Electrifying regional mobility: Planning intercity low-altitude air routes for Chinese cities

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Dear Editor,

The rapid urbanization and economic integration of city clusters worldwide demand innovative transportation solutions. With the rise of electric vertical takeoff and landing (eVTOL) aircraft, intercity low-altitude air routes (LAARs) are emerging as a new paradigm in urban mobility and regional transportation. Through integrating demand-driven planning, straight-line distance, and infrastructure readiness across four key domains, we propose a planning framework for intercity LAARs of China Cities to enhance urban air mobility (UAM). Using Origin-Destination (OD) flows and energy models, we estimate vertiport charging requirements and compare eVTOL CO_2 emissions against High-Speed Rail. These findings support actionable alignment between UAM planning, grid infrastructure, and regional decarbonization goals.

INTRODUCTION: URBAN AIR MOBILITY

As urbanization accelerates and regional economies become increasingly interconnected, the demand for efficient, flexible, and sustainable intercity transportation is more pressing than ever. In this context, electric vertical takeoff and landing (eVTOL)[1] aircraft offers a groundbreaking alternative: urban air mobility (UAM).[2] Compared with traditional aviation, which relies on large airports and long runways, eVTOLs bypass the need for extensive ground infrastructure while offering direct point-to-point connectivity.[3]

Driven by rapid advancements in battery technology,[4] autonomous navigation,[5] and air traffic management,[6] intercity low-altitude air routes (LAARs) are now a feasible and scalable solution. According to forecasts by the Civil Aviation Administration of China, the market size of Chinese low-altitude economy is expected to expand to CNY 3.5 trillion by 2035.[7] Internationally, several corridor-based UAM pilots are underway. In the U.S., the Advanced Air Mobility (AAM) Corridor Project has proposed specific test routes such as Orlando International Airport-Lake Nona and Dallas Fort Worth-Arlington, designed to simulate airport access and short-range commuting. In Europe, the Gulf of Finland project enables drone and eVTOL traffic between Helsinki and Tallinn, while the Amsterdam-Rotterdam corridor explores operations in congested metro regions with digital Unmanned Traffic Management integration. These initiatives focus primarily on urban-scale operational feasibility.

Although national strategies and industrial white papers have emphasized the importance of applying eVTOLs to tourism, emergency response, and urban shuttle scenarios, most current discussions remain conceptual and lack spatially detailed planning. In particular, prior research has primarily focused on intra-city applications, such as airport connections or scenic routes, leaving the intercity dimension of UAM relatively underexplored. This study aims to fill this gap by introducing a quantitative, scenario-driven planning framework that identifies specific LAAR corridors based on economic relevance, population flows, and spatial accessibility. By doing so, we move beyond policy-level generalities and toward actionable, map-based intercity route design.

AVIATION ELECTRIFICATION AND POWER DEMAND

Unlike traditional aviation powered by fossil fuels, eVTOL aircraft rely entirely on electricity, making them a key component of the ongoing energy transition toward electrified transportation systems. The deployment of intercity LAARs necessitates a corresponding upgrade in regional energy infrastructure, including high-capacity charging stations, grid load balancing, and renewable integration.[8] Thus, LAAR planning is not only a mobility innovation but also a critical enabler for next-generation clean energy deployment in transportation. To estimate the total energy demand of an eVTOL aircraft along a given intercity route i, we divide the flight profile into five operational phases: vertical take-off, climb, cruise, descent, and landing.[9] The total energy consumption $E_{\mathrm{eVTOL},i}$ is given by:

$$E_{\mathrm{eVTOL},i} = E_{\text{take-off}} + E_{\text{climb}} + E_{\text{cruise},i} + E_{\text{descent}} + E_{\text{landing}} \tag{1}$$

Among these, the cruise phase dominates the overall energy use and is modeled using aircraft aerodynamic characteristics:

$$E_{\text{cruise},i} = \frac{GTOM \cdot g}{\eta_c} \cdot \frac{d_i}{L/D} \tag{2}$$

where $GTOM$ is the gross take-off mass of the aircraft, g is the gravitational acceleration, d_i is the flight distance on route i, L/D is the lift-to-drag ratio, and η_c is the propulsion efficiency during cruise. Parameter values are based on the Joby S4 platform and literature on eVTOL.[10]

To evaluate the impact on the regional power system, we estimate the average charging power C_i required at each vertiport serving route i, based on daily OD flow and operational schedule:

$$C_i = \frac{F_i \cdot \lambda}{S} \cdot \frac{E_{\mathrm{eVTOL},i}}{H} \tag{3}$$

where F_i is the daily passenger flow on route i, λ is the mode adoption rate for eVTOL, S is the passenger capacity per aircraft and H is the daily operational hours.

The estimated charging demand at each vertiport, derived from OD-based flight volumes and eVTOL energy use, enables preliminary planning for charging infrastructure. Using the Shenzhen-Guangzhou route as an example, with an average energy consumption of 60 kWh per flight, the total daily electricity demand is expected to exceed 180 MWh, with an estimated average charging power requirement of approximately 15 MW. This demand introduces several energy system implications:

- Grid upgrades may be necessary in areas with weak distribution capacity, particularly near tourism zones or islands.
- Fast-charging infrastructure must be co-optimized with aircraft turnaround cycles and battery thermal limits.
- Vertiport clusters could participate in virtual power plant (VPP) schemes and offer flexible load management services.
- Co-location with distributed renewable generation (e.g., rooftop PV) may support local energy self-sufficiency and carbon reduction.

These factors suggest that LAARs are not only a new transport mode but also a strategic anchor for future urban-energy integration. To evaluate the environmental impact of intercity eVTOL operations, we also compute corresponding CO_2 emissions based on regional grid emission factors, enabling comparison with High-Speed Rail (HSR). The CO_2 emissions per passenger for eVTOL flight and HSR are calculated as:

$$CO_{2,\mathrm{eVTOL}} = \frac{P_{\text{cruise}}}{V_{\text{cruise}} \cdot S} \cdot EF_{\text{grid}} \tag{4}$$

$$CO_{2,\mathrm{HSR}} = E_{\mathrm{HSR}} \cdot EF_{\text{grid}} \tag{5}$$

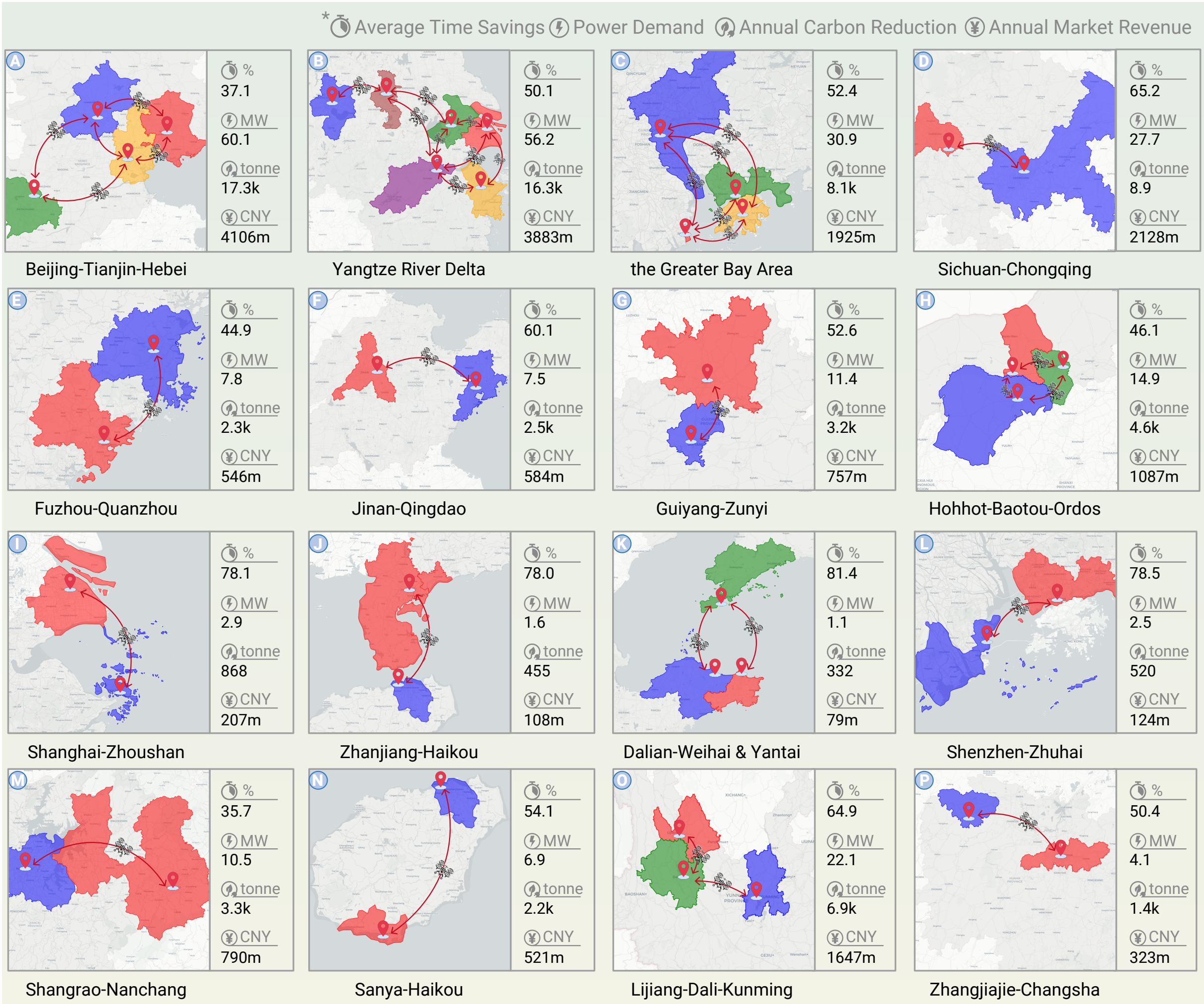

Figure 1. The planning map of intercity LAARs in China. Four representative intercity LAARs for each LAAR category, cross-province LAARs (A-D), provincial LAARs (E-H), cross-sea LAARs (I-L) and tourist LAARs (M-P).

where P_{cruise} is the cruise power demand, v_{cruise} is the cruise speed, EF_{grid} is the regional grid emission factor, E_{train} is the per-passenger energy consumption of the HSR system.

Through calculations, under current grid conditions, eVTOL operations can reduce per-passenger CO_2 emissions by approximately 15-20% compared to HSR. Furthermore, if vertiport charging infrastructure is powered by dedicated clean energy sources, the emissions reduction potential could reach 80-90%, highlighting the significant role of LAARs in supporting long-term decarbonization goals.

PLANNING FRAMEWORK FOR INTERCITY LAARS IN CHINA

To construct a representative framework for intercity LAAR planning in China's emerging low-altitude economy, we first classify routes into four functional categories: cross-province LAARs, provincial LAARs, cross-sea LAARs, and tourist LAARs based on intercity economic relationships, geographic connectivity, and travel purpose. This planning explores four key categories: cross-province LAARs, provincial LAARs, cross-sea LAARs and tourist LAARs, where UAM could alleviate traffic bottlenecks, enhance regional synergy, and unlock economic potential. To assess the economic potential of routes, we integrate urban gross domestic product (GDP) data for each city, sourced from the National Bureau of Statistics of China. For cross-province LAARs, in addition to economic strength, we consider regional coordination policies such as urban integration initiatives. For provincial LAARs, we include only those city pairs where the GDP of the non-capital city reached at least 80% of that of the provincial capital, ensuring economic parity and sufficient demand. Cross-sea LAARs are defined by geographic separations caused by water bodies, where traditional land infrastructure is limited or absent. Tourist LAARs are identified based on the proportion of tourism sector GDP to total city GDP, emphasizing tourism-dependent cities where eVTOLs could enhance accessibility and experience. Figure 1 presents the spatial distribution of the four representative routes selected under each LAAR category.

- Economic megaregions such as Beijing-Tianjin-Hebei (Figure 1A), Yangtze River Delta (Figure 1B), the Greater Bay Area (Figure 1C) and Sichuan-Chongqing (Figure 1D) form the backbone of Chinese economic development. LAARs offer a direct, time-saving alternative to ground transportation for high-frequency business travelers. A direct low-altitude flight between Beijing and Tianjin could reduce travel time from 60 minutes by HSR to 20 minutes, eliminating last-mile inefficiencies. Similarly, routes like Shanghai-Suzhou, Chengdu-Chongqing, and Guangzhou-Hong Kong could significantly cut travel times while providing a premium service for high-value passengers. Several megacities are already piloting eVTOL test flights, making cross-province routes the starting point for commercial deployment.
- While provincial capitals often dominate transportation networks, many non-capital cities exhibit strong economic activity and substantial intercity travel demand. Cities where GDP surpasses 80% of their respective provincial capitals present ideal candidates for LAARs. By complementing existing highway and rail infrastructure, LAARs can foster stronger economic integration within provinces, reducing congestion while improving accessibility for mid-sized cities. Jinan-Qingdao (Figure 1F), linking two major economic centers in Shandong with significant logistics and business travel demand. Similarly, LAARs like Fuzhou-Quanzhou, Baotou-Hohhot, and Guiyang-Zunyi enhance connectivity and facilitate provincial economic integration. These provincial LAARs are highlighted in Figure 1E-H.

• China's coastal geography creates natural bottlenecks where urban connections are restricted by sea channels and major rivers. Unlike ferries, which are slow and prone to delays, or bridges, which require significant infrastructure investment, low-altitude flights can efficiently link these regions with minimal environmental impact. Key cross-sea LAARs include Shenzhen-Zhuhai, addressing bottlenecks on the Pearl River Delta's west side (Figure 1L), and Shanghai-Zhoushan, linking Zhejiang Island (Figure 1I) economy to the mainland. Furthermore, Dalian-Weihai& Yantai provides seamless access across the Bohai Strait (Figure 1K), while Zhanjiang-Haikou strengthens connections between mainland and Hainan Island (Figure 1J), a major tourism and trade hub.

• Tourism-driven LAARs provide significant advantages by enhancing accessibility, offering unique travel experiences, and alleviating congestion in high-traffic areas Additionally, these routes create exclusive aerial experiences, enabling travelers to enjoy breathtaking panoramic views through low-altitude flights over stunning landscapes. By bypassing traditional transit bottlenecks, eVTOL services also help reduce seasonal congestion, particularly during peak tourism periods when conventional transport infrastructure is overwhelmed. Key tourist-focused routes include Sanya-Haikou linking Hainan's two major tourist hubs (Figure 1N), and Kunming-Dali & Dali-Lijiang, which enhance accessibility to Yunnan's top scenic destinations (Figure 1O). Additionally, Changsha-Zhangjiajie and Nanchang-Shangrao establish direct links between provincial capitals and major tourist destinations. Representative tourist LAARs are shown in Figure 1M-P.

Further, we collect the geographic coordinates (latitude and longitude) of major cities and calculate the pairwise great-circle distances, which we constrain within an eVTOL operational range from 50 to 250 km based on the Joby S4, as eVTOLs are capable of straight-line flight between urban centers. To determine the distance d between two cities located at longitude and latitude coordinates (φ_1, λ_1) and (φ_2, λ_2), we apply the Haversine formula:

$$\begin{aligned} a &= \sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right)+\cos\phi_1\cos\phi_2\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right) \\ d &= 2R\cdot\arcsin(\sqrt{a}) \end{aligned} \tag{6}$$

where R=6371 km is the average radius of the Earth. Based on the computed distance, the total eVTOL travel time $t_{\text{eVTOL},\,i}$ for route i is then estimated by summing the durations of five sequential flight phases and security screening and boarding time t_{ground}:

$$\begin{aligned} t_{\text{eVTOL},\,i} &= t_{\text{take-off}}+t_{\text{climb}}+t_{\text{cruise},\,i}+t_{\text{descent}}+t_{\text{landing}}+t_{\text{ground}} \\ t_{\text{ground}} &= t_{\text{security}}+t_{\text{delay}} \\ t_{\text{delay}} &\sim \mathcal{N}(\mu_d,\sigma_d^2) \end{aligned} \tag{7}$$

and cruise time t_{cruise} is distance-dependent and computed as:

$$t_{\text{cruise},\,i}=\frac{d_i}{v_{\text{cruise}}} \tag{8}$$

Other stage durations are assumed to be constant based on aircraft design and operational assumptions. This model enables consistent comparison of travel time across different LAAR scenarios and baseline HSR alternatives. This comparison serves as a standardized reference to evaluate the potential time savings of LAARs under uniform conditions, thereby supporting early-stage route selection and prioritization. A sensitivity analysis on v_{cruise} and t_{ground} is provided in the Supplementary Materials, illustrating its impact on total travel time across representative LAAR routes. The current intercity travel durations are retrieved from China Railway's official timetable, ensuring consistency across regions. Meanwhile, daily passenger flow volumes are compiled on Baidu Migration Big Data, integrating both migration ratio and migration scale index. These data offer a dynamic and spatially explicit indicator of intercity mobility, supporting demand-driven identification and validation of candidate routes within the planning process. After computing aerial travel distances and time estimations, we further evaluate the potential market revenue generated by eVTOL-based low-altitude intercity services. The total revenue R_{total} from the LAAR network is calculated as:

$$R_{\text{total}}=\sum_{i=1}^{N}F_i\cdot\lambda\cdot d_i\cdot P\cdot 365 \tag{9}$$

where P is the average ticket price per km. This simplified revenue model offers a preliminary estimate of the aggregate economic potential of eVTOL deployment across the studied routes, and helps compare LAAR investment opportunities under different adoption and pricing scenarios. Based on this model, the estimated annual market revenue across all proposed routes exceeds CNY 18 billion. For instance, on the high-demand Guangzhou-Shenzhen route, which has strong OD flow and a moderate aerial distance, the projected daily revenue reaches CNY 3 million, highlighting the route's potential as an early-stage LAAR deployment candidate.

CONCLUSION

We propose a structured planning framework for intercity LAARs in China, integrating route classification, mobility data, and energy modeling. Representative routes are selected based on GDP thresholds, travel flows, and geographic conditions. By modeling energy use across flight phases and estimating charging demands, we highlight the infrastructure needs and carbon implications of eVTOL deployment. Using the Guangzhou-Shenzhen route as an example, daily electricity demand may exceed 180 MWh, with average charging power reaching 15 MW and estimated annual market revenue exceeds CNY 18 billion. Compared to HSR, eVTOLs could reduce per-passenger CO_2 emissions by 15-20%, and up to 90% with clean energy.

Our findings suggest that LAARs are not only a fast and flexible mobility solution, but also a strategic enabler for clean energy integration. This work provides early guidance for policymakers on aligning low-altitude air mobility with regional energy and transportation goals.

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AUTHOR CONTRIBUTIONS

All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.