve became flatter, indicating that additional clusters provided only limited improvement in reducing dissimilarity. Therefore, a four-cluster solution was selected because it offered a balance between statistical parsimony and substantive interpretability. Compared with the two- and three-cluster solutions, the four-cluster solution captured differences in respondents' perceptions of UAM impact factors more effectively, while avoiding unnecessary fragmentation caused by an excessive number of clusters.

Figure 3 presents the proportion of respondents in each cluster who classified each PESTLE category as a driver of UAM development. Figure 4 provides the corresponding item-level results for the 54 individual impact factors. The four clusters included 49 respondents in Cluster 0, 47 respondents in Cluster 1, 27 respondents in Cluster 2 and 26 respondents in Cluster 3. Because the original binary variable was coded as 1 for 'barrier' and 2 for 'driver', the results were converted into driver proportions for clearer interpretation. Values above 50% indicate that a majority of respondents in the cluster perceived the factor as a driver, whereas values below 50% indicate that a majority perceived the factor as a barrier. Values close to 50% indicate divided or mixed views within the cluster. The results in Fig. 4 identify four distinct clusters: proactive supporter type, policy-trusting type,

Fig. 1 | Distribution of self-reported familiarity with Urban Air Mobility across stakeholder groups. The horizontal stacked bars show the percentage distribution of five familiarity levels within each stakeholder group, with each bar summing to 100%. The stakeholder groups comprised 10 GovR respondents, 28 KnowEv respondents, 49 OpsExec respondents, 40 StratInv respondents and 22 TechS respondents.

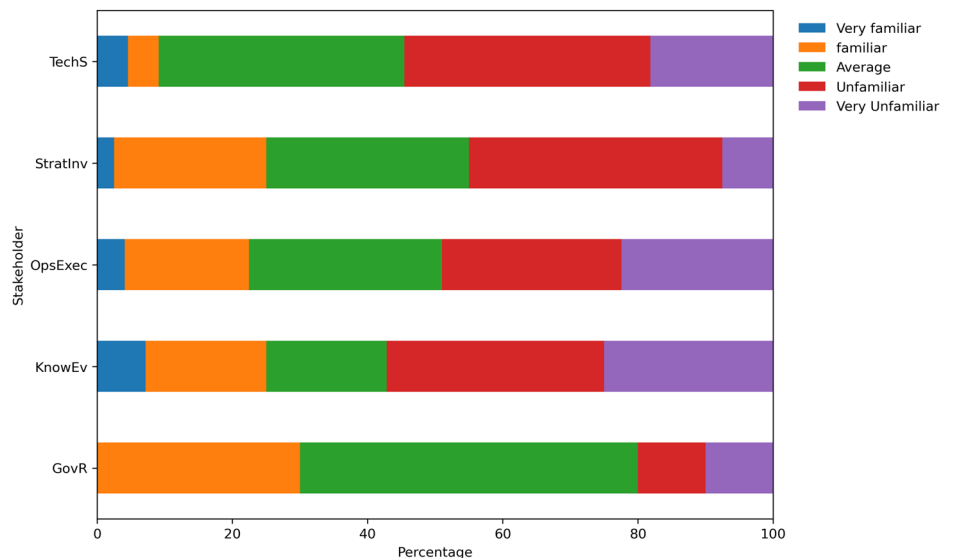
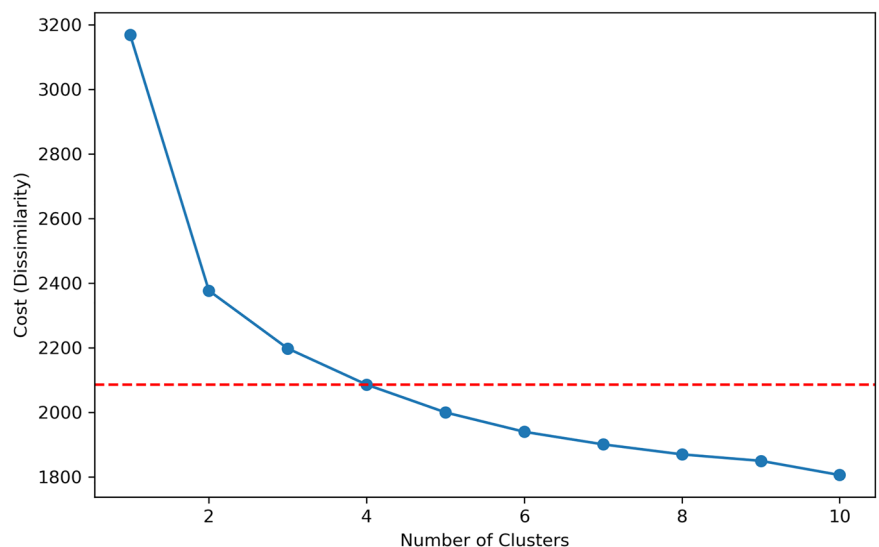


Fig. 2 | Comparison of K-modes clustering costs across candidate numbers of clusters. The horizontal axis shows the number of candidate clusters and the vertical axis shows the total within-cluster dissimilarity cost. Blue circles connected by a blue line represent the clustering cost obtained for each candidate solution. The red dashed horizontal line marks the cost associated with the selected four-cluster solution.



highly cautious type, and technologically neutral type. The cluster labels were assigned after examining the average scores and response patterns across the PESTLE dimensions and should therefore be understood as descriptive interpretations of the quantitative results.

Cluster 0 is labelled as the proactive supporter type. At the category level, this group shows driver-oriented perceptions across most dimensions, particularly policy, legal, social and technical factors, where 76.9% to 82.7% of responses classified these categories as drivers. The economic dimension is also perceived positively, with 65.6% of responses classifying it as a driver. However, the environmental dimension is weaker, with 44.9% of responses classifying it as a driver. The item-level results in Fig. 4 suggest that this lower environmental share is mainly associated with more cautious views on noise pollution and battery-related environmental issues. This suggests that even the most supportive respondents do not regard UAM's environmental performance as a driver.

Cluster 1 is labelled as the highly cautious type. Policy is the only dimension for which a majority of responses classified the category as a driver, at approximately 58%. All other dimensions fall below 50%, with particularly low driver proportions for legal and technical factors. Figure 4 confirms that this caution is not limited to one or two isolated items, but appears across several implementation-related issues, including safety

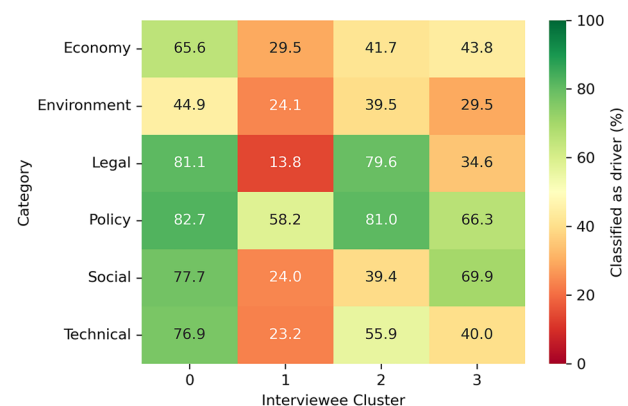


Fig. 3 | Comparison of perceived driver proportions across PESTLE dimensions and attitudinal clusters. Each cell reports the percentage of responses within a cluster that classified the corresponding dimension as a driver rather than a barrier. Green cells indicate higher driver proportions, yellow cells indicate intermediate proportions, and red cells indicate lower driver proportions. The clusters comprised 49, 47, 27 and 26 respondents, respectively.

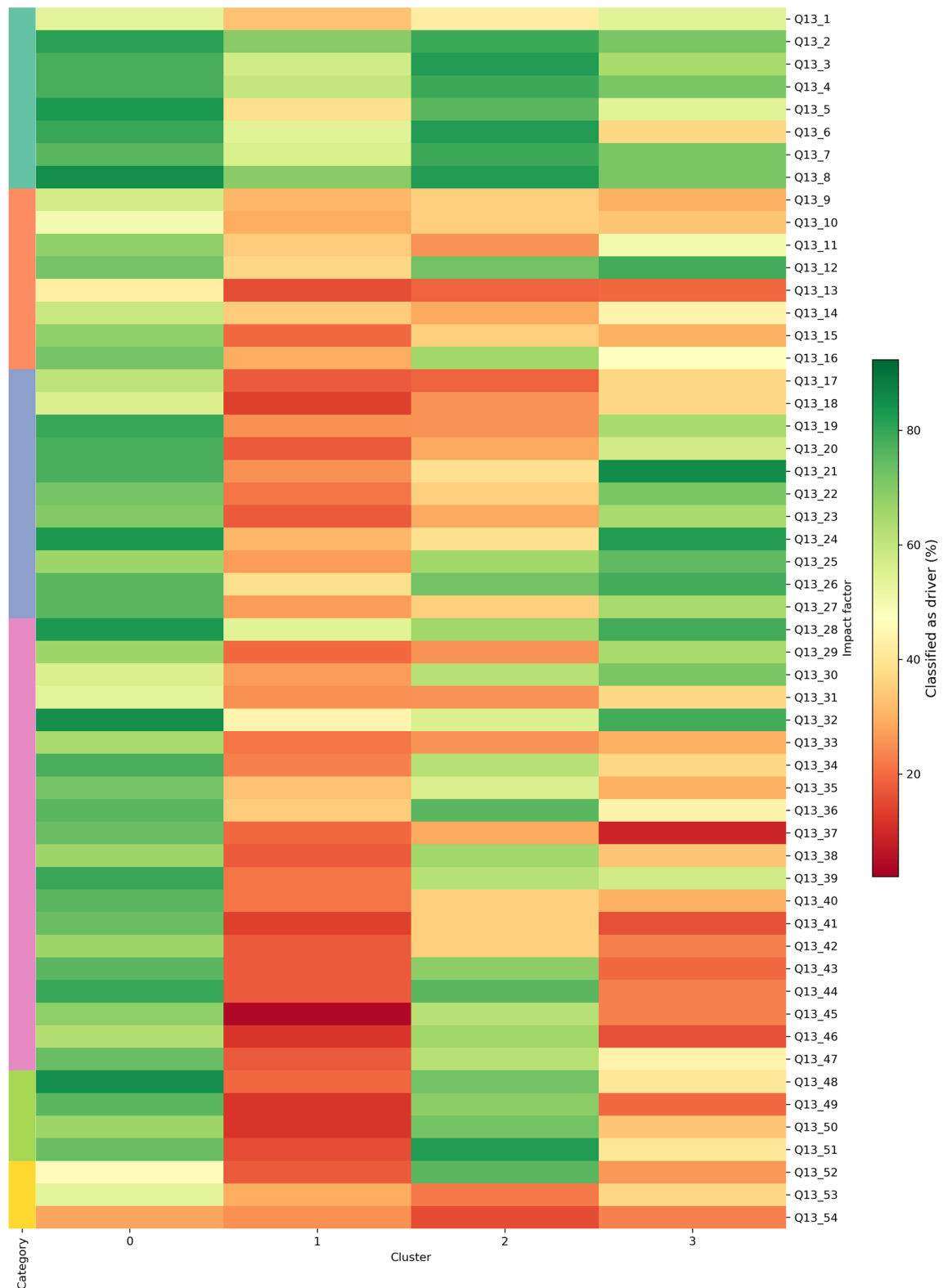
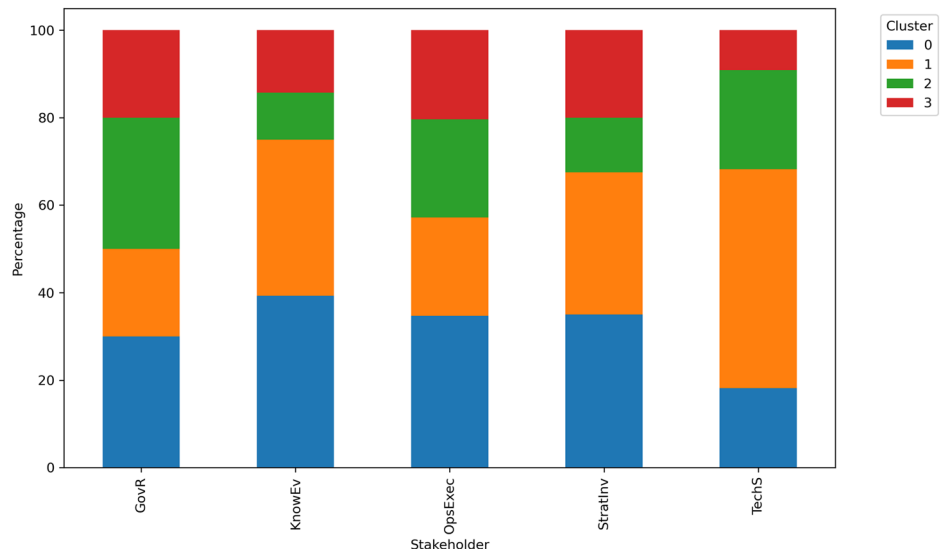


Fig. 4 | Comparison of item-level driver proportions across attitudinal clusters. Rows represent the 54 survey items, coded Q13_1 to Q13_54, and columns represent the four clusters. Each cell shows the percentage of respondents within a cluster who classified the corresponding item as a driver of Urban Air Mobility adoption. Green cells indicate higher driver proportions, yellow cells indicate intermediate

proportions, and red cells indicate lower driver proportions. The coloured band on the left identifies the PESTLE category of each item: turquoise indicates political factors, orange indicates economic factors, blue indicates social factors, pink indicates technical factors, light green indicates legal factors and yellow indicates environmental factors.

Fig. 5 | Distribution of attitudinal clusters within stakeholder groups. Each stacked bar shows the percentage distribution of clusters within one stakeholder group.



regulation, air traffic control, vertiport capacity, ground operations and maintenance facilities. This cluster therefore reflects broad concern about whether current institutional and operational conditions are sufficient to support UAM deployment.

Cluster 2 is labelled as the policy-trusting type. This cluster is characterised by strong institutional confidence but more reserved views of wider implementation conditions. 81% of responses classified policy factors as drivers, and 79.6% classified legal factors as drivers. By contrast, economic, social and environmental dimensions were more often classified as barriers. Figure 4 shows that this group is particularly positive about national macro policies, incentive policies and cybersecurity regulation, but less confident about public perceptions of cost, safety, comfort and market mode. This pattern suggests confidence in policy and regulatory direction, but uncertainty about whether UAM can be translated into a widely accepted and commercially viable urban mobility service.

Cluster 3 is labelled as the technologically neutral type. This group presents a more selective pattern of optimism. Policy and social factors are more often classified as drivers, at 66.3% and 69.9%, respectively, while economic, technical, legal and environmental factors are more often classified as barriers. The item-level results suggest that this group is relatively positive about travel-time benefits, public awareness of environmental protection, stakeholder collaboration and market demand, but more cautious about maintenance, ground operations, vertiport safety and legal regulation. This indicates that respondents in this cluster recognise the social and strategic potential of UAM, while remaining uncertain about its technical and operational implementation conditions.

Overall, Figs. 3 and 4 show that policy support is the most consistently recognised enabling condition across clusters, whereas environmental credibility, market readiness, legal maturity and technical implementation remain more contested. This pattern indicates that UAM adoption is not constrained by a single dominant barrier. Instead, it depends on whether confidence can be built across multiple parts of the emerging UAM ecosystem, including policy, technology, regulation, public acceptance and environmental performance.

To interpret these attitudinal profiles within the broader UAM ecosystem, the distribution of stakeholder groups across clusters was examined. Figure 5 presents the within-group percentage distribution of the four clusters for each stakeholder category. The stakeholder groups included 10 GovR respondents, 22 TechS respondents, 40 StratInv respondents, 49 OpsExec respondents and 28 KnowEv respondents. Because some groups were relatively small, particularly GovR, the stakeholder-group comparisons should be interpreted as descriptive patterns. The results suggest that

stakeholder roles are associated with different patterns of perceived drivers and barriers.

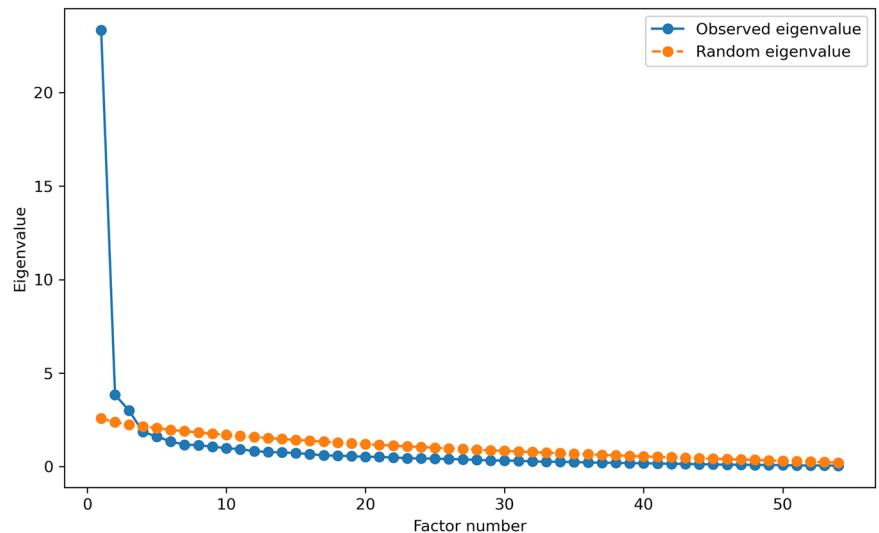
The findings indicate that GovR and OpsExec respondents showed stronger alignment with the proactive supporters and policy-trusting clusters. The counts in parentheses indicate the number of respondents assigned to these clusters. Specifically, 60.0% of GovR respondents ($n = 6$) and 57.1% of OpsExec respondents ($n = 28$) were assigned to these two clusters, compared with 50.0% of KnowEv respondents ($n = 14$), 47.5% of StratInv respondents ($n = 19$) and 40.9% of TechS respondents ($n = 9$). KnowEv respondents therefore occupied a relatively intermediate position, while StratInv respondents showed a more divided pattern between supportive and cautious attitudes. TechS respondents were the most clearly associated with caution, with 50.0% assigned to the highly cautious cluster. This pattern suggests that governance and operational actors were more likely to view UAM as a policy-supported and practically relevant innovation, whereas technical-system stakeholders remained more cautious about implementation feasibility. Within the framework of socio-technical transition theory, the relatively positive views of GovR respondents may reflect landscape-level pressures specific to China, including the national low-altitude economy strategy and early progress in aircraft certification⁵⁷. By contrast, the cautious position of TechS respondents may reflect regime-level concerns, including flight reliability, maintenance requirements, safety assurance and the operational complexity of moving from policy ambition to real-world deployment.

Overall, Fig. 5 shows that stakeholder heterogeneity is not merely a matter of general support or opposition. Rather, it reflects the different institutional roles, responsibilities and risk exposures of actors within the emerging UAM ecosystem. Policy and governance actors appear more inclined to recognise institutional support, while technical actors show stronger caution towards implementation conditions. Research, operational and strategic actors occupy more mixed positions. These differences highlight the need for differentiated coordination strategies, including transparent safety evidence for technical stakeholders, clearer regulatory pathways for investors and operators, and stronger evidence-based communication to bridge perception gaps across the UAM ecosystem.

Exploratory factor analysis results

The second research question of this study is to investigate how different stakeholders perceive the importance of various impact factors. Given the potential overlap and interdependence among 54 impact factors across the six PESTLE dimensions, this study employs EFA to reduce dimensionality. Before conducting factor analysis, the suitability of the Methodology section data was assessed using standard diagnostic checks. The Kaiser-Meyer-

Fig. 6 | Comparison of observed and random eigenvalues across candidate factors. Blue circles connected by a blue solid line represent the observed eigenvalues obtained from the correlation matrix of the 54 survey items. Orange circles connected by an orange dashed line represent the random eigenvalues generated through parallel analysis.



Olkin measure of sampling adequacy was 0.914, indicating a high level of sampling adequacy. Bartlett's test of sphericity was statistically significant, $\chi^2 = 6993.414$, $df = 1431$, $p < 0.001$, confirming that the correlation matrix was significantly different from an identity matrix. These results indicate that the data were appropriate for factor analysis.

The EFA was based on 149 valid responses and 54 items, giving a cases-to-items ratio of 2.76:1. Therefore, the factor structure is interpreted as an exploratory dimensional structure. To make the factor-retention decision more transparent, factor retention was assessed using several criteria, including the Kaiser criterion, Cattell's scree test, parallel analysis, item communalities and interpretability^{58,59}.

The Kaiser criterion and Cattell's scree test initially pointed towards a four-factor interpretation. Figure 6 shows a sharp decline in eigenvalues across the first few factors, with a visible levelling-off after the fourth factor, suggesting that a four-factor solution could provide a meaningful balance between parsimony and explanatory detail. This interpretation was also consistent with the theoretical framing of the study, as the four-factor solution separated Technological Performance and System Safety, Policy Guidance and Economic Incentives, Public Acceptance and Market Awareness, and Environmental Sustainability.

However, the parallel analysis provided a more conservative benchmark. As shown in Fig. 6, the first three observed eigenvalues exceeded the corresponding random eigenvalues, while the fourth observed eigenvalue fell below the random benchmark. Both the random mean rule and the 95th percentile rule therefore suggested a three-factor solution. We therefore examined the three-factor solution as a sensitivity check and compared it with the four-factor solution. The comparison showed that the first three dimensions were broadly stable across the two solutions. In the three-factor solution, battery recycling and emission reduction are absorbed into the broader Technological Performance and System Safety factor. In the four-factor solution, these items formed a narrower but meaningful environmental dimension.

The four-factor solution was therefore retained as a theory-informed exploratory structure. This decision was made for two reasons. First, the four-factor solution provided a clearer substantive interpretation by separating environmental sustainability from the broader technology dimension. This is important because environmental externalities are conceptually central to the legitimacy of UAM within sustainable mobility transitions. Second, the four-factor solution provided better item representation. The mean communality increased from 0.534 in the three-factor solution to 0.562 in the four-factor solution. The minimum communality increased from 0.235 to 0.319, and the number of items with communalities below 0.30 decreased from one to zero. The improvement was particularly

clear for the environmental items. The communalities of Q14_52 and Q14_53 increased from 0.460 and 0.475 in the three-factor solution to 0.681 and 0.682 in the four-factor solution, respectively.

The retained four-factor solution should therefore be understood as an exploratory and theory-informed structure rather than a settled measurement model. The factor loadings and communalities for the four-factor solution are reported in Table S1. The communalities ranged from 0.319 to 0.733, with a mean of 0.562. No item had a communality below 0.30. These results suggest that the four-factor solution provides a useful exploratory summary of the underlying perception structure, while also supporting cautious interpretation.

The four-factor solution reveals the underlying cognitive structure through which respondents evaluate the importance of UAM adoption factors. A loading threshold of 0.40 was used to identify the main variables associated with each factor, while items with cross-loadings were interpreted according to both their highest loading and conceptual relevance. The four factors are labelled as Technological Performance and System Safety, Policy Guidance and Economic Incentives, Public Acceptance and Market Awareness, and Environmental Sustainability.

The first factor, Technological Performance and System Safety, captures the technical and operational foundations required for UAM deployment. It brings together items related to aircraft performance, automation, maintenance, airspace and ground operations, vertiport infrastructure and safety-related regulation. This factor suggests that respondents view UAM adoption as dependent not only on vehicle-level performance, but also on the reliability of the wider operating system.

The second factor, Policy Guidance and Economic Incentives, is mainly associated with policy support, financial incentives, infrastructure investment and early market conditions. This indicates that respondents see government direction and economic support as important mechanisms for reducing uncertainty during the early commercialisation of UAM.

The third factor, Public Acceptance and Market Awareness, reflects the public-facing and service-oriented conditions of UAM adoption. It includes perceptions of travel cost, comfort, travel time, expected benefits, public awareness, stakeholder collaboration and market mode. This factor suggests that UAM will need to be understood not only as an aviation technology, but also as a mobility service whose value must be recognised by users and the wider public.

The fourth factor, Environmental Sustainability, captures concerns about environmental externalities, particularly battery waste and recycling, greenhouse gas emissions and noise-related impacts. Compared with the other factors, this dimension is more narrowly defined, suggesting that

Fig. 7 | Comparison of standardised factor scores across stakeholder groups. The radar chart presents the mean standardised factor score of each stakeholder group for the four dimensions identified by exploratory factor analysis. Positive scores indicate greater-than-average emphasis on a dimension, whereas negative scores indicate less-than-average emphasis.



environmental performance is perceived as a distinct but still emerging concern in UAM adoption.

Overall, the EFA results show that respondents do not evaluate UAM adoption strictly according to the original PESTLE categories. Instead, their perceptions are organised around four broader dimensions: system reliability, policy and economic support, public and market acceptance, and environmental credibility. These dimensions provide the basis for interpreting the coordination challenges discussed in the following section.

Figure 7 compares the factor scores of stakeholder groups across the four latent dimensions. Because factor scores are standardised around the sample mean, positive values indicate stronger-than-average emphasis, while negative values indicate weaker-than-average emphasis. The clearest pattern appears among GovR respondents, who show a particularly high score for Policy Guidance and Economic Incentives and a positive score for Environmental Sustainability. This suggests that governance and regulatory actors attach relatively greater importance to institutional support, incentive mechanisms and environmental legitimacy. By contrast, their slightly negative score for Public Acceptance and Market Awareness indicates comparatively weaker attention to user-facing and market-facing concerns.

The remaining stakeholder groups show less extreme profiles. KnowEv respondents are slightly above average on Technological Performance and System Safety and Policy Guidance and Economic Incentives, but below average on Public Acceptance and Environmental Sustainability. OpsExec respondents remain close to the sample average across all four factors, indicating a relatively balanced perception profile. StratInv respondents score below average on technical-system and policy-related dimensions, but above average on public acceptance and environmental sustainability, suggesting greater attention to market perception and sustainability-related value creation. TechS respondents are slightly above average on the first three factors but below average on Environmental Sustainability, reflecting a stronger concern with system feasibility than with environmental externalities.

Overall, Fig. 7 indicates that stakeholder groups prioritise different dimensions of UAM adoption. These differences highlight the need for coordination mechanisms that can align policy incentives, technical

feasibility, market acceptance and environmental credibility across the emerging UAM ecosystem.

Discussion

The findings of this study show that the adoption of UAM in China is shaped not only by technological maturity but also by the interplay of diverse stakeholder perceptions, institutional expectations, and systemic constraints. By integrating the PESTLE framework with clustering and factor analysis, the study uncovers both who differs in their assessment of UAM and why these differences arise, thereby offering insights into how UAM can transition from a policy-driven niche to an operationally viable mobility service.

Stakeholders' baseline familiarity with UAM provides an important context for interpreting the clustering results. In China's current low-altitude economy, UAM has become a visible policy and industrial agenda, but it has not yet developed into a routine passenger transport service with mature operational procedures, stable user experience, maintenance systems and regulatory interfaces⁵. Stakeholders therefore evaluate UAM through different forms of exposure. GovR and StratInv actors may encounter UAM primarily through policy discussion, strategic planning and investment narratives, while TechS and OpsExec actors are more likely to focus on technical uncertainty, safety assurance and operational implementation. KnowEv actors may occupy an intermediate position by engaging with both conceptual development and evidence generation.

This uneven exposure helps explain why stakeholder attitudes are not fully aligned. The clustering results suggest indicative differences across stakeholder groups. GovR respondents appear to show stronger recognition of policy and institutional support, whereas TechS respondents appear more closely associated with cautious attitudes towards implementation feasibility. KnowEv, StratInv and OpsExec display more mixed profiles, suggesting that their perceptions are shaped by both opportunity recognition and uncertainty assessment. These patterns should be interpreted descriptively because some subgroup sizes are small, particularly GovR. The results therefore indicate possible areas of stakeholder heterogeneity. These differences suggest that stakeholder perceptions are not simply expressions of

general support or opposition. Rather, they reflect the different functional positions, responsibilities and risk exposures of actors within the emerging UAM ecosystem³⁹.

From a socio-technical transition perspective, this pattern reflects a gap between landscape-level policy momentum and regime-level operational readiness. Policy support and industrial experimentation have created strong expectations for UAM development, particularly for GovR and parts of StratInv. However, TechS and OpsExec are closer to the unresolved practical requirements of deployment, including technical validation, maintenance capability, vertiport operation, airspace integration, safety assurance and service reliability. Their caution should therefore not be interpreted as resistance to innovation. Instead, it indicates a more direct awareness of the conditions that must be satisfied before UAM can move from demonstration to scalable operation.

This finding is important for ecosystem coordination. UAM adoption depends on the alignment of actors who promote, regulate, design, finance, operate and evaluate the system¹⁴. If policy and investment expectations develop faster than technical and operational confidence, the ecosystem may experience expectation gaps⁸. Therefore, the central coordination challenge is not simply to increase stakeholder support, but to create mechanisms through which GovR, TechS, StratInv, OpsExec and KnowEv can align policy ambition, technical evidence, operational experience, investment expectations and public value.

The exploratory factor analysis further clarifies the cognitive structure underlying stakeholder perceptions. The analysis reveals that the complex array of drivers and barriers is organised into four latent dimensions: technological performance and system safety, policy guidance and economic incentives, public acceptance and market awareness, and environmental and sustainability concerns. These dimensions represent the implicit criteria that stakeholders use to evaluate the feasibility of systemic UAM adoption. More importantly, they indicate the main implementation priorities that must be addressed if UAM is to move from pilot demonstration to scalable passenger service.

The prominence of technological performance and system safety identifies operational credibility as the foundational gatekeeper for adoption. Although national policy support acts as a strong driver, stakeholders perceive technical maturity, specifically regarding vertiport construction, safety oversight, and maintenance capability, as a critical barrier that must be overcome before expansion can occur, which also aligns with previous literature²¹. This finding aligns with socio-technical transition theory by confirming that niche innovations cannot break through into the regime until they demonstrate stability within existing technological environments⁶⁰. From an implementation perspective, this means that pilot projects should not focus only on aircraft demonstration. They should also test the wider operating system, including vertiport access, maintenance response, airspace coordination, ground operations, passenger handling and emergency procedures.

The second dimension, which centres on policy guidance and economic incentives, highlights the dual role of government influence. While strong policy support currently serves as a primary driver by mobilising resources and reducing initial uncertainty, the heavy reliance on administrative decisions introduces a potential barrier. If regulatory requirements or approval pathways remain unpredictable, stakeholders may hesitate to scale operations⁶¹. Consequently, effective adoption requires a governance transition from temporary pilots to stable and performance-based arrangements. For policymakers, this implies the need to clarify approval procedures, safety responsibilities, data-sharing requirements, liability arrangements and measurable criteria for expanding pilot operations.

Public acceptance and market awareness constitute the third dimension and directly address the systemic interactions component of the first research question. From the perspective of feMaaS, UAM is not an aviation technology but a service layer within a wider ecosystem. Perceptions of safety, comfort, and integration with ground transport are therefore decisive. This confirms that adoption depends not only on technical feasibility but also on how users experience the system's value proposition relative to

existing mobility options⁶². Therefore, public acceptance should be embedded in service design rather than treated as a communication issue after technical deployment. Early pilots should include user information, booking and payment interfaces, fare transparency, intermodal access and feedback mechanisms.

The final dimension indicates that environmental legitimacy is shifting from a peripheral concern to a core driver of long-term viability. Stakeholders emphasise emissions, noise, and battery recycling as essential factors for securing a social licence to operate. This suggests that UAM must explicitly align with China's broader sustainability objectives to be perceived as a legitimate transport solution rather than an isolated luxury innovation. The relatively mixed perceptions of environmental factors suggest that the environmental benefits of UAM need to be empirically demonstrated. This requires life cycle emission assessment, noise monitoring, battery recycling plans and comparisons with existing low carbon transport alternatives.

Taken together, these four dimensions demonstrate that the barriers to UAM are interconnected rather than isolated. Progress in technology cannot compensate for a lack of regulatory stability or public trust. Similarly, strong policy support cannot substitute for operational reliability, market acceptance or environmental credibility. This systemic interdependence implies that no single stakeholder group can resolve these barriers on its own. The practical challenge is therefore to convert these four latent dimensions into coordinated implementation priorities across policy, technology, operations, market development and sustainability governance.

To address the second research question, which asks what forms of coordination are required to enable systemic integration, this study synthesises the findings from the clustering and factor analyses. The results reveal that the stakeholder divergence identified in RQ1 is not merely a barrier, but a structural indicator of where 'systemic frictions' must be resolved. By viewing UAM through the lens of innovation ecosystem theory, tailored coordination strategies can be designed to align the incentives and capabilities of each group. The key implication is that UAM governance should not adopt a uniform stakeholder engagement strategy. Different groups require different forms of evidence, institutional support and implementation guidance.

TechS stakeholders, who expressed high caution regarding operational risks, require mechanisms that reduce uncertainty through transparency. As suggested by prior safety assurance literature¹⁸, open test-flight data, structured incident reporting, and simulation-supported validation are essential to strengthen confidence. Furthermore, collaborative standard-setting with regulators ensures that certification rules reflect operational realities rather than abstract metrics. In practical terms, TechS should be involved early in the design of safety standards, maintenance protocols, airspace procedures and vertiport operation rules. This would help ensure that regulatory requirements are technically feasible and that implementation risks are identified before wider deployment.

GovR stakeholders must shift their focus from aspirational 'landscape' signalling to predictable 'regime' governance⁶¹. To address regulatory uncertainty-related barriers, it is critical to institutionalise cross-departmental coordination and establish performance-based regulation. Regular consultation mechanisms with TechS and OpsExec can help align high-level policy ambition with feasible operational pathways, preventing the expectation gaps that currently hinder adoption. This implies that government agencies should move beyond general policy encouragement and develop clear approval pathways, safety accountability structures, data governance rules and criteria for moving from trial flights to commercial service pilots.

StratInv actors, whose participation is sensitive to policy stability. StratInv actors are particularly sensitive to policy stability. Their participation depends on contractual certainty and transparent institutional rules, which aligns with the economic dimension of the PESTLE analysis, where investment is constrained by the predictability of the regulatory environment rather than market demand alone. For this group, coordination should focus on reducing uncertainty around market entry, pricing models, public-private investment arrangements, liability allocation and long-term revenue

prospects. In parallel, OpsExec groups demand standardised protocols and reliable operational interfaces to manage day-to-day delivery, utilising their frontline experience as a critical feedback loop to refine safety procedures and dispatching systems for real-world urban environments⁶³. For OpsExec, pilot projects should therefore include end-to-end service trials rather than isolated flight demonstrations. These trials should cover booking, access, boarding, dispatching, intermodal connection, emergency handling and customer feedback. Complementing these roles, KnowEv stakeholders reduce information asymmetries by combining their modelling and evaluation capabilities. They foster adaptive learning, enabling the ecosystem to evolve from a fragmented collection of actors into a coordinated network. Their contribution is especially important in generating independent evidence on demand, safety, public acceptance, environmental performance and cost-effectiveness. KnowEv can therefore serve as knowledge brokers between GovR, TechS, StratInv, OpsExec and the wider public.

Finally, effective coordination must address both vertical alignment between policy goals and operational reality and horizontal integration across airspace, vertiports, and service platforms. Without such alignment, UAM risks remaining a technologically feasible but institutionally fragmented niche that fails to achieve the integration envisioned in the feMaaS. The necessity of these dual alignment axes suggests that the transition to a functional urban aviation system depends as much on the quality of institutional linkages as on the maturity of the aircraft themselves. For implementation, this means that future UAM pilots should be designed as ecosystem pilots rather than technology pilots. They should test not only whether the aircraft can operate, but also whether governance arrangements, safety evidence, service interfaces, market mechanisms and environmental monitoring can work together in real urban mobility contexts.

Theoretically, this study advances the literature by integrating socio-technical transition theory with innovation ecosystem frameworks to quantify the dynamics of UAM adoption. Unlike traditional qualitative applications of the multi-level perspective, this research operationalises the tension between 'landscape' policy pressures and 'regime' operational inertia through quantitative stakeholder clustering. It extends ecosystem theory by demonstrating that coordination challenges arise not merely from distinct organisational roles, but from divergent cognitive structures regarding risk and value³⁹. Furthermore, by embedding the feMaaS perspective, the study reframes UAM from a standalone aviation technology to an integrated, platform-based service layer, challenging the isolationist focus of early engineering-centric literature.

This study also extends innovation ecosystem theory by showing that coordination challenges arise not only from functional interdependence among actors, but also from differences in cognitive priorities. Stakeholders interpret policy support, technical feasibility, public acceptance and environmental credibility in different ways. These differences are important because the adoption of UAM requires complementary actions from multiple actors. If one group regards policy support as the main driver, while another considers safety assurance to remain unresolved, expectation gaps may emerge within the ecosystem, even when all actors broadly support the overall direction of development³⁶.

The FeMaaS perspective further reframes UAM as more than an aviation technology. UAM needs to be integrated with ground transport, digital platforms, pricing systems, passenger information, safety-related communication and urban sustainability goals. This shifts the analytical focus from vehicle performance to service integration. It also explains why public acceptance, market awareness and environmental legitimacy emerge as important dimensions alongside technical and regulatory factors.

Practically, the results provide a targeted roadmap for stakeholders in China to bridge the gap between policy ambition and operational reality. The findings underscore a critical need to shift from aspirational signalling to predictable governance arrangements, as establishing performance-based regulations is essential to reduce the uncertainty that currently inhibits strategic investment. For industry and operations, greater transparency regarding safety risks and clearer procedures for verification are required to strengthen confidence among technical and operational groups, supporting

the translation of technical progress into institutional legitimacy and social acceptance³⁸.

These implications are particularly relevant to regions such as Jiangsu, where policies for the low-altitude economy, industrial trials and eVTOL-related activities are developing rapidly, while regular UAM services remain at an early stage. In this context, the key task is not only to accelerate experimentation, but also to ensure that pilot activities generate transferable experience, shared standards and institutional learning. This would help narrow the gap between policy ambition and operational practice. Although advances in technologies have made early deployment feasible, large-scale adoption is still constrained by institutional uncertainty, infrastructure readiness, regulatory developments and public acceptance. Therefore, there is a need to support the transition from isolated demonstration projects to scalable and trusted UAM services.

Conclusions

This study examines how UAM can move from a technological vision to an operational and institutional reality within China's low-altitude economy. It focuses on eVTOL-based air taxi and flying car services. The findings show that the adoption of passenger-centred UAM is not constrained by a single technical bottleneck. Instead, it depends on coordination across policy, technology, operations, research and development, investment, and public-oriented service design. Using a PESTLE framework with clustering and factor analysis, we show that progress is less governed by any single bottleneck than by coordination across policy, technology, operations, research, and management. Four latent dimensions matter most: technological performance and system safety; policy guidance and economic incentives; public acceptance and market awareness; and environmental and sustainability concerns. Four stakeholder profiles also emerge, including proactive supporters, policy-trusting, highly cautious, and technologically neutral. Regulators and strategic managers are more optimistic; engineers and frontline operators are understandably cautious. Framing UAM within feMaaS shifts attention from aircraft to service integration, translating technical maturity into social legitimacy and operational reliability. These findings confirm that while policy acts as a catalyst, operational credibility and environmental legitimacy serve as the gatekeepers for systemic adoption.

Implications suggest that governance should pivot from acceleration to predictable, performance-based regimes that reduce uncertainty for operators and investors. Technical and operational actors need transparent safety evidence, shared testing environments and standardised procedures. Public acceptance should focus on user experience, affordability and trust, supported by staged pilots and clear communication. Environmental metrics should be embedded from the outset to align with the city's carbon goals.

Jiangsu Province, as the focus of this study, represents both a strength and a limitation. As one of the regions in China actively promoting the low altitude economy, Jiangsu provides a suitable empirical setting for examining stakeholder perceptions. In this province, policy support, industrial trials, eVTOL-related manufacturing and low-altitude application scenarios have already begun to develop. This regional focus allows the findings to be interpreted in relation to the actual stage of UAM development in Jiangsu, rather than as abstract perceptions detached from local policy and industrial conditions. More specifically, the results show how stakeholders perceive UAM in a context where low-altitude economic activities are expanding, but regular passenger eVTOL services have not yet been widely deployed.

At the same time, this context-specific research design means that the findings should be generalised to other regions with caution. Provinces with different industrial bases, policy priorities, airspace governance arrangements, market maturity or eVTOL testing experience may have different stakeholder perceptions and coordination needs. In addition, the analysis is based on survey data and may be affected by self-reporting bias, uneven familiarity with UAM and differences in respondents' direct involvement in UAM-related activities. Given the exploratory nature of the analysis, the identified factor structure could also be validated in future studies using

larger and more diverse samples. The cross-sectional design also captures stakeholder perceptions at a single point in time and cannot assess how attitudes may change as UAM technology, regulation and market applications become more mature. Future research should compare multiple Chinese provinces at different stages of low-altitude economy development, track long-term changes in stakeholder attitudes, use multi-group structural equation modelling to test the identified development pathways, and evaluate FeMaaS pilot projects that integrate UAM with rail, bus and ride-hailing services. Such pilots should use safety, reliability, equity and carbon emission performance as shared key performance indicators. This would help assess technological progress and public value within a consistent evaluation framework.

Data availability

Due to ethical considerations and privacy restrictions imposed by the Institutional Review Board, the data supporting the findings of this study cannot be shared publicly. The data include sensitive information about participant demographics, which are subject to confidentiality agreements to protect participant privacy. For further inquiries, please contact the corresponding author. The data can be made available from the authors upon reasonable request and with the permission of the IRB.

Code availability

No custom code or scripts were used in the generation or analysis of the data. All analyses were performed using standard, publicly available software packages.

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Author contributions

R.S. and T.Y. wrote the main manuscript text. R.S. prepared all figures and tables. R.S. contributed to data analytics. T.Y. contributed to data collection and data processing. A.J. contributed overall structure. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Tiansheng Yang.

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