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# Impact Assessment of Regional Air Mobility Using an Agent-Based Demand Model: A First Result

Mengying Fu[a,b]

[a]Bauhaus Luftfahrt e. V., Willy-Messerschmitt-Straße 1, Taufkirchen, 82024, Germany
[b]Technical University of Munich, Arcisstraße 21, Munich, 80333, Germany

## 1. Introduction

Short-haul services using electric aircraft and Regional Air Mobility (RAM) concepts present promising opportunities, including improved access to regional airports and the potential for emission reductions. This study focuses on 19-passenger hybrid-electric aircraft (HEA) capable of serving routes up to 950 km. The objective is to estimate RAM demand within Germany and neighboring countries while evaluating its contribution to sustainability goals and regional connectivity.

Previous research has primarily examined the potential of RAM and regional electric aviation in terms of time savings (Grimme et al., 2020; Benchekroun et al., 2025) and emission reductions (Baumeister et al., 2020). Some studies have forecasted demand using secondary travel data (Paproth et al., 2020; Justin et al., 2021; Benchekroun et al., 2025). However, these studies have not incorporated behavioral aspects such as mode choice.

To address this gap, our study is among the first to estimate RAM demand by accounting for passenger behavior using an agent-based modeling approach. We introduce an adoption-aware framework that incorporates a calibrated mode-choice model (Pukhova et al., 2021), allowing us to simulate individual travel decisions and realistic adoption patterns. We present demand-weighted changes in door-to-door travel time and $CO_2$-eq emissions, identify high-impact travel corridors based on actual adopters, and explain adoption using indicators such as changes in accessibility and consumer surplus.

The main contributions of this study are as follows: (1) estimating RAM demand based on individual behavior; (2) integrating recent stated-preference survey data, and (3) analyzing time savings and emission reductions in relation to travel choice and demand.


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Table 1: Technical specifications and service characteristics of the 19-passenger HEA

| Technical and service features | Reference values |
|---|---|
| Cruise speed | 0.4 Mach (Strathoff et al., 2022) |
| Cruise altitude | 23,000 ft (Strathoff et al., 2022) |
| Block time | $y = 0.0041x + 0.4333$ ($x$ is the distance (NM) and $y$ is the corresponding block time (hours) (Strathoff et al., 2022) |
| Pre-boarding time / Post-arrival transition time | 40 mins / 20 mins (Fu et al., 2025) |
| Ticket price | €0.45 - €0.60 per Revenue Passenger Kilometer (RPK) (Fu et al., 2025) |
| Life cycle emissions | 43 g $CO_2$-eq emissions per passenger km (Strathoff et al., 2022) |

## 2. Data and Method

The study area covers Germany and its neighboring countries, divided into 11,875 zones used to allocate population, employment, education, and retail data. Of these, 11,717 zones represent Germany in high detail, while 158 zones cover the surrounding European regions with greater detail near the German border and progressively less detail further away. This spatial resolution overcomes the low granularity often seen in traditional models (Paproth et al., 2020; Grimme et al., 2020), allowing for a more accurate evaluation of local effects.

To reflect real-world demographics such as age, gender, employment status, and household size, a synthetic population was generated using Iterative Proportional Updating based on census data. The resulting dataset includes approximately 80 million individuals in 53 million households. (Pukhova et al., 2021) The analysis in this study is based on a representative 5% sample of the entire population.

The multimodal network includes travel times and distances between all zones for every transport mode considered. More details on the data sources and network construction for the existing modes can be found in Pukhova et al. (2021). For the 19-passenger HEA, the preliminary air network consists of 54 IFR-equipped airports and airfields in Germany, as well as 341 in neighboring countries.

Table 1 summarizes the key technical specifications and service characteristics of the 19-passenger HEA considered in this study.

Our trip-based travel demand model includes three components: trip generation, destination choice, and mode choice. Trip generation determines whether an individual undertakes a long-distance trip on a given day, using a multinomial logit (MNL) model that distinguishes between private and business travel. The destination choice module, also based on an MNL model, selects among the 11,875 zones in the study area.

The mode choice model was extended to include the 19-passenger HEA, with car used for both first- and last-mile segments. Competing modes include car, rail (with public transport access and egress), conventional air travel (with car access and egress), and long-distance buses (with public transport access and egress). Unlike traditional models relying on secondary data such as household travel surveys, our mode choice model incorporated stated-preference estimates, including willingness-to-pay values, derived from a recent passenger survey covering RAM options (Fu et al., 2025). Due to the absence of observed RAM market data, we simulated adoption scenarios with assumed RAM market shares of 2%, 5%, and 10%.

We assessed the impact of RAM using three main indicators: travel time savings, emissions reduction, and accessibility or welfare gains. For time and emissions, we computed: (i) the theoretical maximum benefit, comparing RAM with the fastest or greenest existing mode (Equation 1 and 2), and (ii) the expected benefit, weighted by predicted RAM adoption and compared to the currently chosen mode (Equation 3 and 4).

To prioritize promising routes, we classified them based on levels of savings or reductions, combined with total travel demand and predicted RAM demand. For regional connectivity, we measured accessibility as the change in the positive logsum between the baseline mode set and the expanded set including RAM (Equation 5 and 6) (Guzman et al., 2023). This accessibility gain was translated into equivalent minutes of generalized travel time saved per trip and monetized using the mode-choice coefficients and value of time (VOT) derived from the survey conducted by Fu et al. (2025) (Equation 7 and 8). This yields the consumer surplus.

*RAM vs. existing modes*

$$\Delta T_{\max} = \sum_i w_i \left( \min_{m \in M_0} T^0_{i,m} - T^0_{i,\mathrm{RAM}} \right)_+ \tag{1}$$

$$\Delta E_{\max} = \sum_i w_i \left( \min_{m \in M_0} E^0_{i,m} - E^0_{i,\mathrm{RAM}} \right)_+ \tag{2}$$

**Notation.** $i$: trip index; $w_i > 0$: analysis weight; $M_0$: set of existing modes; $T$: door-to-door travel time; $E$: door-to-door $CO_2$-eq emissions; superscript 0: baseline; $(x)_+ = \max(x, 0)$.

*RAM vs. the chosen existing mode*

$$\Delta T_{\text{exp}} = \sum_i w_i\, p_i \big(T_i^0 - T_{i,\text{RAM}}^0\big) \tag{3}$$

$$\Delta E_{\text{exp}} = \sum_i w_i\, p_i \big(E_i^0 - E_{i,\text{RAM}}^0\big) \tag{4}$$

**Notation.** $p_i \in [0,1]$: predicted probability that trip $i$ adopts RAM; $T_i^0, E_i^0$: outcomes for the *observed chosen* baseline mode; other symbols as above.

*Accessibility & consumer surplus — before vs. after introducing RAM*

$$\text{logsum}_i^{(s)} = \frac{1}{\mu} \ln\left( \sum_{m \in C_i^{(s)}} e^{\mu V_{im}^{(s)}} \right), \qquad s \in \{0, \text{new}\} \tag{5}$$

$$\Delta\text{logsum}_i = \text{logsum}_i^{(\text{new})} - \text{logsum}_i^{(0)} \quad \geq 0 \tag{6}$$

$$\Delta T_{\text{tot}}^{\text{eq}} = -\frac{1}{60} \sum_i w_i \frac{\Delta\text{logsum}_i}{\beta_{GT,i}} \quad [\text{hours}] \tag{7}$$

$$\Delta CS_{\text{tot}} = -\sum_i w_i\, \Delta T_i^{\text{eq}}\, \text{VoT}_i \;=\; \frac{1}{60} \sum_i w_i \frac{\Delta\text{logsum}_i}{\beta_{GT,i}}\, \text{VoT}_i \tag{8}$$

**Notation & conventions.** $\text{logsum}_i^{(s)}$ is the *positive* inclusive value; higher implies better accessibility. $\Delta\text{logsum}_i \geq 0$ when RAM expands the choice set or improves utilities. $\beta_{GT,i} > 0$ is the (absolute) disutility per generalized time; thus improvements yield $\Delta T_i^{\text{eq}} < 0$. $\text{VoT}_i$ is the value of time of each mode; using €/h introduces the $1/60$ factor in $\Delta CS_{\text{tot}}$. $w_i$ are analysis weights.

## 3. Key results

*Overall travel demand*

A total of 222,155 trips were generated for 5% of the German population on an average weekday. After filtering for trips within the HEA's operational range of 950 km, 216,647 trips remained. Most of these (88.2%) are within Germany, while 11.8% cross the border. Private and leisure travel accounts for 63.3% of trips, and business travel makes up 36.7%.

*Travel time savings by RAM*

Compared to the fastest available mode, RAM enables average door-to-door time savings of 1.1 hours (66 minutes) on 47.9% of routes. For trips up to 500 km, 79.5% benefit from time savings of up to 2 hours. For longer trips over 500 km, 87% see savings of up to 4 hours.

Against the currently chosen modes, RAM offers an average time saving of 1.13 hours (68 minutes) on 60.8% of routes. For distances up to 500 km, 87.8% of trips gain up to 2 hours. Among trips longer than 500 km, 83.4% show time savings between 2 and 6 hours.

*Emission reductions by RAM*

Compared to existing modes, assuming that RAM trips use cars for both first and last mile segments, RAM reduces average $CO_2$-eq emissions by 57 kg compared to conventional air travel and by 3 kg compared to car travel. Emission savings increase with the trip length of car. For air travel, the largest reduction, up to 121 kg, occurs on very short routes under 200 km. Between 200 and 700 km, reductions rise from 27 kg to 50 kg. Beyond 700 km, the reduction gradually decreases.

When compared to the modes actually selected by travelers, RAM reduces emissions by an average of 35 kg compared to air and 2 kg compared to car. In general, the emission reductions grow with distance, ranging from 0 to 81 kg.

Table 2 presents a categorization of routes within Germany based on potential travel time savings when switching to RAM and the estimated RAM demand, assuming a 5% market share. Among all routes within Germany based on trips by 5% of the population, 3.9% were both selected by travelers for RAM and showed that RAM outperformed the fastest available non-RAM mode. The remaining routes, where RAM was not chosen but could offer time savings, are grouped into four categories. These categories are defined by distance-based thresholds[1] and whether the route has general travel demand. Among these, 34.4% of routes show high time savings but no observed travel demand. In comparison, 60.9% of routes offer only low time savings and also lack general demand. A list of the top routes, where RAM was chosen and outperformed the fastest non-RAM option, is provided in Appendix A.1.

[1] 0.5 hours for distance up to 200 km; 0.75 hours for distance between 200 and 400 km; 1 hour for distance between 400 and 600 km; 1.5 hours for distance between 600 and 950 km

Table 2: Categorization of routes based on RAM time saving potentials and demand

| Category | No. of routes | Share |
|---|---|---|
| High time savings with RAM demand | 7382 | 3.9% |
| High time savings with trip demand (RAM not chosen) | 369 | 0.2% |
| High time savings no trip demand (RAM not chosen) | 64673 | 34.4% |
| Low time savings with trip demand (RAM not chosen) | 1116 | 0.6% |
| Low time savings no trip demand (RAM not chosen) | 114623 | 60.9% |

A similar analysis was carried out to categorize routes based on potential emissions reduction. The top routes where travelers selected RAM, and it outperformed both the fastest and the greenest non-RAM options, are listed in Appendix A.2.

*Adoption of RAM*

Under the scenario assuming a 5% market share for RAM, adoption varies across traveler types and route characteristics. Business travelers show a higher uptake, with 7.6% choosing RAM, nearly double the share observed among non-business travelers, which stands at 4%. Income level also influences adoption, with RAM shares declining from 6.6% to 4.7% as income decreases. In terms of route types, higher adoption is observed on routes connecting rural areas (Landgemeinde) and large cities (Stadt) at 5.9%, and between small cities (Kleinstadt) and large cities at 6.8%. These values are above the average RAM share of 5% across all other route types.

*Impacts on accessibility*

Under the 5% RAM market share scenario, the introduction of RAM leads to a modest but positive effect on accessibility. On average, the total consumer surplus increases from €813.3 to €842, which represents a 3.6% improvement. By travel purpose, business travelers experience greater benefits, with total gains rising by 5% from €492.3 to €517. In contrast, non-business travelers see a smaller increase of 1.2%, from €321 to €324.9.

Across income groups, the overall gains are similar, although individuals with very high and high incomes benefit slightly more, with a 3.7% increase of the consumer surplus. This compares to 3.4% for those with low to medium incomes, and 3.2% for individuals with very low incomes. When looking at route types, the largest total gains are observed on routes connecting rural areas to large cities, which increase by 4.5%. These are followed by corridors between small cities and large cities at 3.9%, and between large cities at 3.8%. Corridors between rural areas show the smallest improvement, with a 2.8% increase.

## 4. Implications

RAM shows advantages in reducing travel time, even when compared to the fastest available modes. These benefits become even more pronounced when compared to the modes that travelers currently choose. Time savings generally increase with longer travel distances, highlighting the strength of RAM on medium and long-distance routes. In terms of environmental impact, RAM primarily competes with conventional air travel, especially on very short routes under 200 km, where it delivers the greatest emissions reductions.

Based on the route categorization in Table 2, a tiered strategy for route prioritization is proposed. Routes that combine substantial time savings with observable RAM demand, particularly those that also lead to emission reductions, should be prioritized for early deployment or expansion. Ensuring reliability and providing appropriate capacity on these routes will be essential. Another important group consists of routes that show high time savings but currently have limited travel demand. These may be suitable for temporary pilot programs, especially when aligned with strategic objectives such as equity or regional connectivity. Such pilots should include predefined review criteria, for example, a short trial period (e.g., 6 to 12 months) on rural or underserved corridors, with success measured by modest increases in adoption.

Regarding RAM's impacts on accessibility, while the impact per trip is relatively modest, the cumulative benefit is meaningful when scaled. Gains are concentrated in the business travel segment, where travelers typically place a higher value on time. This suggests that RAM significantly improves accessibility where time savings are most valuable. On a broader level, RAM enhances regional accessibility, with the largest improvements observed on corridors connecting rural or small towns to large cities. Gains are smaller on connections between rural areas. In addition, accessibility increases are also observed across income groups, although the benefits are somewhat smaller for individuals with lower incomes. This may reflect their lower presence on major city corridors or weaker access to these routes. To address this gap, policymakers may consider implementing supportive measures such as integrated ticketing systems, transfer discounts, and targeted feeder services to ensure wider access to RAM.

## 5. Conclusion and Outlook

This study uses an agent-based demand model to simulate 5% of the German population and evaluate the impacts of RAM enabled by 19-passenger HEA. The initial results indicate that RAM can deliver meaningful benefits in terms of travel time savings, emissions reduction, and improved accessibility. These outcomes highlight RAM's potential as a viable addition to the future regional transport system. However, the current analysis does not account for induced travel that may result from the introduction of RAM. This represents a limitation, as additional trips could influence both demand patterns and environmental outcomes.

In the next steps, the established modeling framework will be extended to the entire population to provide a more comprehensive national-level assessment. Future analyses will also incorporate projections for the year 2030, considering expected socio-demographic changes. Additionally, we will explore a range of policy scenarios, including pull measures such as subsidies and enhancements to feeder services, push measures such as taxation or restrictions on short-haul conventional air travel, and combined strategies. Through this expanded analysis, the study aims to deliver more detailed policy and planning insights. These will support infrastructure investment decisions and contribute to the broader goal of promoting a more sustainable and accessible transportation system.

# Appendix A. Supplementary tables of top routes

Table A.1: Top routes where RAM was chosen and outperformed the fastest non-RAM option

| Origin | Destination | Origin airport | Destination airport | Avg. time savings (h) (vs. fastest mode) | No. of travelers per day (5% of population) | No. of travelers choosing RAM per day (5% of population) |
|---|---|---|---|---|---|---|
| Hamburg-Eimsbüttel | Kiel, Landeshauptstadt | EDDH | EDHK | 0.96 | 4 | 3 |
| Zwönitz, Stadt | Berlin-Friedrichshain-Kreuzberg | EDAC | EDDB | 2.59 | 2 | 2 |
| Aldenhoven | Hamburg-Mitte | EDLN | EDDH | 2.22 | 2 | 2 |
| Zinnowitz | Hamburg-Nord | EDAH | EDDH | 2.08 | 2 | 2 |
| Ellerau | Bremen-Ost | EDDH | EDDW | 1.86 | 2 | 2 |
| Friedrichshafen, Stadt | Remseck am Neckar, Stadt | EDNY | EDDS | 1.68 | 2 | 2 |
| Hamburg-Wandsbek | Braunschweig, Stadt | EDDH | EDVE | 1.64 | 6 | 2 |
| Hamburg-Harburg | Bremen-Ost | EDDH | EDDW | 1.45 | 4 | 2 |
| Bremen-Ost | Hamburg-Nord | EDDW | EDDH | 1.17 | 7 | 2 |
| Neubrandenburg, Stadt | Berlin-Pankow | EDBN | EDDB | 1.16 | 2 | 2 |
| Bremen-Ost | Hannover-Ricklingen | EDDW | EDDV | 1.09 | 2 | 2 |
| Hamburg-Eimsbüttel | Mannheim, Universitätsstadt | EDDH | EDDF | 1.07 | 3 | 2 |
| Hannover-Linden-Limmer | Hamburg-Nord | EDDV | EDDH | 1.02 | 2 | 2 |
| Hamburg-Wandsbek | Delmenhorst, Stadt | EDDH | EDDW | 1.02 | 2 | 2 |
| Georgsmarienhütte, Stadt | Köln-Ehrenfeld | EDDG | EDDK | 0.91 | 2 | 2 |
| Mülheim an der Ruhr, Stadt | Echzell | EDDL | EDDF | 0.84 | 2 | 2 |
| Hamburg-Wandsbek | Kiel, Landeshauptstadt | EDDH | EDHK | 0.63 | 8 | 2 |
| Duisburg-Mitte | Rheine, Stadt | EDDL | EDDG | 0.61 | 2 | 2 |
| Münster, Stadt | Paderborn, Stadt | EDDG | EDLP | 0.54 | 3 | 2 |
| Augsburg | Reutlingen, Stadt | EDMA | EDDS | 0.53 | 2 | 2 |
| Hamburg-Mitte | Bremen-Nord | EDDH | EDDW | 0.40 | 3 | 2 |
| Ratekau | Hamburg-Altona | EDHL | EDDH | 0.29 | 3 | 2 |
| Mettmann, Stadt | Bonn, Stadt | EDDL | EDDK | 0.28 | 5 | 2 |
| Troisdorf, Stadt | Hofheim am Taunus, Kreisstadt | EDDK | EDDF | 0.20 | 2 | 2 |
| Staßfurt, Stadt | Weimar, Stadt | EDDP | EDDE | 0.13 | 2 | 2 |
| Mönchengladbach, Stadt | Köln-Innenstadt | EDLN | EDDK | 0.08 | 6 | 2 |
| Köln-Porz | Neuss, Stadt | EDDK | EDDL | 0.05 | 4 | 2 |
| Recklinghausen, Stadt | Münster, Stadt | EDLW | EDDG | 0.03 | 4 | 2 |

Table A.2: Top routes where RAM was chosen and outperformed both the fastest and the greenest non-RAM options

| Origin | Destination | Origin airport | Destination airport | Avg. time savings (h) (vs. fastest mode) | Avg. $CO_2$-eq emissions reduction (kg) | No. of travelers per day (5% of population) | No. of travelers choosing RAM per day (5% of population) |
|---|---|---|---|---|---|---|---|
| Berlin-Marzahn-Hellersdorf | Freyung, Stadt | EDDB | EDME | 3.53 | 49.39 | 1 | 1 |
| Stralsund, Hansestadt | Vellmar, Stadt | EDBH | EDVK | 3.53 | 0.48 | 1 | 1 |
| Berlin-Marzahn-Hellersdorf | Perlesreut | EDDB | EDME | 3.52 | 49.94 | 1 | 1 |
| Papenburg, Stadt | Schauenstein, Stadt | EDWE | EDQM | 3.43 | 21.06 | 1 | 1 |
| Garz/Rügen, Stadt | Kassel | EDBH | EDVK | 3.32 | 41.45 | 1 | 1 |
| Neuenburg am Rhein, Stadt | Lüssow | EDTL | EDBH | 3.21 | 43.25 | 1 | 1 |
| Erwitte, Stadt | Berlin-Marzahn-Hellersdorf | EDLP | EDDB | 2.98 | 0.61 | 1 | 1 |
| Kirchberg (Hunsrück), Stadt | Hof | EDFH | EDQM | 2.94 | 2.27 | 1 | 1 |
| Bärnau | Dägeling | EDQM | EDDH | 2.88 | 47.61 | 1 | 1 |
| Köln-Mülheim | Schauenstein, Stadt | EDDK | EDQM | 2.86 | 45.24 | 1 | 1 |
| Tiefenbach | Großheide | EDMS | EDWE | 2.81 | 54.06 | 1 | 1 |
| Warstein, Stadt | Dresden-Klotzsche | EDLP | EDDC | 2.58 | 4.43 | 1 | 1 |
| Norderney, Stadt | Alzenau, Stadt | EDWE | EDDF | 2.57 | 28.50 | 1 | 1 |
| Rosengarten | Schwarzenbach a.Wald, Stadt | EDDH | EDQM | 2.51 | 51.95 | 1 | 1 |
| Königs Wusterhausen, Stadt | Hofgeismar, Stadt | EDDB | EDVK | 2.46 | 4.79 | 1 | 1 |
| Berlin-Treptow-Köpenick | Kassel | EDDB | EDVK | 2.37 | 2.31 | 1 | 1 |
| Friedland, Stadt | Sondershausen, Stadt | EDBN | EDDE | 2.24 | 41.07 | 1 | 1 |
| Lindern (Oldenburg) | Mutlangen | ETND | EDTY | 2.20 | 58.95 | 1 | 1 |
| Masserberg | Langenhagen, Stadt | EDDE | EDDV | 2.11 | 23.75 | 1 | 1 |
| Anröchte | Schnaittach | EDLP | EDDN | 2.06 | 8.78 | 1 | 1 |

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