Urban Air Mobility: Potential and Challenges Based on Research at the Institute of Aerospace Systems

Ansgar Kirste

Institute of Aerospace Systems (ILR)
RWTH Aachen University

Kolloquium Urban Air Mobility: "Lieferdrohnen & Lufttaxis im Jahr 2025?"
Aachen, July 16th 2024

ILR Institute of Aerospace Systems | RWTH AACHEN UNIVERSITY

Introduction

What is the first thing that comes to your mind when you think of Urban Air Mobility?

Survey Results from Audience Poll on 16th July 2024

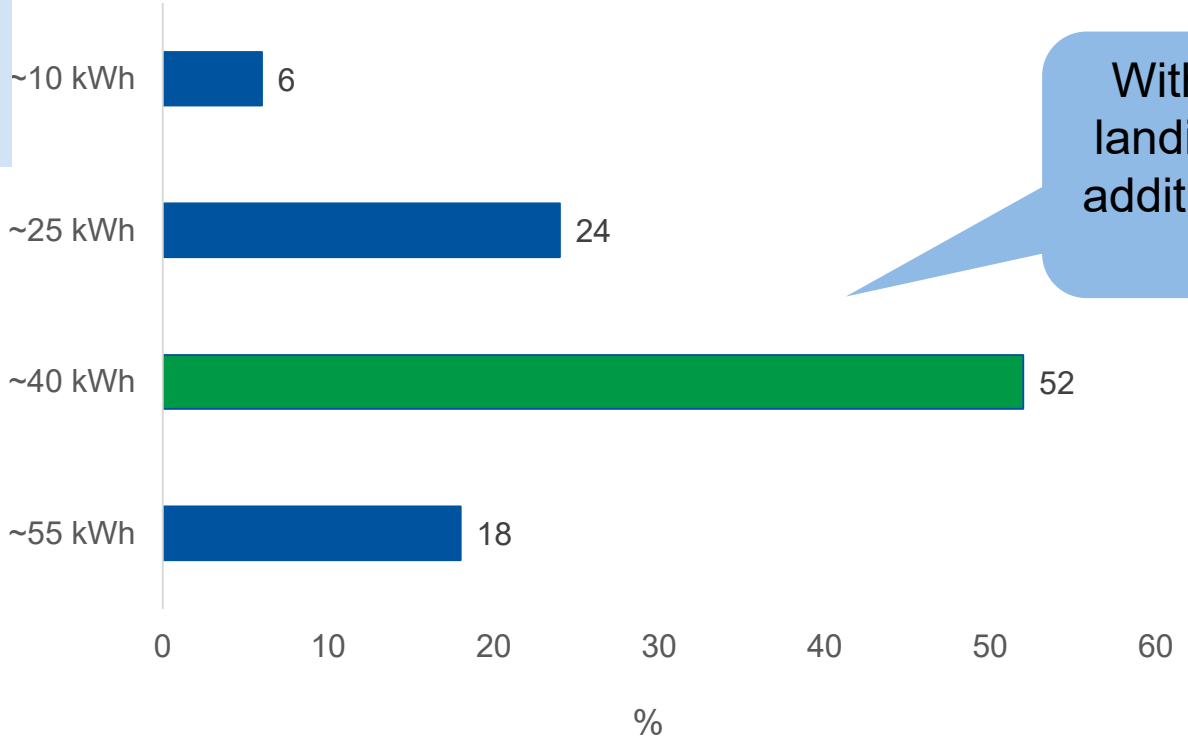
Data collected via audience poll.

Introduction

How high is the energy consumption of the Airbus A^3 Vahana vehicle concept? (Aachen-Cologne, 70km)

Survey Results from Audience Poll on 16th July 2024

Note: The energy consumption of a electric car (Tesla Model 3) is around 14-16 kWh/100km, resulting in 10.5 kWh/70km.



With a short take-off and landing phase and without additional effects from wind and maneuvering

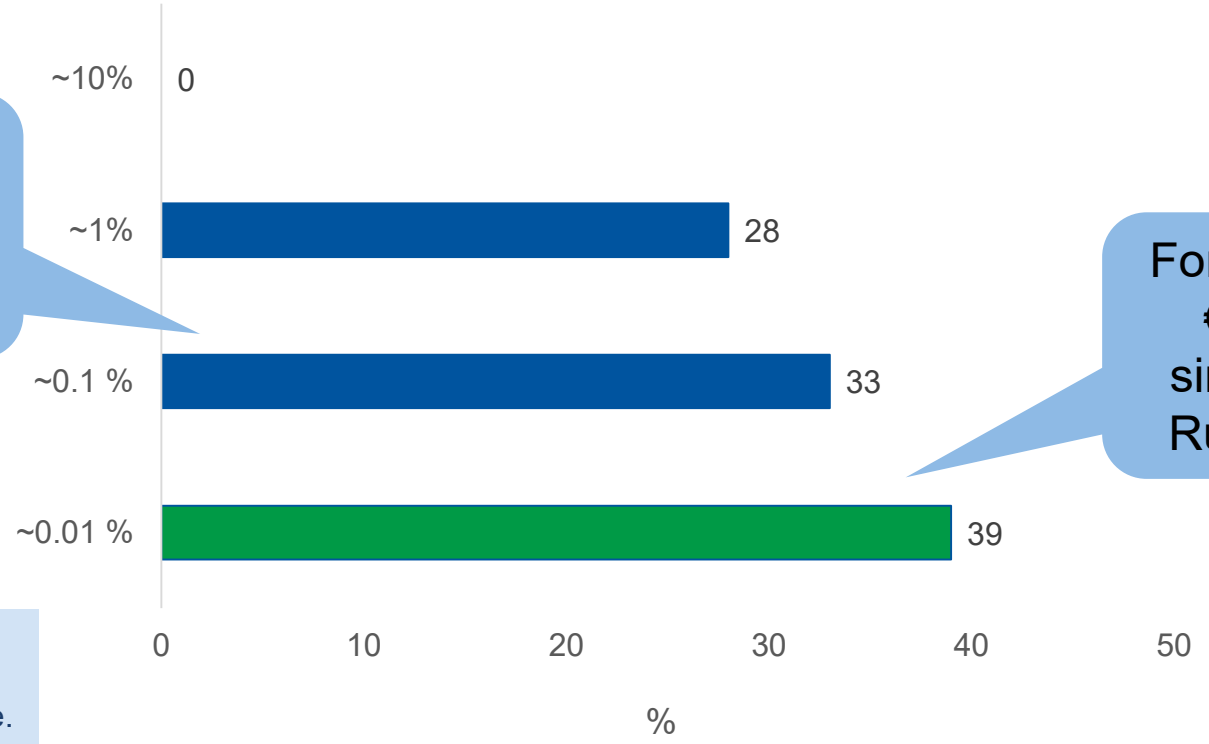
Data collected via audience poll.

Introduction

Which modal split could UAM achieve (for a scenario with travel distances up to 100 km)?

Survey Results from Audience Poll on 16th July 2024

For ticket prices below 1.50 €/pkm and progressive assumptions for the **year 2030**



For ticket prices **from 1.50 €/pkm** based on data simulations in the Rhine-Ruhr metropolitan region

Note: Relative mobility shares vary depending on whether micro-mobility or walking are included in the reference.

Data collected via audience poll.

Motivation

Recent research

➢ *Vehicle Level UAM*

- Continuous development and analyses of eVTOL vehicles
- Studies on vehicle performance
- Noise emission reduction

➢ *Air Transportation System Level UAM*

- Market potential analysis
- System modeling with competing modes of transportation
- User and public acceptance

Research questions

- Are UAM operations **feasible** and cost-efficient?
- How can a **UAM network** be simulated and optimized?
- How are piloted and **autonomous UAM flights** accepted?
- Is UAM sustainable and brings **environmental benefits**?

We need a **scientific** approach including **interdisciplinary** research!

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

8 Noise Emissions

9 CO2e

10 User Acceptance

11 Ticket Pricing

12 Business Case

Overall Evaluation

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

What constitutes an overall evaluation of UAM?

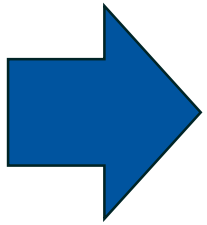
1 **Certification**

Technical Foundation
Operational Analysis
Environmental Impact
Market & Social Factors

Certification

Current status

- **Regulatory framework:** EASA and FAA are developing guidelines for eVTOL certification
- **Pilot projects:** Test flights in urban areas, including demonstration flights with approvals (e.g. Ehang)
- **Technological advancements:** Development and testing of autonomous flight systems



Future requirements and development

- **Certification process:** Implementation of a phased based approach by EASA and FAA for eVTOL
- **Infrastructure requirements:** Essential for skyport construction and station network planning
- **eVTOL downwash/outwash:** Safety zones due to the downwash effects caused by vehicles

What constitutes an overall evaluation of UAM?

1 **Certification**

2 **eVTOL Performance**

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

eVTOL Performance

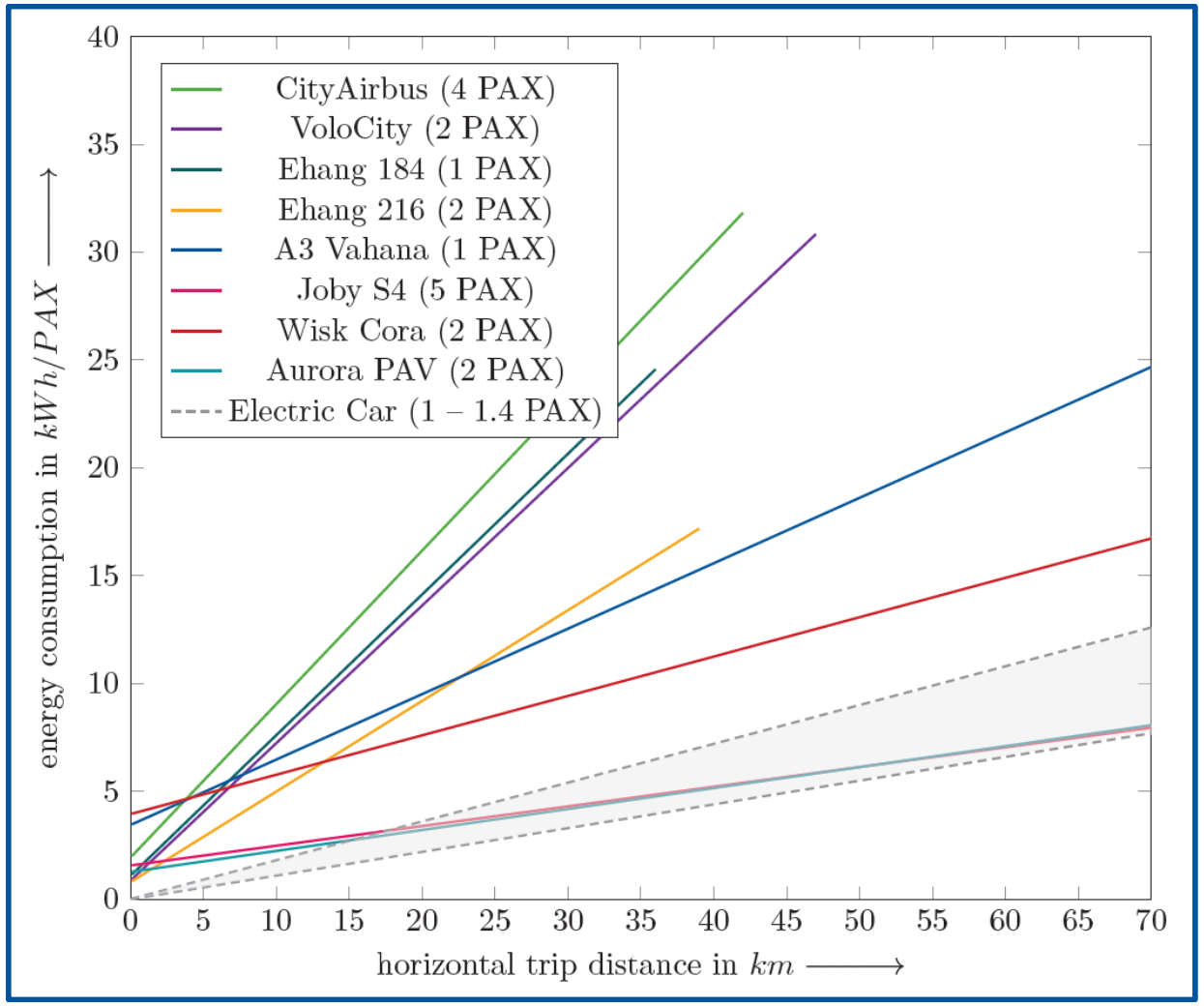
eVTOL vehicles

eVTOL vehicle	Configuration	PAX
City Airbus	Multicopter	4
VoloCity	Multicopter	2
Ehang 184	Multicopter	1
A3 Vahana	Tilt-Wing	1
Joby S4	Tilt-Rotor	5
Wisk Cora	Lift + Cruise	2
Aurora PAV	Lift + Cruise	2

Note: There are many more eVTOL vehicles, including use cases for passenger transport, emergency assistance, and logistic of goods.

Findings

"perfect" eVTOL configuration for efficient UAM fleet operations **unclear**



Kirste et al. (2023a)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

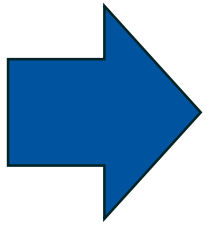
3 Station Planning

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Station Planning

How it is often analyzed

- Optimization based on **mobility demand data**
- **K-means clustering** of similar demand patterns
- Constraints:
  - Accessibility
  - Capacity
  - Peak hour performance



How it could be enhanced

- Input of simulated **UAM demand** and scenarios
- Theoretical best stations as option for further studies
- **Individualized analysis** of each station option:
  - Property ownership
  - Take-off and landing constraints
  - Connection to other modes of transportation

What constitutes an overall evaluation of UAM?

1 Certification

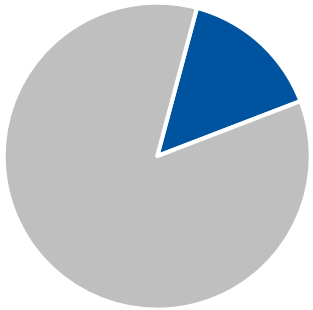
2 eVTOL Performance

3 Station Planning

4 eVTOL Production

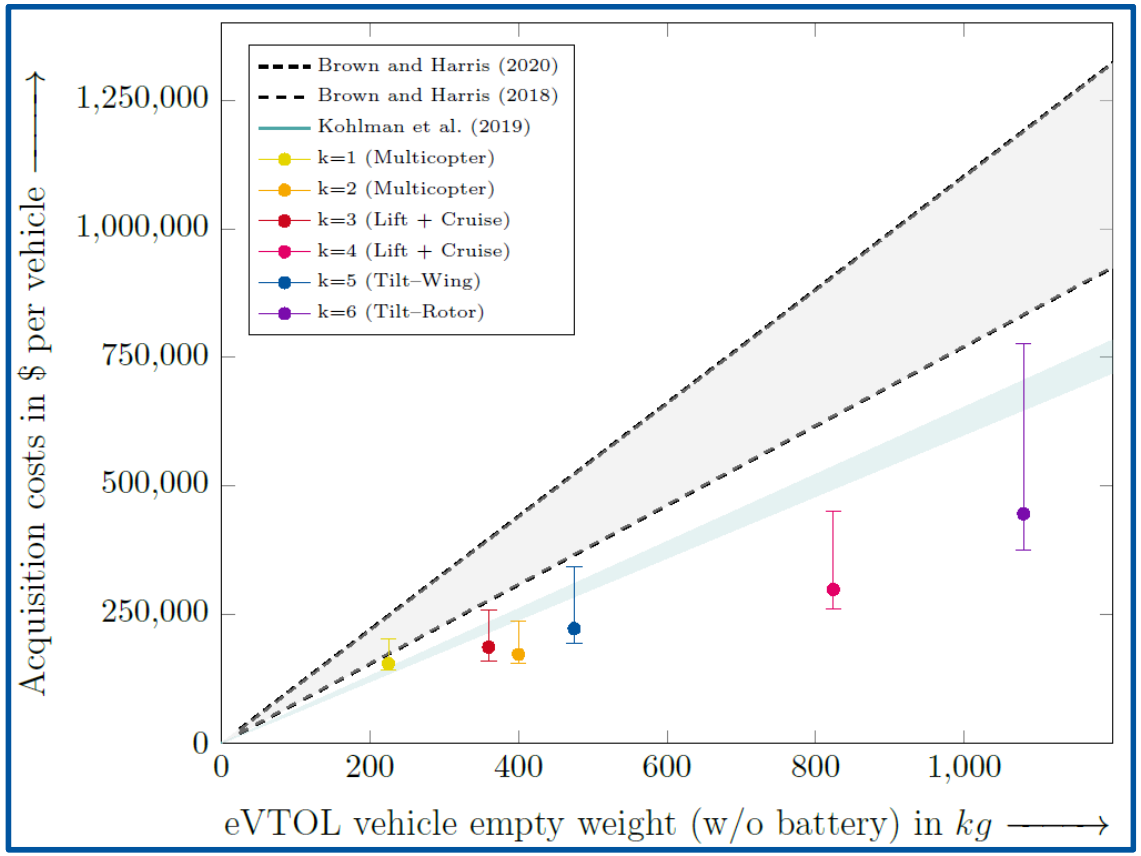
- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

eVTOL Production



UAM fleet costs
≈ 10 – 30 ct/pkm

- Empty mass dependent **linearization** approaches
- **Calibration** of parametric models is decisive
- Impact of **production volume** is most decisive



Kirste & Stumpf (2024a)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

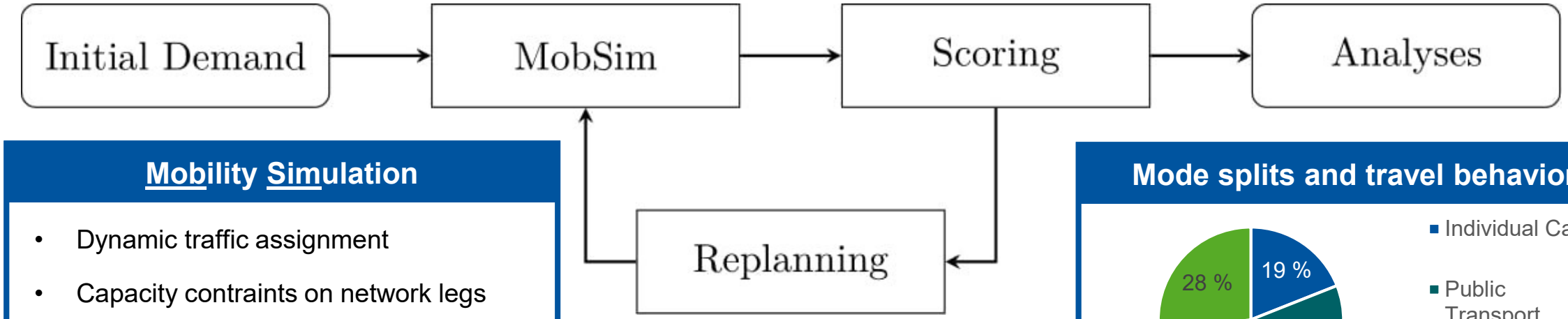
5 Mobility Simulation

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Mobility Simulation (utilizing *MATSim*)

Mobility trips in the Metropolitan Region Rhine-Ruhr

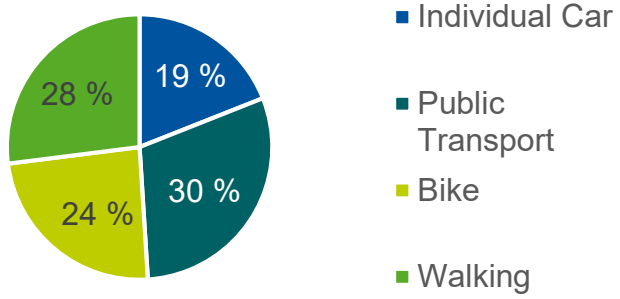
- Ticket price
- Value of travel time
- Disutility of waiting



Mobility Simulation

- Dynamic traffic assignment
- Capacity contraints on network legs
- Modeling of congestion and waiting
- Route choice behavior

Mode splits and travel behavior



MATSim iterative optimization process based on: Horni et al. (2016)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

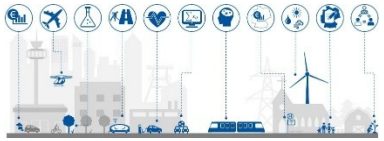
6 UAM Fleet Simulation

Technical Foundation
Operational Analysis
Environmental Impact
Market & Social Factors

UAM Fleet Simulation

Interdisciplinary Research Project *ACCESS!**

- user acceptance
- other modes of transport
- specific scenario



Input

Demand Data and Fleet Simulation

Agent-based Transportation Simulation (e.g. MATSim)

ML Substitute Model

UAM Demand & Flight Sequences

Air Transportation System UAM

Postprocessing

- Cost Optimization
- Pricing Strategies
- Sustainability Aspects
- Vehicle Design

Output

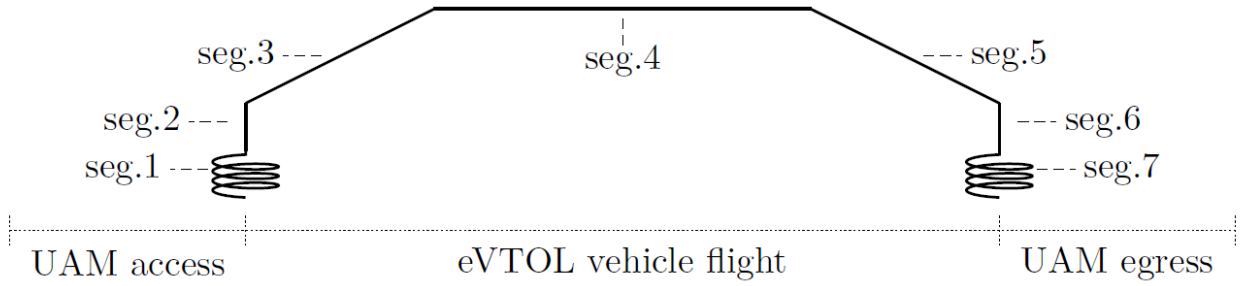
Aircraft Design

* https://www.accessnrw.rwth-aachen.de/

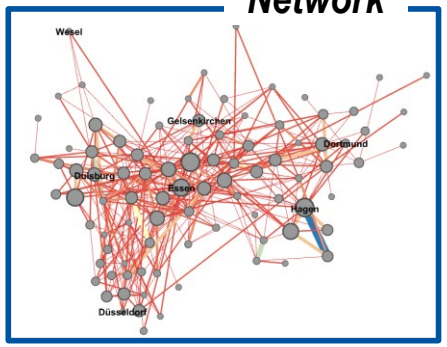
Kirste (2024c)

UAM Fleet Simulation

Flight missions



Network

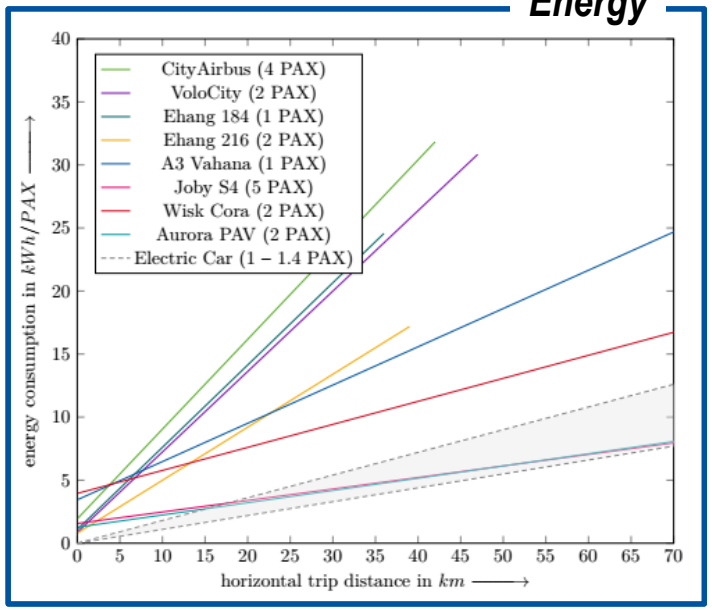


Base Case of Rhine-Ruhr simulation with MATSim

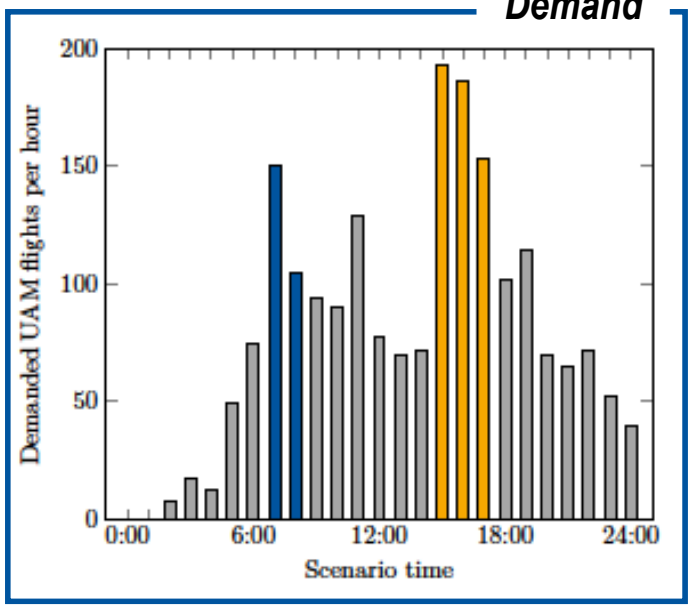
eVTOL vehicle

eVTOL vehicle	Configuration	PAX
City Airbus	Multicopter	4
VoloCity	Multicopter	2
Ehang 184	Multicopter	1
A3 Vahana	Tilt-Wing	1
Joby S4	Tilt-Rotor	5
Wisk Cora	Lift + Cruise	2
Aurora PAV	Lift + Cruise	2

Energy



Demand



Figures from Kirste et al. (2023a), Kirste & Stumpf (2023b), and Kirste & Stumpf (2024b)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

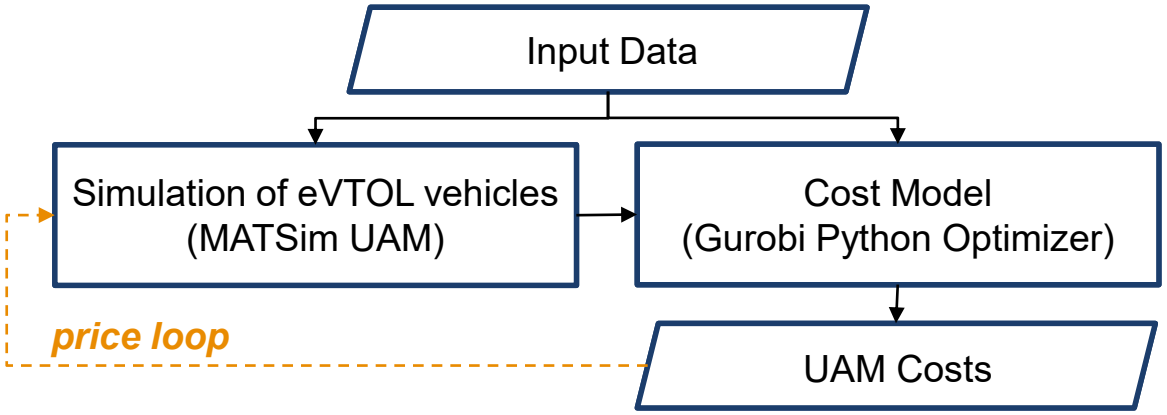
5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

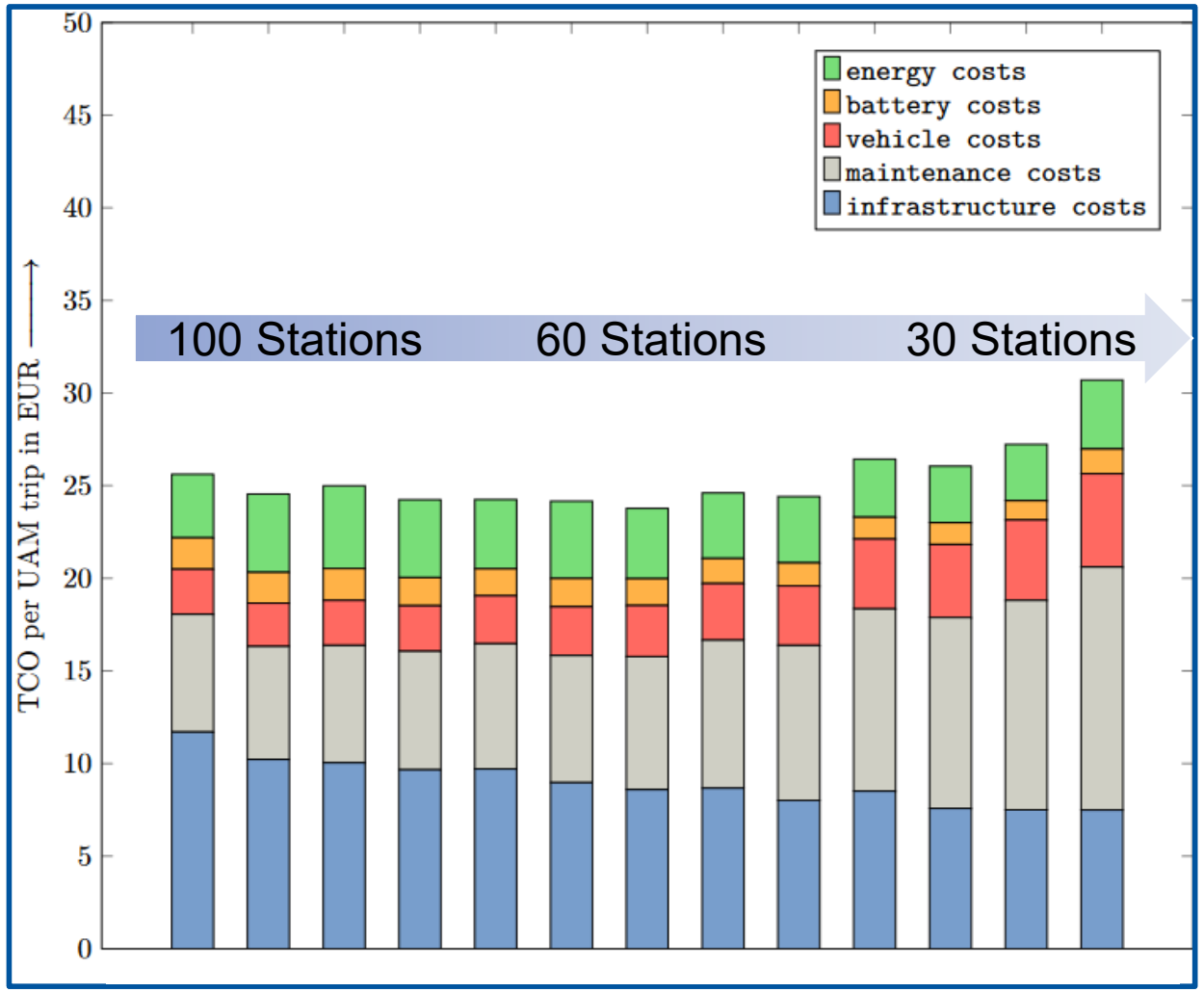
- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Total Costs



Findings

- For a **medium station density**, total UAM costs are around **1.50 €/pkm** (optimized)
- Feasible operation can only be found within **1.20 to 1.70 €/pkm**
- **Piloted** flight operations are **cost-inefficient** in a considered cases of the study scenario



Figures from Kirste et al. (2022), Kirste & Stumpf (2024b), and Kirste (2024c)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

8 Noise Emissions

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

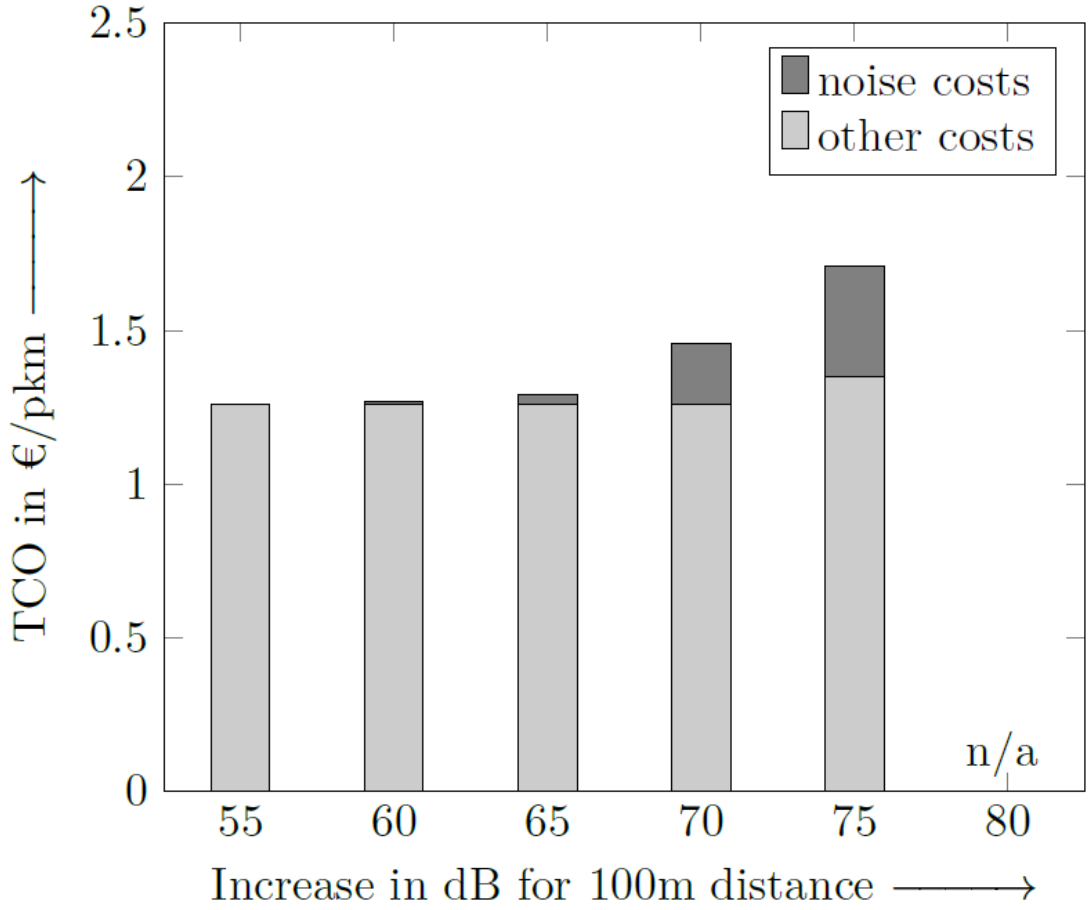
Noise Emissions

- **Hedonic pricing** method
- Number of **real estate properties** are linked to each vertiport option
- Noise costs result from the number of flight affecting the properties and their noise levels

Note: The assessment of noise emissions from drones is not solely dependent on the sound level. It is also influenced by subjective perception and the frequency of flight operations. This approach represents a simplification of the broader research field.

Findings

- **75 dB** noise emission for 100 m distances are critical
- Different **station placements** are considerable for feasable operations



Kirste et al. (2023a)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

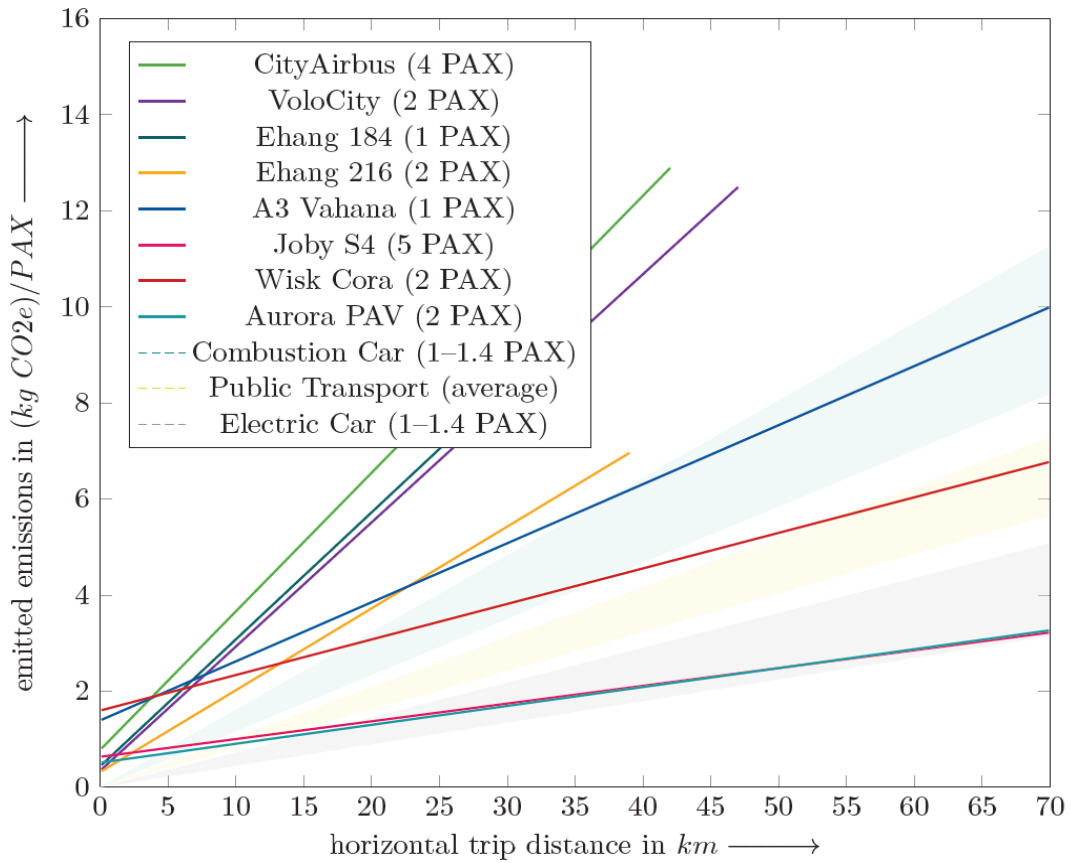
8 Noise Emissions

9 CO2e

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Environmental assessment

CO_2 emissions for different transport modes



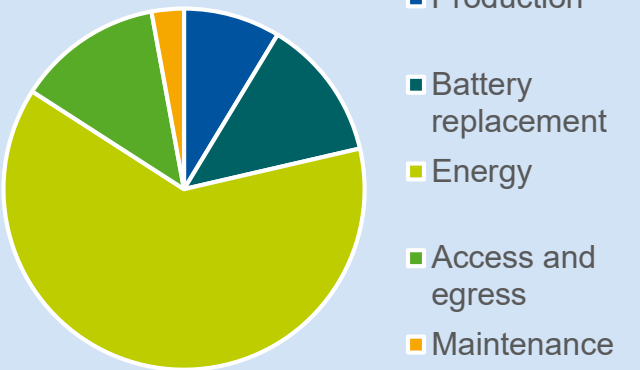
Life cycle emissions for UAM

2019

≈ 346 gCO_2/pkm

2030

≈ 160 gCO_2/pkm



CO_2 Findings:

- At present, eVTOL operations **cannot** be considered **environmentally sustainable**
- An increased **share of green electricity** could significantly reduce the ecological footprint of UAM

Kirste et al. (2023a)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

8 Noise Emissions

9 CO2e

10 User Acceptance

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

User Acceptance / User Preferences

General survey design

"Would you fly with an air taxi?"

- **Advantage:** Many survey responses
- **Disadvantages:**
  - Potential bias due to lack of comprehensive information about air taxi operations
  - User attitude does not necessarily correspond to user behavior

Findings

- **Noise and safety** are common general concerns
- Higher acceptance for search and rescue missions as well as **emergency flights**
- Support for **passenger** transport is increasing but remains **significantly lower**

Choice-based-Conjoint (CBC) study design

Attribute	Option 1	Option 2	Option 3
Skyport	Airport	Rural area	Urban area
Price	56 €	68 €	83 €
Automation	Pilot remote	Pilot on-board	Autonomous
Environmental Impact	1.5 times the status quo	2 times the status quo	0.5 times the status quo
Extras	W-Lan	Radio	Special seat

Findings:

- **Key attributes:** Price and travel time are identified as the most significant attributes
- **Environmental friendliness:** When explicitly asked about environmental friendliness, it is considered highly relevant by respondents

Results and survey design examples are partly based on: Tepylo et al. (2023), and Lotz et al. (2023)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

8 Noise Emissions

9 CO2e

10 User Acceptance

11 Ticket Pricing

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Ticket Pricing (Case study simulation Rhine-Ruhr)

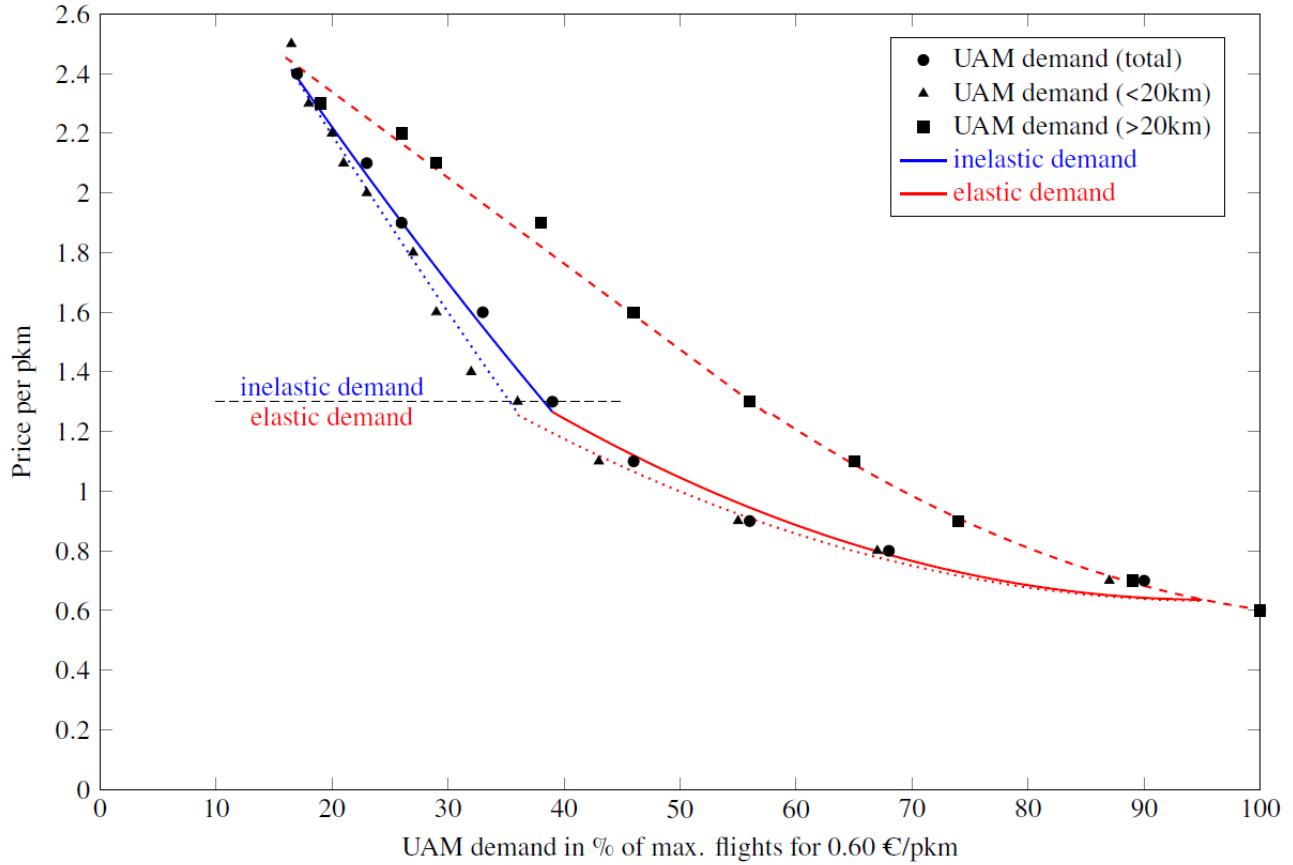
Simulation of Rhine-Ruhr scenario

- **1%** simulation scenario (MATSim)
- 100 iterations to enable innovative **UAM flights**
- Cruise speed depending on **eVTOL vehicle** (e.g. 150-200 km/h for Tilt-X configurations)
- Average **process times** of 15 min per UAM trip

Findings

- **Elastic demand** for longer flights (>20km) and for prices **≤ 1.30 €/pkm**
- Ticket prices should vary based on trip length and **time of request**

Price Elasticity



Kirste & Stumpf (2024b)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

8 Noise Emissions

9 CO2e

10 User Acceptance

11 Ticket Pricing

12 Business Case

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Business Case (Case study simulation Rhine-Ruhr)

Input

Sets

- eVTOL vehicle concepts, pricing options, time
  - ➢ UAM fixed base price: 0 – 12 €
  - ➢ UAM variable price: 0 – 2.50 €/pkm

Decision Variables and Constraints

- Vehicle concept
- Binary variable for price setting
  - ➢ Constraints: One pricing option per time period

Parameters (sample)

- Energy costs: 0.30 €/kWh
- Maintenance costs: 50 €/FH
- Battery and autonomy assumptions for 2030

eVTOL vehicle	Pricing	Profit in %
Aurora PAV	static	7.7
	dynamic I	15.3
	dynamic II	24.0
Airbus A^3 Vahana	static	- 4.1
	dynamic I	3.1
	dynamic II	15.4
Ehang 216	static	- 11.1
	dynamic I	- 3.9
	dynamic II	4.2
VoloCity	static	- 50.0
	dynamic I	- 22.0
	dynamic II	- 10.4

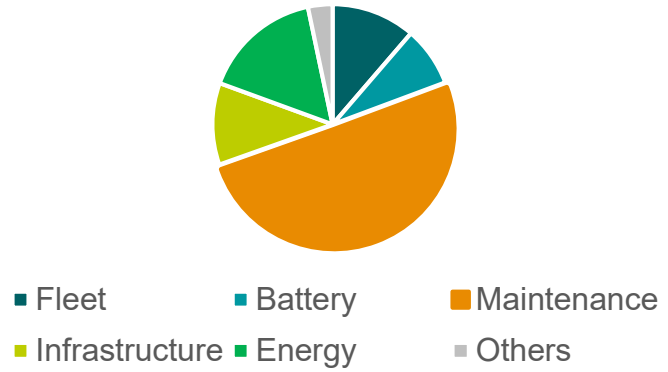
Note: The complete model includes additional cost parameters and constraints. Also, technology developments for 2030 are assumed.

Kirste & Stumpf (2024b)

Business Case (Case study simulation Rhine-Ruhr)

Total costs

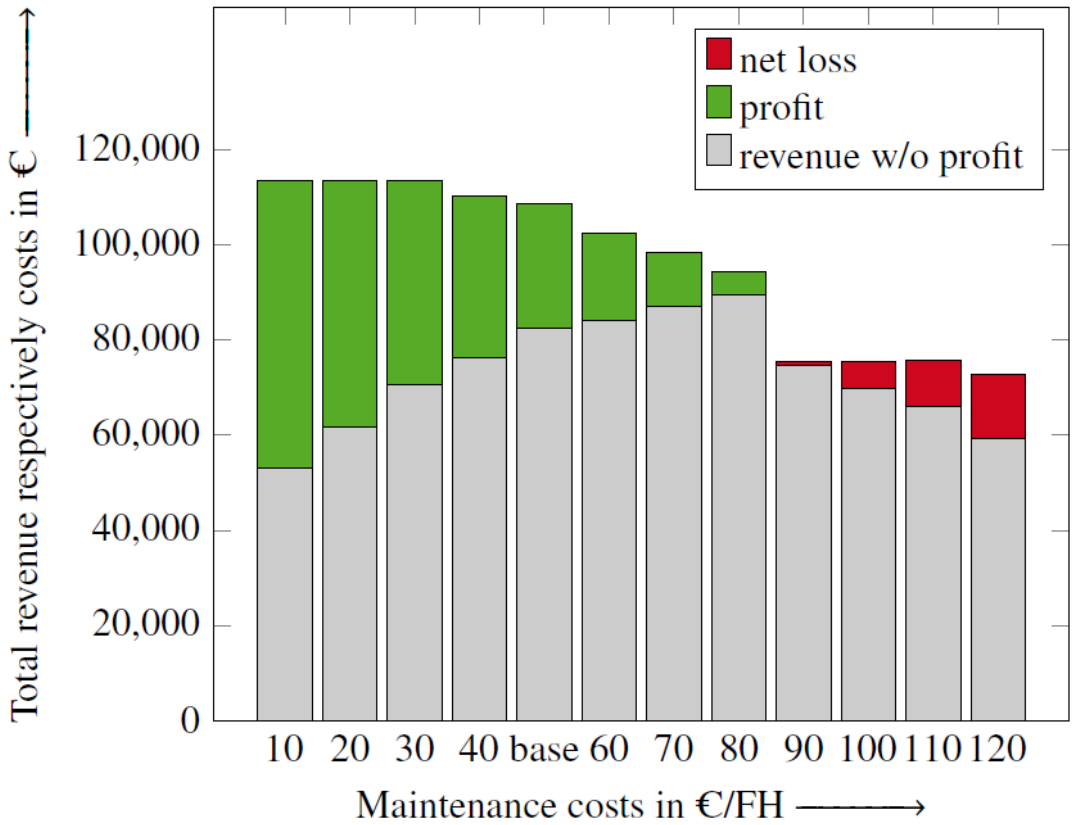
Average case with high utilization due to efficient pricing



Findings

- **Business cases** are currently dependent on many **uncertainties**
- Increase in eVTOL **fleet utilization** (+ 10 % rkm) and profit for temporal dynamic pricing
- Maintenance costs at most **80 €/FH** are decisive

Sensitivity of maintenance costs



Kirste & Stumpf (2024b)

What constitutes an overall evaluation of UAM?

1 Certification

2 eVTOL Performance

3 Station Planning

4 eVTOL Production

5 Mobility Simulation

6 UAM Fleet Simulation

7 Total Costs

8 Noise Emissions

9 CO2e

10 User Acceptance

11 Ticket Pricing

12 Business Case

Overall Evaluation

- Technical Foundation
- Operational Analysis
- Environmental Impact
- Market & Social Factors

Evaluation

Potential

- **Faster mode of transportation** utilizing the third dimension
- Initial implementation of airport shuttles and demonstration flights
- Short-term potential with **governmental support** (e.g. in metropolitan regions in Asia)
- Feasible business cases for progressive **technology develpment** by 2030
- Potential for emergency medical services

Challenges

- **Autonomous eVTOL** flights are decisive for feasible fleet operations
- **Regulatory** hurdles remain
- Large-scale implementation unclear
- UAM is in competition with **Intelligent Transport Systems** (ITS)
- **Public acceptance** among non-users
- **Noise emissions** and **eVTOL downwash** effects

- ➢ UAM is currently either strongly criticized or hyped (in Germany)
- ➢ UAM is **scenario-specific**, but has to be further developed and analyzed
- ➢ Successful implementation requires collaboration among all stakeholders

Thank you

Ansgar Kirste
M.Sc.

Research Associate

Wuellnerstrasse 7
52062 Aachen | GERMANY
Tel +49 241 80-96803
kirste@ilr.rwth-aachen.de
www.ilr.rwth-aachen.de

References

Horni, A., Nagel, K., & Axhausen, K. (2016). *Introducing MATSim*. In *Multi-Agent Transport Simulation MATSim*. Ubiquity Press. ISBN 978-1-909188-75-4.

Kirste, A., & Stumpf, E. (2024a). Development of a generalized eVTOL vehicle cost model for urban air mobility operations. In: *2024 ATRS World Conference*. Paper submitted to *Journal of the Air Transport Research Society* (in review).

Kirste, A., & Stumpf, E. (2024b). Modeling and analysis of dynamic pricing potential for urban air mobility operations. In *AIAA Aviation 2024 Forum*. https://doi.org/10.2514/6.2024-3938.

Kirste, A. (2024c). Modular air transportation system evaluation for urban air mobility. *Research Consortium ACCESS!*. Manuscript in preparation. https://www.accessnrw.rwth-aachen.de/index.php?id=modulare-lufttransportsystembewertung-fur-urban-air-mobility&lang=de#english_version.

Kirste, A., Husemann, M., & Stumpf, E. (2023a). Analysis of Sustainability Specifications of Urban Air Mobility Fleet Operations using Agent-based Transportation Simulation. In *AIAA Aviation 2023 Forum*. https://doi.org/10.2514/6.2023-3264.

Kirste, A., & Stumpf, E. (2023b). Developments of Urban Air Mobility Analyses using Multi-Agent Transport Simulation. *MATSim User Meeting 2023*. https://ethz.ch/content/dam/ethz/special-interest/baug/ivt/ivt-dam/events/2023/09/05/presentations/Kirste_Stumpf_MUM_2023.pdf accessed 2023-12-10.

Kirste, A., Husemann, M., & Stumpf, E. (2022). Analysis and Evaluation of Urban Air Mobility Fleet Operations using Agent-based Transportation Simulation. Oral presentation: *German Aerospace Congress 2022*, Dresden, Germany.

Lotz, V., Kirste, A., Lidynia, C., Stumpf, E., & Ziefle, M. (2023). User acceptance of urban air mobility (uam) for passenger transport: A choice-based conjoint study. In *2023 25th International Conference on Human-Computer Interaction*. HCI International. https://doi.org/10.1007/978-3-031-35678-0_20.

Tepylo, N., Straubinger, A., & Laliberte, J. (2023). Public perception of advanced aviation technologies: A review and roadmap to acceptance. *Progress in Aerospace Sciences*, Vol. 138. https://doi.org/10.1016/j.paerosci.2023.100899.

Additional Sources

Babetto, L., Kirste, A., Deng, J., Husemann, M., & Stumpf, E. (2023a). Adoption of the Urban Air Mobility System: Analysis of technical, legal and social aspects from a European perspective. *Journal of the Air Transport Research Society*, Vol. 1, No. 1, pp. 152–174. https://doi.org/10.59521/C97BE694514DD2FE.

Babetto, L., König, R., Fassnacht, J., & Stumpf, E. (2023b). Study on public acceptance of eVTOL: safety & noise. *German Aerospace Congress 2023*, Stuttgart, Germany. Document ID: 610319. https://www.dglr.de/publikationen/2024/610319.pdf

Garrow, L., German, B., & Leonard, C. (2021). Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research. *Transportation Research Part C: Emerging Technologies*, Vol. 132. https://doi.org/10.1016/j.trc.2021.103377.

Husemann, M., Kirste, A., and Stumpf, E. (2023). Analysis of Cost-Efficient Urban Air Mobility Systems: Optimization of Operational and Configurational Fleet Decisions. In: *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2023.04.040.

Kiesewetter, L., Shakib, K.H., Singh, P., Rahman, M., Khandelwal, B., Kumar, S., & Shah, K. (2023). A holistic review of the current state of research on aircraft design concepts and consideration for advanced air mobility applications. *Progress in Aerospace Sciences, Vol. 142*. https://doi.org/10.1016/j.paerosci.2023.100949.

Rajendran, S., & Srinivas, S. (2020). Air taxi service for urban air mobility: A critical review of recent developments, future challenges, and opportunities. *Transportation Research Part E: Logistics and Transportation Review*, Vol. 143. https://doi.org/10.1016/j.tre.2020.102090.

Tepylo, N., de Jesus Krings, T., Chamberland, O., & Laliberte, J. (2024). Predictive modelling of willingness to fly on urban air mobility aircraft. In *AIAA Aviation 2024 Forum*. https://doi.org/10.2514/1.D0427.

The Boeing Company (2023). *Concept of operations for uncrewed urban air mobility* (Version 2.0). Retrieved July 15, 2024, from https://wisk.aero/wp-content/uploads/2023/12/Concept-of-Operations-for-Uncrewed-Urban-Air-Mobility-v2.0.pdf.

Ziemke, D., Kaddoura, I., & Agarwal, A. (2019). Entwicklung eines regionalen, agentenbasierten Verkehrssimulationsmodells zur Analyse von Mobilitätsszenarien für die Region Ruhr. *Mobilität in Zeiten der Veränderung*. https://doi.org/10.1007/978-3-658-26107-8_29.