Advanced Air Mobility: The new flying

Final document

Ministerie van Infrastructuur en Waterstaat

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Executive summary (1/2)

A Background and methodology

- Roland Berger was asked to provide insight how eC/VTOL aircrafts can contribute to zero-emission mobility and to determine the focus areas for the Ministry and top sectors
- People from a variety of backgrounds (industry, government, academia) have been involved in the project through three workshops

B Introduction of Advanced Air Mobility

- Society faces a number of mobility challenges and opportunities – Advanced Air Mobility (AAM) can add a new mobility dimension and complement the existing systems
  - It is expected that AAM will allow people and cargo to hop on and off comfortably and quickly fly to many regional destinations
  - For many people in The Netherlands there is an airport at less than 20 minutes – Vertiports will ensure total coverage
- Advanced Air Mobility can be defined as regional short-haul flights with manned and unmanned aircraft systems for passenger and cargo applications
  - Multiple electric aircraft configurations exist, each with different characteristics that have significant influence on performance
  - Over 100 AAM aircrafts are currently in development using new electric conventional and VTOL aircrafts – Europe accounts for 46%
- Adoption of Advanced Air Mobility is driven by social-cultural factors, technology, infrastructure, economics and regulation
  - Sustainability, social integration, safety and noise/visual pollution are crucial social-cultural factors for AAM adoption: If safe, sustainable, low-noise, green (air) mobility solutions are available this can improve connectivity of regions and replace polluting planes
  - Flight, propulsion and control technology are the three areas that drive AAM adoption from a technology point of view
  - AAM requires three levels of infrastructure: physical, digital and ground transport integration
  - AAM is not likely to be the cheapest and most energy efficient alternative, but is expected to be cost-competitive with traditional air transport
  - Required regulatory approvals relate to the aircraft, MRO, operations and various others
- Non-passenger transport is expected to have greater near-term adoption as result of lower technological and regulatory barriers

Executive summary (2/2)

C Implications for The Netherlands and Western Europe

- A wide variety of passenger and non-passenger applications exist for AAM in The Netherlands and Western Europe
- Two selected use-cases have been detailed: regional air mobility up to 250 km (eVTOL) and Air Traffic Electrification up to 1,000 km (eSTOL and eCTOL)
- RAM consists of scheduled passenger transport and can increase accessibility by offering sustainable transport options
  - It is estimated that 20-40 k passengers per day will use eVTOL transport in 2050 for which 700-1,400 aircrafts are required, predominantly tilt wing
  - The addressable area for eVTOL is between 50-250 km – For Utrecht, cities such as The Hague, Deventer, Middelburg and Cologne would be in range
  - 20-40 k passengers per day are expected to use eVTOLs by 2050 – The switch rate is expected to be higher for longer distances
  - 700 to 1,400 eVTOLs are expected for RAM in 2050 based on the estimated 20-40 k eVTOL movements in 2050
  - Effects and considerations of eVTOL as a tourism shuttle to the Efteling have been assessed – Potential other use cases (e.g. Wadden) to be assessed
- Air traffic can be partly electrified by eSTOL and eCTOL to create sustainable alternatives for conventional air traffic while increasing accessibility
  - It is estimated that 4-14 k passengers per day will use eSTOL and eCTOL transport in 2040 for which 110-310 aircrafts are required
  - The addressable area for eSTOL and eCTOL is up to 1,000 km – Cities such as London, Manchester, Prague and Oslo would be in range
  - The demand in 2040 is estimated to be 2.5-12 k passengers per day based on the current number of movements and a switch rate between 0-20%
  - 60-260 required eSTOLs/eCTOLs are expected for Air Traffic Electrification in 2040 based on the estimated 2.5-12 k eSTOL/eCTOL movements in 2040
  - Passenger transport by eCTOL en eSTOL could start to kick in with piloted aircrafts around 2030

D Required actions for the government and the top sectors

- Government's key responsibilities are regulation, infrastructure and social-cultural factors while top sectors must focus on technology and economics
- Concrete next steps are identified for the government and top sectors to accelerate development of Advanced Air Mobility in the short-term
  - Program further research on AAM
  - Research public opinion on AAM
  - Bring together relevant stakeholders to accelerate AAM technology development
  - Stimulate research on AAM
  - Develop required AAM regulations with EASA
  - Map infrastructure requirements for AAM in NL

A. Background and methodology

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RB was asked to provide insight how eC/VTOL aircrafts can contribute to zero-emission mobility and to determine the focus areas for the Ministry and top sectors

Background and goal

Background

- With the **rise of 'the new flying'** (electric drones – eVTOL[1] aircrafts), new possibilities are added to our mobility system
- It is now **difficult to imagine** what regional or urban air mobility could look like with large-scale application and to what extent this form of mobility will have an **impact on space, mobility and the economy**
- Roland Berger is asked for support in **providing insight** how eC/VTOL aircrafts can contribute to making **zero-emission mobility** possible on a large scale
- This project was conducted in a **short-time span** of a few weeks limiting thorough analysis on the vast number of factors influencing advanced air mobility

Goal of the project

Determine the **focus areas** for the Ministry and the top sectors with the mission of a **public-private arrangement** that serves, among other things, the "**Klimaatakkoord**" and all parties that have committed to it

1) Electric vertical take-off and landing

Source: Roland Berger

People with diverse backgrounds have been involved in the project – In total three workshops have been organized

Overview of people involved

Group	Name	Organization
Project team		MinIenW
		MinIenW
		MinIenW
	Jeroen Kroonen	MissieTeam Dplus
	Casper Veenman	Roland Berger
	Niek Cuperus	Roland Berger
Sounding board	**Roel Hellemons**	Airport Eindhoven
		MinIenW
		MinIenW
	Arjan Vergouw	MissieTeam Dplus
	Martin Nagelsmit	NLR
Workshop participants	**Dean Boljuncic**	Airport Eindhoven
	Gijs Vrenken	Airport Eindhoven
	Sjoerd Berning	Bayards
	Wesley Poland	Bayards
	Maurice Boogerd	Corendon
	Chris Popps	Fokker
	Michiel Wevers	Fokker
	Idius Greving	Fundashon Mariadal
	Martine Verweij	Greenbridges
Workshop participants	**Kyara Metz**	LVNL
	Frans Sengers	Milieu Centraal
		MinIenW
		MinIenW
		MinIenW
		MinIenW
		MinIenW
		MinIenW
		MinIenW
	Robbert Jan Kooij	Oost NL
	Robert Dingemanse	PAL-V
	Jaap Hatenboer	RAV
		RWS
	Geert Boosten	Stichting Duurzaam Vliegen
	Mark Rademaker	Stichting Duurzaam vliegen
	Tim te Velde	Stichting Duurzaam vliegen
	Yanniek Huisman	Stichting RHIA
	Matthijs de Haan	Teuge Airport
	Toon Meelen	Universiteit Utrecht
	Joost Dieben	Venturi

Source: Roland Berger

To support legibility, the report contains numerous abbreviations

List of abbreviations

Abbreviation	Meaning
#	Number
%	Percentage
/	Per
~	Approximately
<	Smaller than
>	Larger than
∑	Total
AAM	Advanced air mobility
ATE	Air traffic electrification
BE	Belgium
c	Circa
CBS	Centraal Bureau voor de Statistiek
CO2	Carbon dioxide
DG	Directoraat-generaal
DOA	Design organization approval
e.g.	Exempli gratia (for example)
EASA	European Union Aviation Safety Agency
eCTOL	Electric conventional take-off and landing
eSTOL	Electric short take-off and landing
eVTOL	Electric vertical take-off and landing
excl	Excluding
h	Hour
I&W	Infrastructure and Water management
i.e.	Id est (that is)
incl	Including
k	Thousand
kg	Kilograms
km	Kilometers
max	Maximum
min	Minimum
min	Minutes
MOA	Maintenance organization approval
n/a	Not applicable
NL	The Netherlands
POA	Product organization approval
RAM	Regional air mobility
RB	Roland Berger
Top sec	Top sectors
UAV	Unmanned aerial vehicle
US	United States
W-EU	Western Europe

Source: Roland Berger

Roland Berger

B. Introduction of Advanced Air Mobility

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Advanced Air Mobility can add a new mobility dimension and complement the existing systems

The opportunities for Advanced Air Mobility

Mobility challenges

Environmental effects of mobility

Congestion increases traffic fatalities and long commute times

Mobility infrastructure is increasingly **costly** and using up more and **more space**

Opportunities

Technological developments bring new opportunities (e.g. less emission, better noise control, lower cost)

One of the potential answers

Advanced Air Mobility

Advanced Air Mobility adds a new mobility dimension and complements existing systems

Source: Roland Berger

It is expected that AAM will allow people and cargo to hop on and off comfortably and quickly fly to many regional destinations

The Customer Journey

1

BOOK IT

Book spontaneously, even while on your way to the airport, or schedule in advance

2

HOP ON

Never miss a beat. Get dropped off right next to the plane or walk through a small building or gate

3

SIT BACK

Relax or be productive – no need to keep your eyes on the road

4

HOP OFF

Go directly to an automatically arranged waiting rideshare or parked car

Source: NASA, Roland Berger

For many people in The Netherlands there is an airport at less than 20 minutes – Vertiports would ensure total coverage

Coverage (20-min) of airports in The Netherlands

Airports[1] (today)

Vertiports added (future potential)

- There already is an airport at less than 20 minute for most people in The Netherlands
- Once vertiports are added, take-off and landing locations come even closer and accessibility is increased
- This would allow all people in The Netherlands to arrive at take-off and landing locations within 20 minutes

1) Excluding heliports

Source: OurAirports.com, Roland Berger

Advanced Air Mobility can be defined as regional short-haul flights with manned and unmanned aircraft systems for passenger and cargo applications

Advanced Air Mobility

Advanced Air Mobility can be defined as **electric conventional**[1)] and **vertical take-off and landing (VTOL)** for **short flights** with a **radius of 80-km**[2)] and **intraregional flights of hundreds kms**[3)] between urban and rural areas

It does not include

- Conventional helicopters
- Small drones (typically with a payload <100 kg; not capable of transporting passengers)
- UAVs
- Long distance (autonomous) aircraft

1) Including short take-off and landing (STOL); 2) Range of AAM flights could be shorter for specific use-cases (e.g., emergency medical service); 3) Range could be longer (up to c. 1000 km) in case of electric conventional aircrafts

Source: Roland Berger

Multiple electric aircraft configurations exist, each with different characteristics that have significant influence on performance

AAM aircraft architectures – Overview

	eVTOL					eSTOL / eCTOL	
	Multicopter	Quadrocopter	Lift & cruise (hybrid)	Tilt-propeller	Tilt-wing	eSTOL	eCTOL
Disc loading[1]	– –	–	~	+	+	++	++
Hoovering efficiency[2]	++	+	~	–	–	– –	– –
Downwash[3] speed & noise level	++	+	~	–	–	– –	– –
Gust resistance and stability	– –	–	~	+	+	++	++
Forward flight speed & efficiency	~60-130 km/h	~130-190 km/h	~130-190 km/h	~140-300 km/h	~140-300 km/h	~140-350 km/h	~300-500 km/h
Approximate range[5]	30-80 km	up to 150 km	up to 300 km	up to 300 km	up to 500 km	up to 800 km	up to 900 km
Approximate payload[6]	~200 kg	up to 500 kg	up to 800 kg	up to 800 kg	up to 800 kg	up to 1,000 kg	up to 2,000 kg
Advantages	• Adapted for short trip with frequent hoovering	• Design accommodating multiple mission types	• VTOL and STOL[4] • No tilting mechanism	• Combination of VTOL capacity and range	• Reduced mass • VTOL and STOL[4]	• Potential greener solution, depending on source of electricity	• Potential greener solution, depending on source of electricity
Disadvantages	• Low range and speed	• Energy consumption in cruise • Complex design	• Mass • Unused propellers • Drag in cruise	• High cost and complexity of the tilting mechanism • Complex maneuvers	• High cost and complexity of the tilting mechanism • Complex maneuvers	• Requires a runway albeit shorter than conventional aircrafts	• Requires conventional runway
Time to market	Fastest certification	n/a	Slower certification	Slowest certification	n/a	n/a	n/a

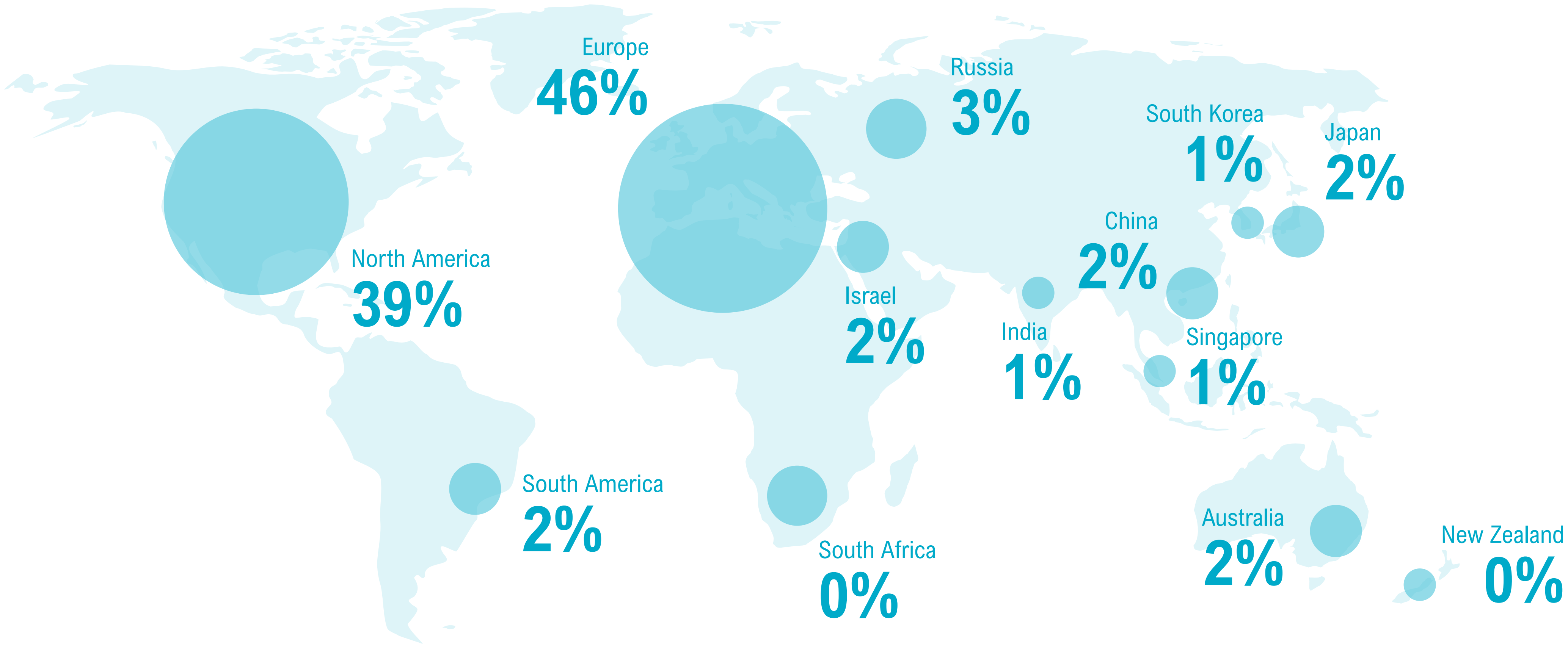
++ Very high + High ~ Neutral – Low – – Very low

1) Disc loading defined as AAM weight divided by total rotor disc area; 2) Lower disc loading generates improved hovering efficiency; 3) Ground-oriented airflow during lift or landing phases; 4) Also possible as short takeoff and landing (STOL)
5) Expected range at commercial launch; 6) Varies according to number of seats for each concept

Source: Desk research, Roland Berger

Over 100 AAM aircrafts are currently in development using new electric (potentially autonomous) conventional and VTOL aircrafts – Europe accounts for 46%

Distribution of ~280 publicly known electrically propelled aircraft programs, Aug 2021[1)2)]



1) Only including developments with first flights from 2010 and major electric concepts; excluding UAVs and purely recreational developments; 2) Percentages may not add up due to rounding

Source: Roland Berger Sustainable Aircraft Database

Adoption of Advanced Air Mobility is driven by social-cultural factors, technology, infrastructure, economics and regulation

Overview of the AAM adoption drivers

	1 Social-cultural	2 Technology	3 Infrastructure	4 Economics	5 Regulation & certification
Criteria	Match with **values, views, expectations** of consumers, citizens and other stakeholders	Technological development of the **aircraft**, the **propulsion** and the **control** of it	Development of **infrastructure** (physical and digital) and **ground transport integration**	Development of **unit economics** compared to alternatives	Maturity of AAM **regulation** and **certification** across regions
Current maturity[1)]	LOW	MEDIUM	LOW	LOW	LOW

1) Based on overall estimation (acknowledging differences between aircrafts and use-cases)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

The adoption drivers for AAM each have their underlying sub-drivers

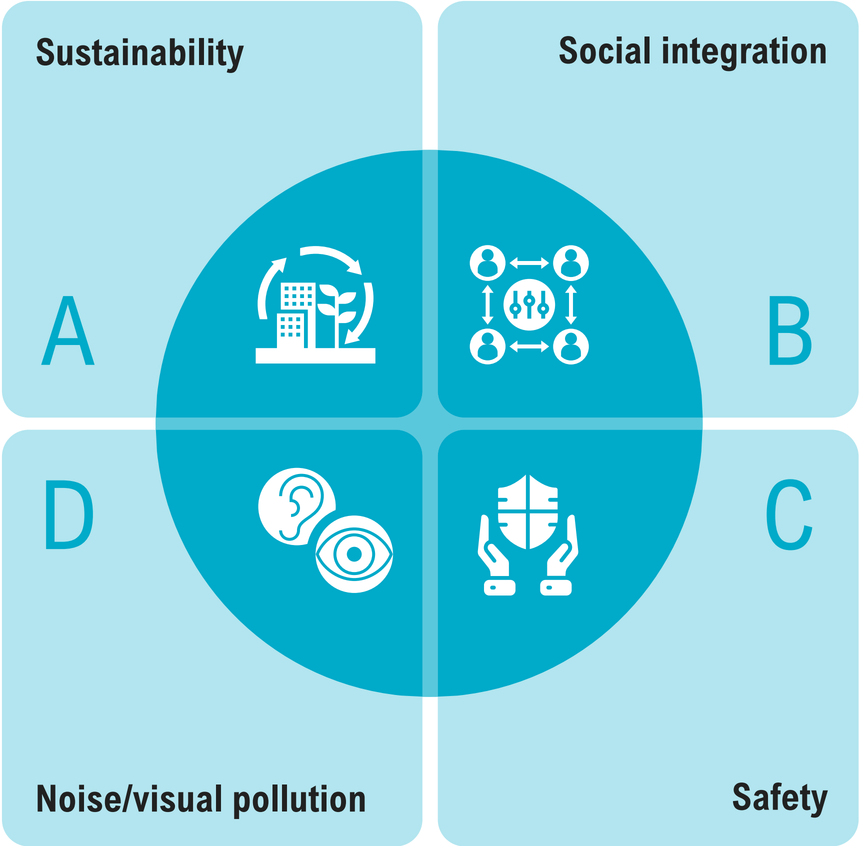
Detailed adoption drivers

Driver	Sub-drivers
1 Social-cultural factors	Sustainability
	Social integration
	Safety
	Noise/visual pollution
2 Techno-logy	Flight technology
	Propulsion technology
	Control technology
3 Infrastructure	Physical and operational infrastructure (e.g. vertiports, energy)
	Digital infrastructure
	Ground transportation integration
4 Economics	Economics
5 Regulation & certification	Aircraft approvals
	Maintenance organization approval
	Operational certificates
	Other regulations

Source: Desk research, Expert Interviews, Workshops, Roland Berger

Sustainability, social integration, safety and noise/visual pollution are crucial social-cultural factors for AAM adoption

AAM adoption drivers: Social-cultural factors



A Sustainability
Providing safe, sustainable, low-noise, green (air) mobility solutions could improve connectivity of regions and replace polluting planes (i.e. relating to emissions and energy)

B Social integration
Social integration (including public acquaintance as part of other modalities) is necessary to complement long-distance and local transport services

C Safety
Safe operations especially in dense urban areas for both passengers and pedestrians are always paramount

D Noise/visual pollution
Noise/visual pollution produced by an AAM aircraft especially around vertiports is influenced by an aircraft's design and the way it is operated

Current maturity[1)]

Expected developments

- Social-cultural factors are mainly driven by **sustainability**, **social integration**, **safety, and noise/visual pollution**
- **Non-passenger applications** (e.g. postal, emergency services) expected to **gain public acceptance faster**, picking up by 2025, helping to **pave the way for passenger application**
- **Piloted applications** to gradually gain acceptance with first commercial services emerging starting 2025 - **autonomous passenger applications** are **not expected** to gain widespread acceptance **before 2035** mainly due to safety concerns
- Increasing **airspace saturation** leading to noise/visual pollution **will most likely decrease public acceptance**

1) Based on overall estimation (acknowledging differences between aircrafts and use-cases)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

Flight, propulsion and control technology are the three areas that drive AAM adoption from a technology point of view

AAM adoption drivers: Technology

Flight technology

- Five key **eVTOL flight architectures** in development: multicopters, quadrocoptors, lift & cruise (hybrid), tilt-propeller, tilt-wing
- Two other **electric flight architectures**: eCTOL, eSTOL

Propulsion technology

- **Electric systems** as key compenents in AAM aircraft
- **Full-electric** and **hybrid** configuration mainly driven by market application (e.g. hybrid for highly frequent missions such as emergency medical services)

Control technology

- **Piloted** vs. **autonomous solutions**
- Autonomous is expected to come first for non-passenger applications in rural areas
- Autonomous for passenger application will likely come in steps

Current maturity[1)]

MEDIUM

Expected developments

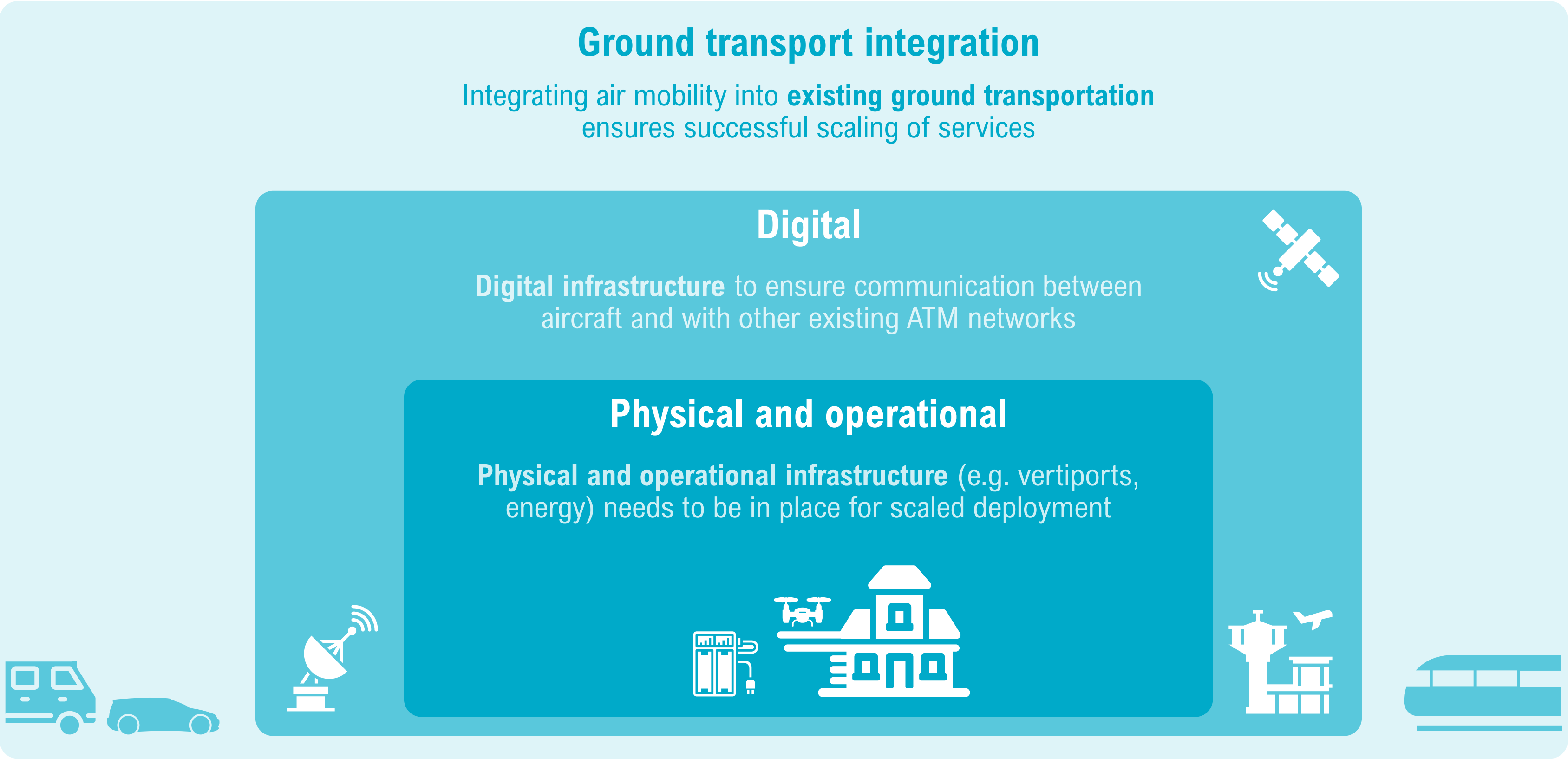
- Different aircraft platforms are being developed from **multicopters** with few mechanics involved, **lift & cruise** solutions with double propulsion to more complex **tilting mechanism**
- Among new technologies, the **electric/hybrid propulsion system** is the key component to improve air mobility economics
- While most technology exists for **autonomous flight system**, the absolute robustness of the system is very difficult to obtain – Nevertheless first pilot should come for **non-passenger application** in safe environment over the next decade
- **Additional autonomous system**, specifically for air traffic management, are expected to come in the 2030s to support crowded airspace coming with mass deployment of air mobility solution

1) Based on overall estimation (acknowledging differences between aircrafts and use-cases)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

AAM requires three levels of infrastructure: physical, digital and ground transport integration

AAM adoption drivers: Infrastructure



1) Based on overall estimation (acknowledging differences between aircrafts and use-cases)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

Current maturity[1)] LOW

Expected developments

- Physical infrastructure picking up **by 2025** with the first commercial **non-passenger** applications
- Infrastructure for **passenger applications** is expected to develop in line with the market, however it is of **higher complexity** in design and operations, and is expected to **pick up** significantly **around 2030**
- Physical infrastructure in **rural areas** is going to develop first due to easier conditions (space, charging, regional airport) and will be paramount even for **urban operations starting around 2025**
- Digital infrastructure for **piloted applications** is already in place today, but must be fine-tuned to better support high-density, low-altitude air mobility
- Digital infrastructure for **autonomous applications** is expected to start developing and collecting more data points at around 2025 with first non-passenger applications

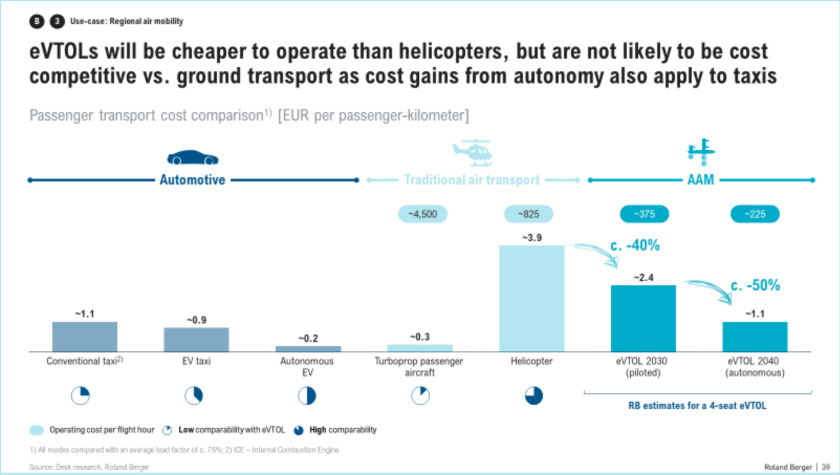
AAM is not likely to be the cheapest alternative, but is expected to be cost-competitive with traditional air transport

AAM adoption drivers: Economics

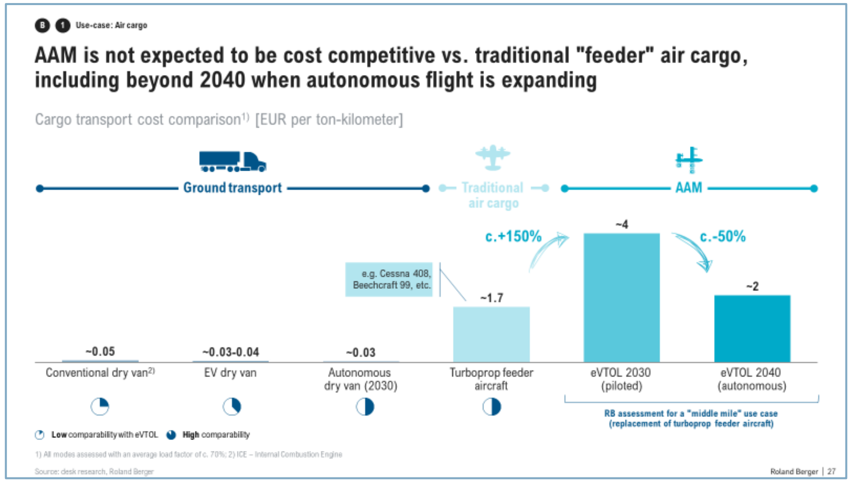
Current maturity[1)]

LOW

PASSENGER



NON-PASSENGER



Expected developments

- Advanced Air Mobility is **not likely to be cost-competitive** to the cheapest alternative
  - **Passenger**: cost of ground transport is expected to decrease as cost gains from autonomy also apply to taxis
    - Advanced Air Mobility is expected to be cost-competitive versus traditional air transport
  - **Non-passenger**: traditional 'feeder' air cargo is expected to be cheaper as result of higher payload per unit versus Advanced Air Mobility
- Advanced Air Mobility needs to be **affordable for the general public** as opposed to being a niche product for the affluent society in order to gain broad traction

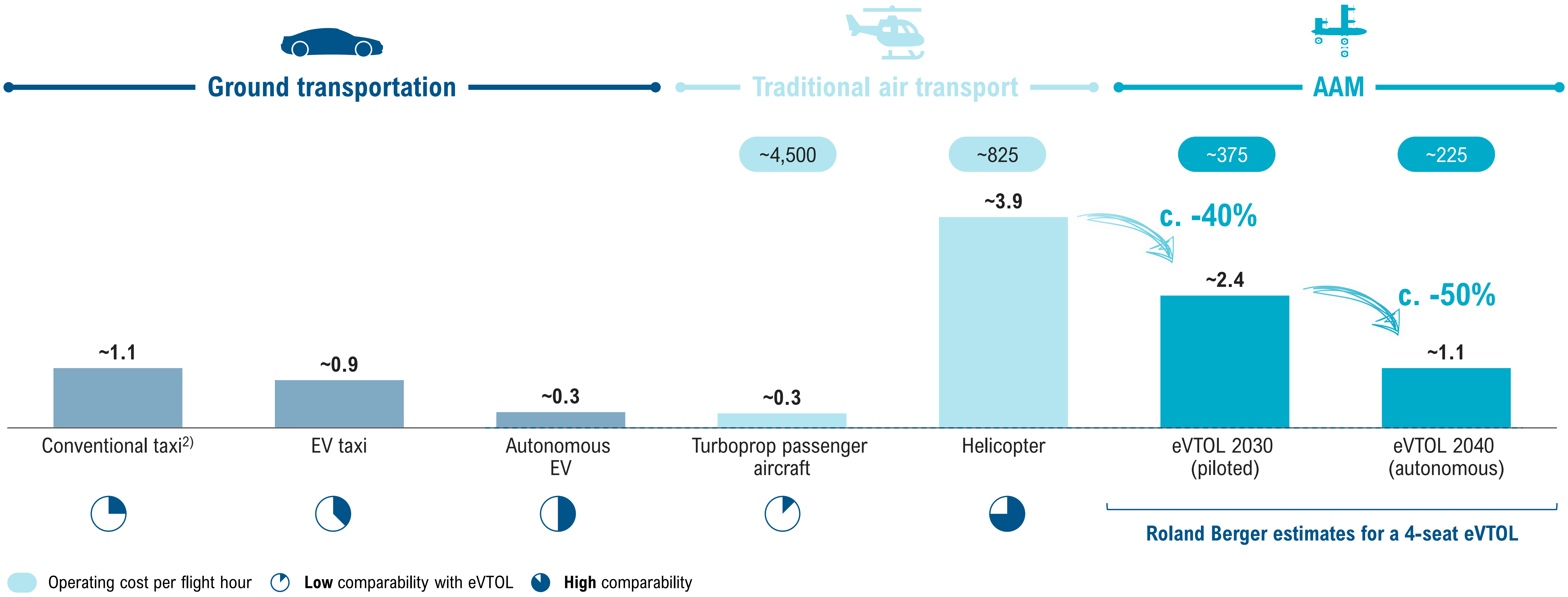
1) Based on overall estimation (acknowledging differences between aircrafts and use-cases)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

Backup: eVTOLs will be cheaper to operate than helicopters, but are not likely to be cost competitive vs. ground transport as cost gains from autonomy also apply to taxis

Passenger transport cost comparison[1)] [EUR per passenger-kilometer]

2030 estimates

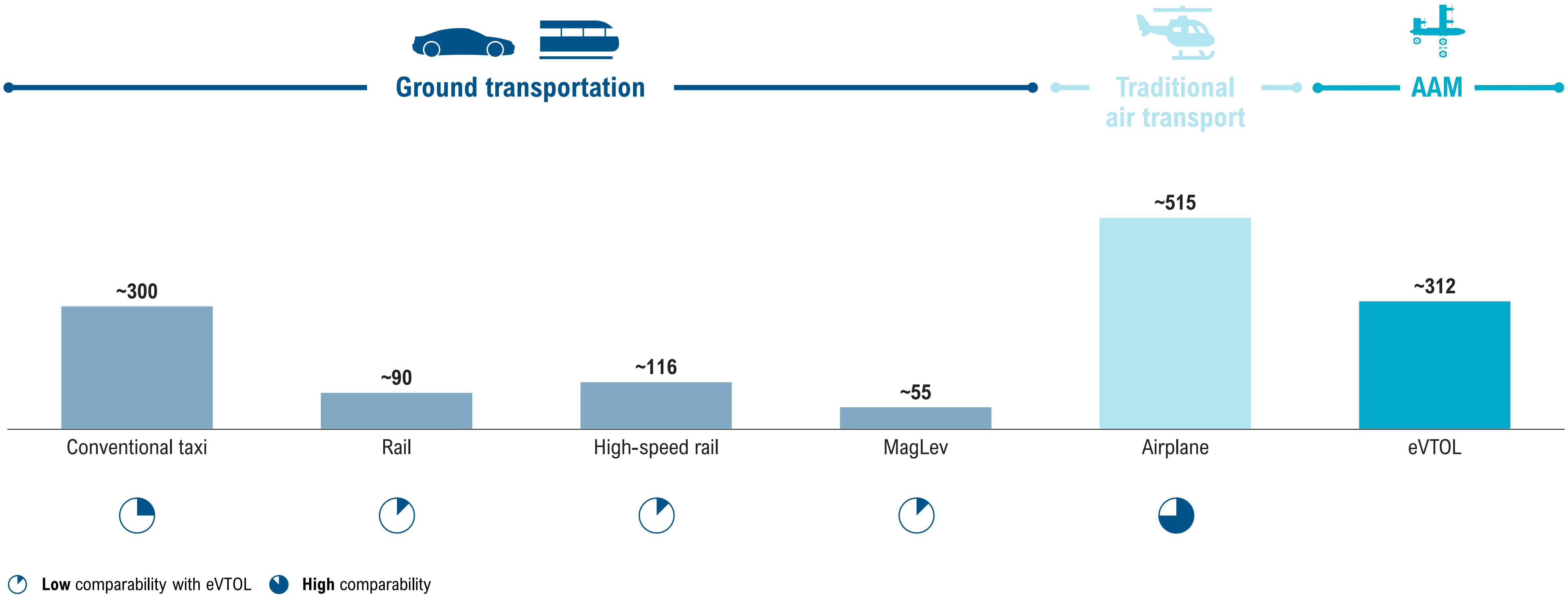


1) All modes compared with an average load factor of c. 75% based on 2021 prices not adjusted for inflation; 2) ICE – Internal Combustion Engine

Source: Desk research, Roland Berger

Backup: eVTOLs are more energy efficient than traditional airplanes but are not likely to be energy competitive vs. ground transport due to high energy usage

Passenger transport cost comparison [Wh per passenger-kilometer]



Source: Desk research, Roland Berger

Required regulatory approvals relate to the aircraft, MRO, operations and various others

Current maturity[1)] LOW

AAM adoption drivers: Regulation & certification

Aircraft

Design Organization Approval (DOA)

- DOA complies with the **requirements of** EASA's Part 21, which contains rules for a company **designing and/or producing aircrafts, aircraft parts,** and **appliances**
- DOA details elements **required for design organization** and **activities** of products such as large aircrafts, engines, small rotorcraft, and sailplanes to ultimately decide whether a company can bring a **safe aircraft** to market

Production Organization Approval (POA)

- POA related procedures are integrated into the EASA **Quality Management System**, which also complies with the requirements of EASA's Part 21
- Under the POA, companies manufacturing products and parts must prove that the **production** and **quality management processes** are in accordance with regulatory standards

Authority must issue a Type Certificate for each aircraft design before to start any commercial operation

MRO

Maintenance Organizational Approval (MOA)

- MOA is a **standard for** the approval of **organizations** that **perform maintenance on aircraft and aircraft components** that are registered in EASA Member States

Operations

Air Operator Certificate (AOC)

- AOCs are **granted by** the relevant authority in each jurisdiction, typically the **National Aviation Authority**
- Main objective of AOC is to ensure **operations are safe and compliant with regulation.** Regulator examines extensively the operator's workforce skills, procedures and operating manuals

Commercial Pilot License (CPL)

- Aviation authority requires **certified pilot to operate manned aircraft**
- Pilot must follow a standard training and demonstrate required capabilities in order to obtain a valid CPL

Other regulations [non-exhaustive]

Air traffic management

- Air traffic **controller** must comply to the EASA regulation

Local regulations

- **Cities** and **local governments** control, at least in part, the develop-ment of the ground infrastructure and operations parameters (e.g. noise level, no fly zone, emission) therefore the development of new routes

Spectrum allocation

- International and national bodies are responsible for **spectrum allocation**, notably to support autonomous system

1) Based on overall estimation (acknowledging differences between aircrafts and use-cases)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

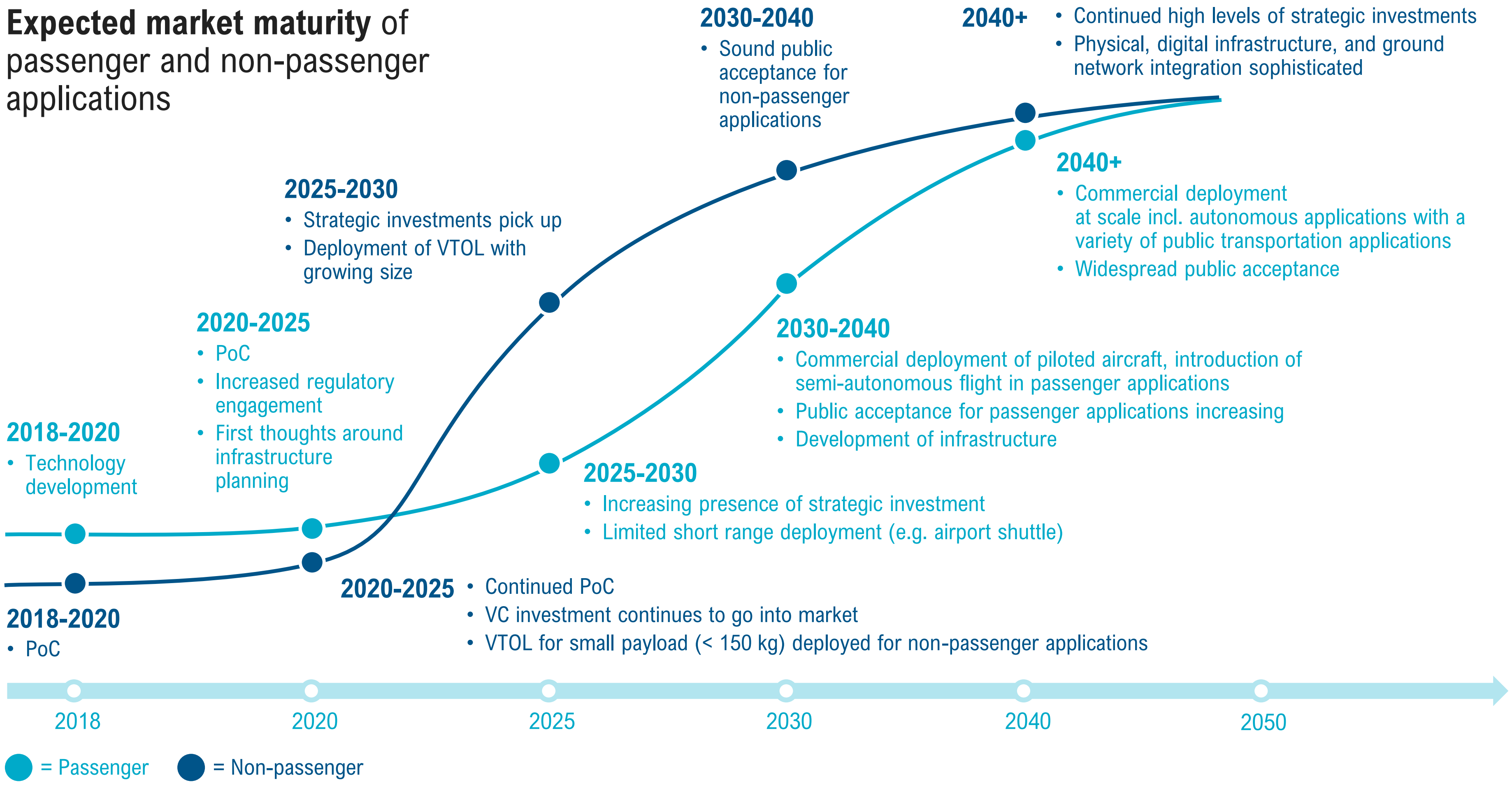
Expected developments

- Regulation and certification work in charge of **Aviation mobility** authorities and **Aerospace manufacturing** (e.g. EASA in Europe)
- China, US and Europe are **defining the market** and consequently regulation and certification
- Regulatory environment is primarily defined at **national level**
- **Risk management** is at the heart of all regulators favoring **non-passenger piloted applications in rural environment**, especially as proof of concept
- Autonomous operation will be proof tested on cargo application first, **autonomous pilot** for passenger applications will follow
- eVTOLs face **certification risks** due to the novelty this market represents in the Air Mobility in terms of both **design, technology** and **use cases**

After 2030-40 more widespread adoption of AAM mobility will take place – Non-passenger transport is expected to have earlier adoption as result of lower barriers

AAM adoption curves

Expected market maturity of passenger and non-passenger applications



- **Selected pilots** for cargo and passenger transport in selected cities already in place
- First **commercial applications** may emerge around 2025 with focus **on cargo** in **rural areas** and first adopter cities (starting with small drone – payload < 150 kg
- **Passenger transport** may start to kick in with piloted aircrafts around 2030 – After 2035 and 2040 widespread adoption of air mobility will take place

Source: Desk research, Expert Interviews, Roland Berger

C. Implications for The Netherlands and Western Europe

Ministerie van Infrastructuur en Waterstaat

A wide variety of passenger and non-passenger applications exist for AAM in The Netherlands and Western Europe

Potential AAM use-cases (non-exhaustive)

PASSENGER USE CASES

Scheduled

- Regional air mobility
- Air traffic electrification
- Airport shuttle
- Airline feeder flights

On-demand

- Emergency medical services (air ambulance)
- Tourism shuttle
- Intra-city air taxi
- Commuter air taxi

Other

- Regional airline routes1)
- Offshore services (e.g. windmill parks)

NON-PASSENGER USE CASES

Cargo transportation

- Transportation of air cargo
- Intralogistics
- Emergency medical services (medical supply, live organs, lab samples)
- Remote supply (e.g. scarcely populated areas)
- Offshore services (cargo)

Other

- Site/area surveying
- University research
- Law enforcement
- Construction support
- Firefighting
- Military applications

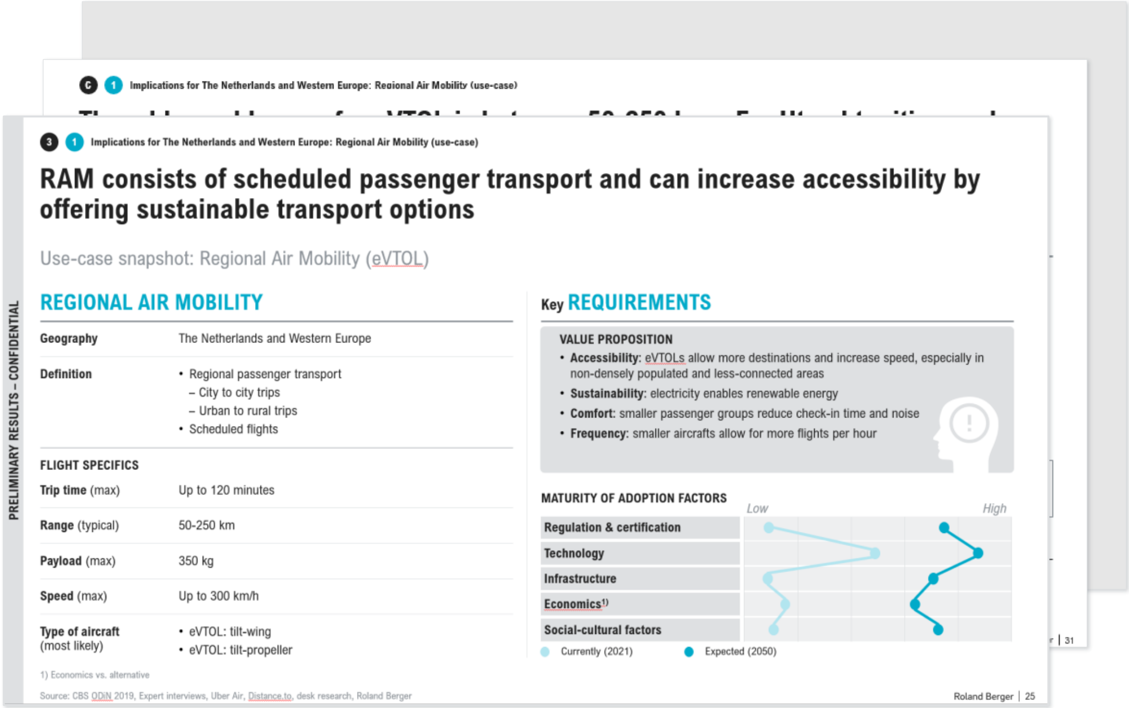
1) Once sufficient ranges can be achieved

Source: Roland Berger

Two selected use-cases have been detailed: regional air mobility up to 250 km (eVTOL) and Air Traffic Electrification up to 1,000 km (eSTOL and eCTOL)

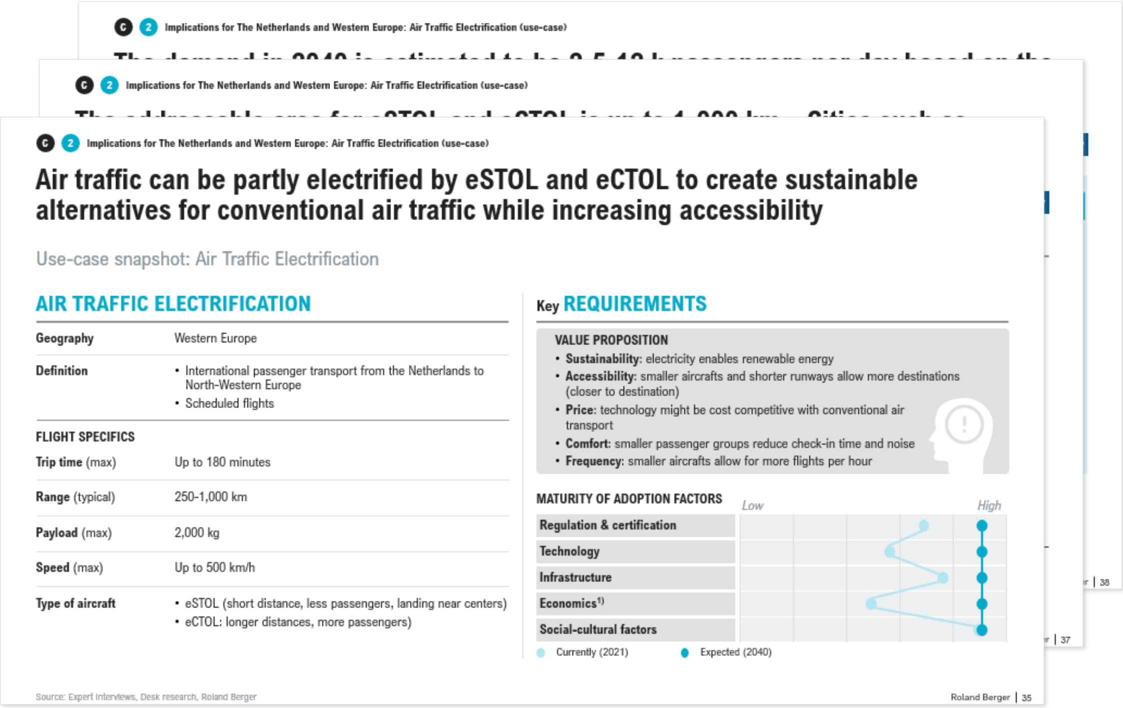
Selected use-cases

1 Regional air mobility (up to 250 km range): eVTOL



Including use case specification: tourism shuttle for the Efteling

2 Air traffic electrification (250-1,000 km range): eSTOL and eCTOL



RAM consists of scheduled passenger transport and can increase accessibility by offering sustainable transport options

Use-case snapshot: Regional Air Mobility (eVTOL)

REGIONAL AIR MOBILITY

Geography	The Netherlands and Western Europe
Definition	• Regional passenger transport – City to city trips – Urban to rural trips • Scheduled flights

FLIGHT SPECIFICS

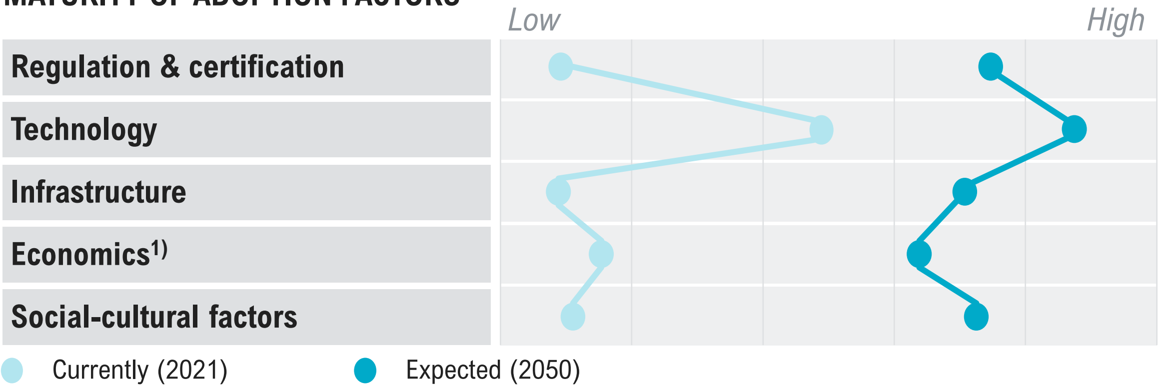
Trip time (max)	Up to 120 minutes
Range (typical)	50-250 km
Payload (max)	350 kg
Speed (max)	Up to 300 km/h
Type of aircraft (most likely)	• eVTOL: tilt-wing • eVTOL: tilt-propeller

Key REQUIREMENTS

VALUE PROPOSITION

- **Accessibility**: eVTOLs allow more destinations and increase speed, especially in non-densely populated and less-connected areas
- **Sustainability**: electricity enables renewable energy
- **Comfort**: smaller passenger groups reduce check-in time and noise
- **Frequency**: smaller aircrafts allow for more flights per hour

MATURITY OF ADOPTION FACTORS



1) Economics vs. alternative

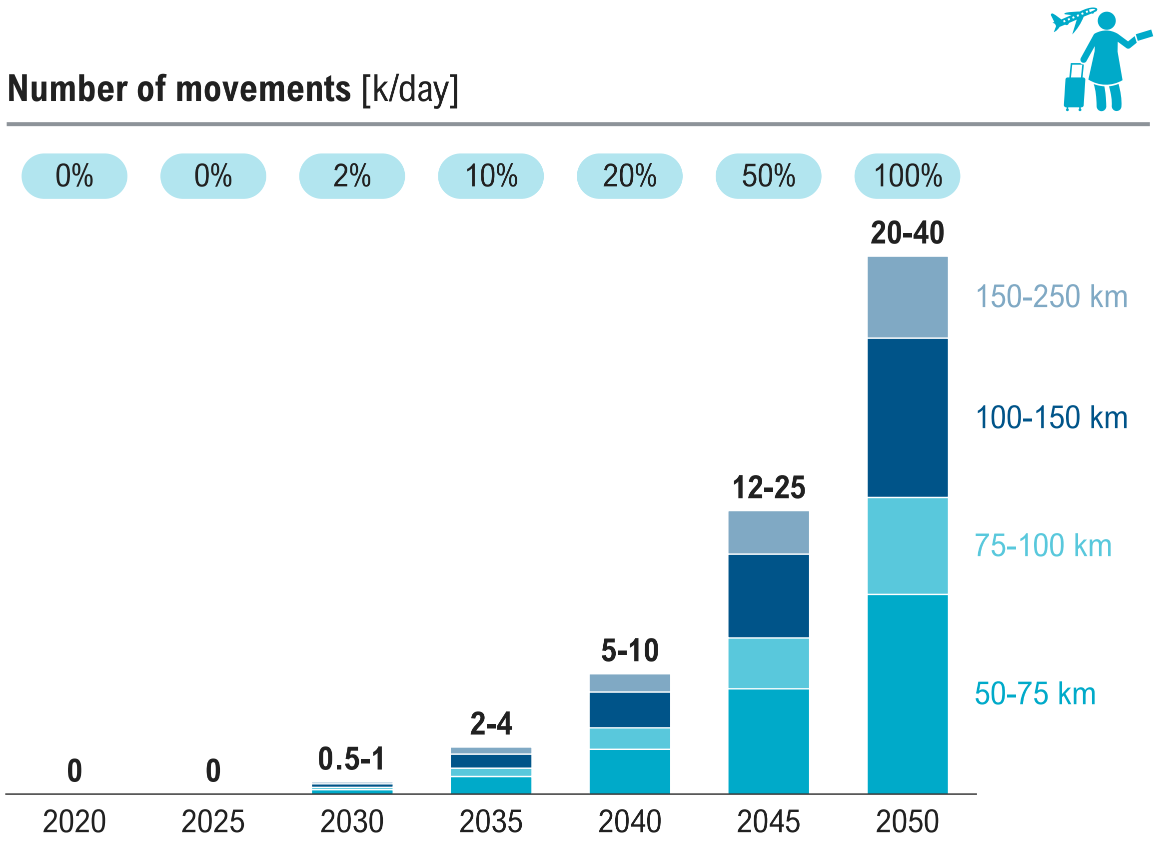
Source: Expert interviews, Desk research, Roland Berger

It is estimated that 20-40 k passengers per day will use eVTOL transport in 2050 for which 700-1,400 aircrafts are required, predominantly tilt wing

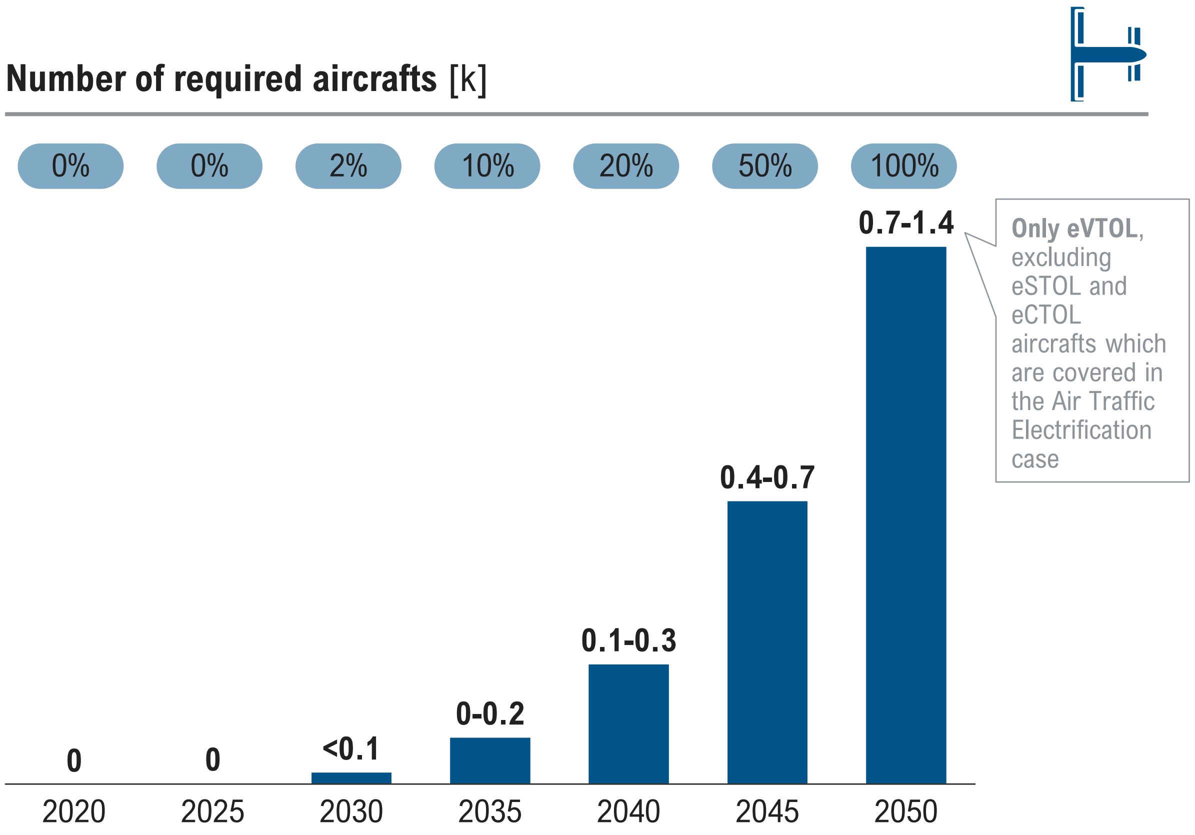
Market sizing results RAM

Estimation – Assumptions apply[1)]

Number of movements [k/day]



Number of required aircrafts [k]



x% Estimated ramp up to 2050 rate in given year

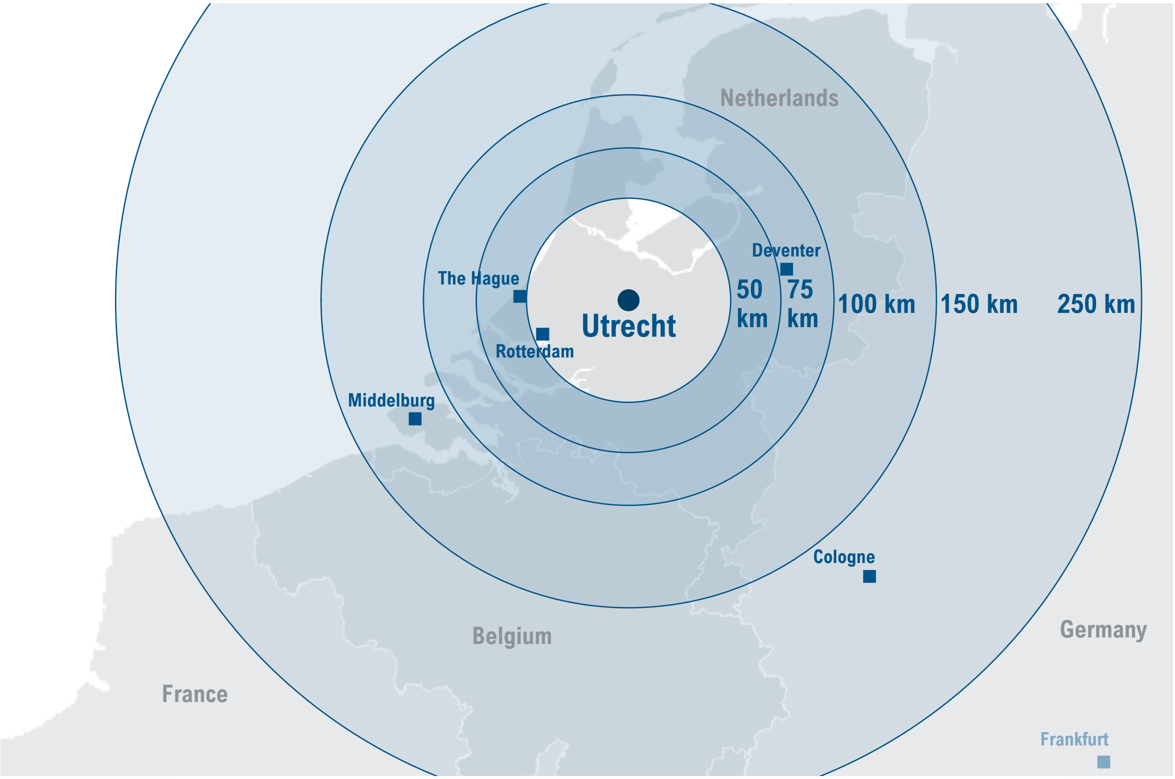
1) Assumptions include that the adoption drivers (social-cultural, technology, infrastructure, economics and regulation) are fully met, and a 3% switch rate if time is 100% reduced

Source: CBS ODiN 2019, Expert interviews, Uber Air, Distance.to, Desk research, Roland Berger

The addressable area for eVTOL is between 50-250 km – For Utrecht, cities such as The Hague, Deventer, Middelburg and Cologne would be in range

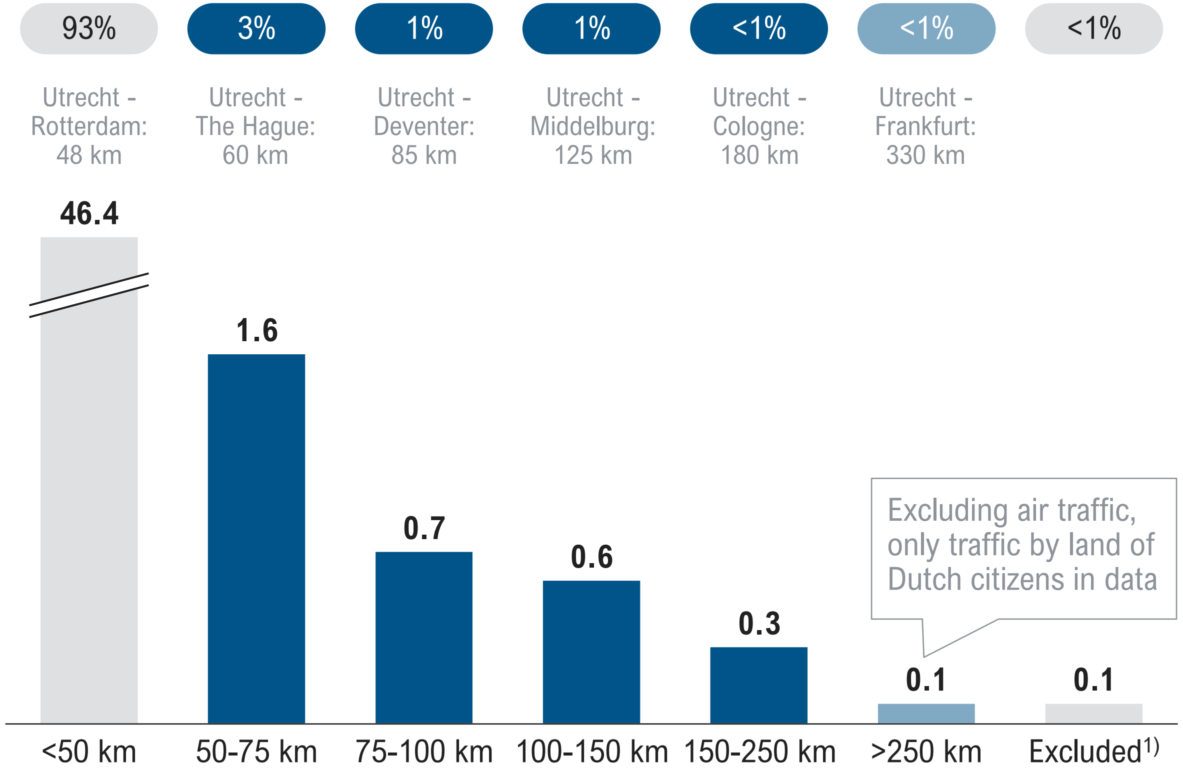
Addressable area and associated movements: Regional Air Mobility

Addressable area of a station in Utrecht



Addressable eVTOL | Addressable eSTOL/eCTOL

Movements in, from and to the Netherlands [m/day]



Addressable eVTOL | Addressable eSTOL/eCTOL | Not addressable

1) Tours (departure address same as arrival address, e.g., hiking) and movements with intermediate stops (e.g., package delivery) excluded

Source: CBS ODiN 2019, Distance.to, Roland Berger

20-40 k passengers per day are expected to use eVTOLs by 2050 – The switch rate is expected to be higher for longer distances as result of higher time savings

Market sizing movements (demand): Regional Air Mobility

Assuming adoption drivers are fully met !

Estimation – Assumptions apply

Range	Movements [m/day]	Share	Example travel	Aircraft type (most likely)	Typical time saving	Estimated switch rate	Est. demand 2050[2] [k movements/day]
<50 km	46.4	93%	Utrecht - Rotterdam: 48 km	n.a.	~20%	0%	0
50-75 km	1.6	3.2%	Utrecht – The Hague: 60 km	eVTOL[3]	~25%	0.5-1%	8-15
75-100 km	0.7	1.5%	Utrecht – Deventer: 85 km	eVTOL[3]	~25%	0.5-1%	4-8
100-150 km	0.6	1.2%	Utrecht – Middelburg: 125 km	eVTOL[3]	~50%	1-2%	6-12
150-250 km	0.3	0.7%	Utrecht – Cologne: 180 km	eVTOL[3]	~50%	1-2%	3-6
>250 km	0.1 (Substitution of land traffic only)	0.2%	Utrecht – Frankfurt: 330 km	eSTOL	~70%	1.5-2.5%	1-2 (Included in the Air Traffic Electrification use case (p.37)
Excluded	0.1	0.3%		N.a.	N.a.	N.a.	N.a.
Source	Movements in ODiN 2019 (CBS), extrapolated to entire Netherlands			Expected most (time) efficient aircraft	Assumptions apply[1]	! Assuming 3% switch rate if time is 100% reduced	

∑ 20-40 k

1) Assuming pre/post travel 15 min each, lift-off/landing 2 min each, speed 280 (tilt wing) km/h or 450 km/h (eCTOL), compared to car; 2) 2040 for eSTOL; 3) Tilt-wing assumed for eVTOL calculations

Source: CBS ODiN 2019, Expert interviews, Uber Air, Distance.to, Desk research, Roland Berger

700 to 1,400 eVTOLs are expected for RAM in 2050 based on the estimated 20-40 k eVTOL movements in 2050

Market sizing required aircrafts (supply): Regional Air Mobility

Estimation – Assumptions apply

Range	Est. demand 2050[1] [k movements/day] ∑ 20-40 k	Est. peak demand 2050 [k movements/h]	Aircraft type (most likely)	Capacity [passenger]	Occupancy at peak	Turn around time [min]	Required aircrafts in 2050[1] [k] ∑ 0.7-1.4 k
<50 km	0	0	n.a.	n.a.	n.a.	n.a.	0
50-75 km	8-15	0.6-1.2	eVTOL[2]	5	67%	30	0.2-0.5
75-100 km	4-8	0.3-0.6	eVTOL[2]	5	67%	30	0.1-0.3
100-150 km	6-12	0.5-1	eVTOL[2]	5	67%	30	0.2-0.5
150-250 km	3-6	0.2-0.5	eVTOL[2]	5	67%	30	0.1-0.3
>250 km	1-2	0.1-0.2	eSTOL	8	80%	45	<0.1 (Included in the Air Traffic Electrification use case (p.38))
Excluded	N.a.		N.a.	N.a.	N.a.	N.a.	
Source		~50% of passengers travel within the 4 peak hours (based on movements in ODiN 2019 of CBS)	Expected most (time) efficient aircraft	AAMs typically 4-6, eSTOL/ eCTOL ~8	Some inefficiency in occupancy	Time for charging (expert interview based)	

1) 2040 for eSTOL; 2) Tilt-wing assumed for eVTOL calculations

Source: CBS ODiN 2019, Expert interviews, Uber Air, Desk research, Roland Berger

As an example, effects and considerations of eVTOL as a tourism shuttle to the Efteling have been assessed – Other use cases (e.g. Wadden) to be assessed

RAM use case specification: tourism shuttle for the Efteling

Rough estimation – Assumptions apply

RAM specification: Efteling

- Efteling has **strong growth ambitions**: 7 m visitors/y
  - Pre-COVID (2019) 5 m visitors/y
- **Peak periods** with 37 k/day visitors put pressure on nearby villages and highways
- **eVTOL might be a solution to future congestion problems**

Expected VOLUMES on peak days

City	Visitor movements/ day total	Commuter switch rate	Visitor movements/ day eVTOL	Required eVTOLs
Amsterdam	3,000	~1%	30	3
The Hague	2,500	~1%	25	2.4
Groningen	500	~1.5%	8	1.1
Almere	750	~1%	8	0.8
Brussels	1,600	~1.5%	23	2.4
Antwerp	650	~1%	6	0.6
Gent	250	~1.3%	3	0.3
Total			**86** + 17	**9** + 1.4

Assumptions
- 50 k visitors on peak days assumed (in line with growth ambition)
- Movements/day by city based on known NL/BE visitor split and city sizes (with a correction for distance)
- Only largest cities in NL/BE for which eVTOL safes significant time given, grey rows excluded in final calculation due to low eVTOLs
- Commuter switch rate, eVTOL movements and required eVTOLs calculated like RAM eVTOL sizing

Key EFFECTS and CONSIDERATIONS

- 86 movements/day by eVTOL will lead to a reduction of 17 cars / 34 car movements (assuming c.2.5 passengers per car)
- Since alternative modes of transport (public transport, car) also probably depend on renewable energy sources by 2050
- Estimates of AAM energy consumption vary[1], but the range **0.5-1.5 kWh/km seems plausible for a ~100 km distance**, a flight between Efteling and Amsterdam (~80 km) then requires 40-120 kWh, whereas the trip by electric car requires 17 kWh[2]
- **Flexible allocation**: eVTOLs can be used for intercity/work transport on weekdays, and for tourism in the weekend
- In the calculation a commuter switch rate of ~1-1.5% was used, **switch rate could become larger** if Efteling would focus on eVTOL promotion and offer combined transport and entrance tickets

1) Depending on source, aircraft type and distance, significant energy consumption during lift-off and landing results in more efficiency on longer distances; 2) Assuming 106 km (distance Google Maps) and 16 kWh per 100 km (Tesla Model 3)

Source: Efteling, Stec Groep, Looopings, Expert interviews, Uber Air, Distance.to, Shashank Sripad et al., Alessandro Bacchini et al., Tesla, Desk research, Roland Berger

Air traffic can be partly electrified by eSTOL and eCTOL to create sustainable alternatives for conventional air traffic while increasing accessibility

Use-case snapshot: Air Traffic Electrification

AIR TRAFFIC ELECTRIFICATION

Geography	Western Europe
Definition	• International passenger transport from the Netherlands to North-Western Europe • Scheduled flights

FLIGHT SPECIFICS

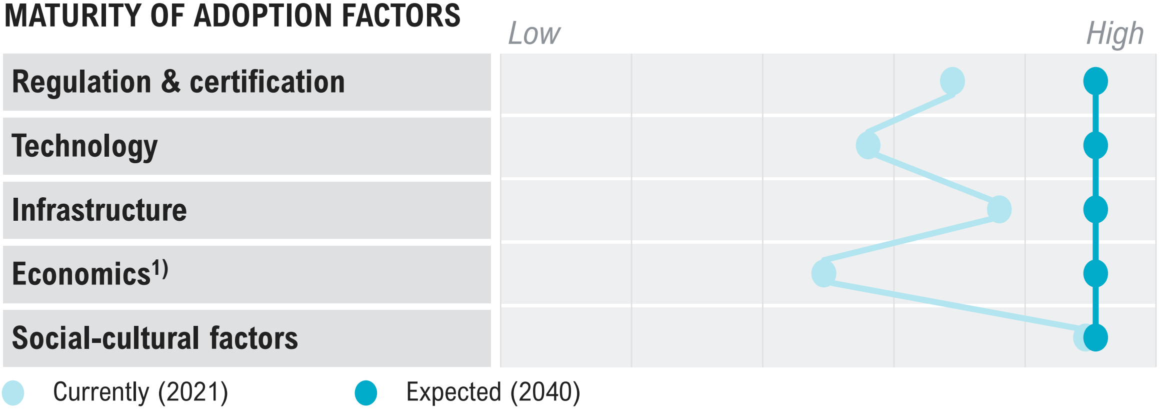
Trip time (max)	Up to 180 minutes
Range (typical)	250-1,000 km
Payload (max)	2,000 kg
Speed (max)	Up to 500 km/h
Type of aircraft	• eSTOL (short distance, less passengers, landing near centers) • eCTOL: longer distances, more passengers)

Key REQUIREMENTS

VALUE PROPOSITION

- **Sustainability**: electricity enables renewable energy
- **Accessibility**: smaller aircrafts and shorter runways allow more destinations (closer to destination)
- **Price**: technology might be cost competitive with conventional air transport
- **Comfort**: smaller passenger groups reduce check-in time and noise
- **Frequency**: smaller aircrafts allow for more flights per hour

MATURITY OF ADOPTION FACTORS



Source: Expert interviews, Desk research, Roland Berger

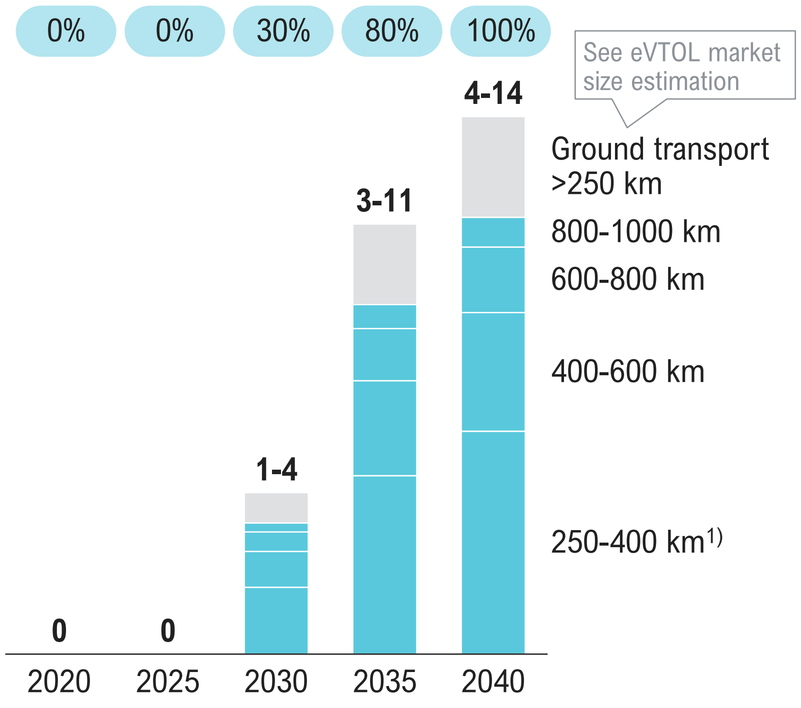
It is estimated that 4-14 k passengers per day will use eSTOL and eCTOL transport in 2040 for which 110-310 aircrafts are required

Market sizing results eSTOL and eCTOL

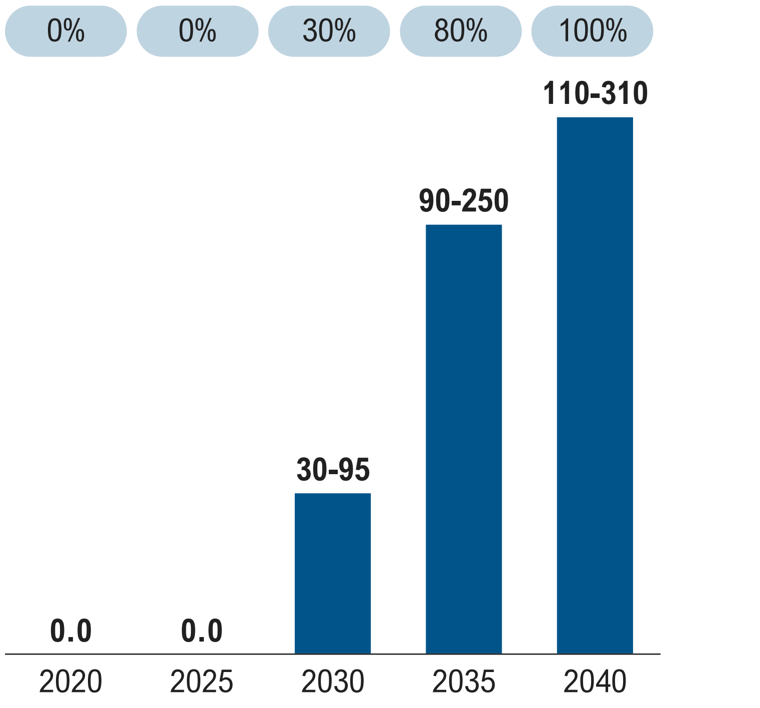
! Uncertainty: adoption strongly influenced by regulation

Estimation – Assumptions apply

Number of movements [k/day]

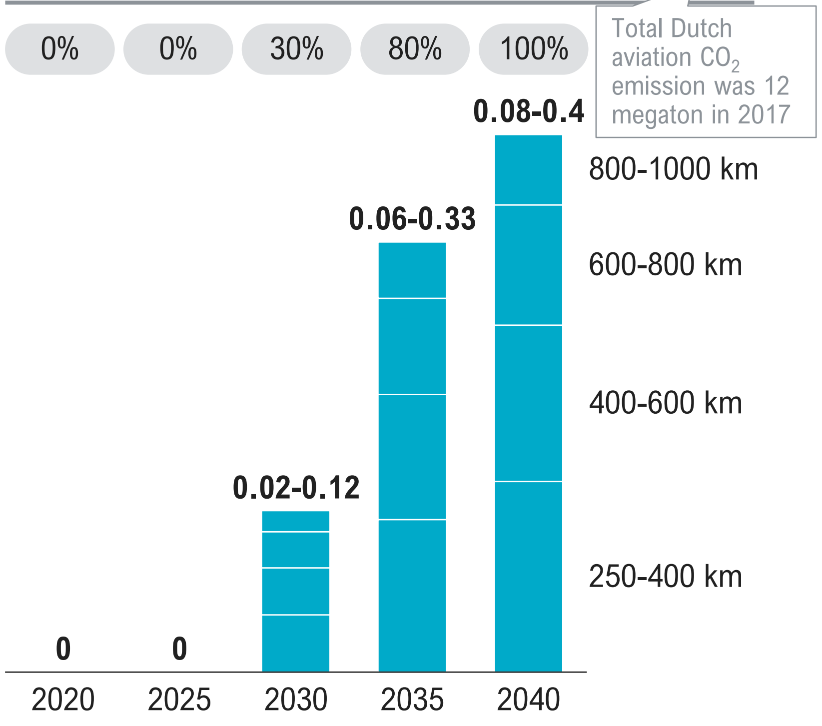


Number of required aircrafts [#]



Assumption: <600 km: eSTOL (more landing flexibility), >600 km: eCTOL (less energy consumption)

Emission reduction [megaton CO_2/year]



Assuming 200 gr CO_2/passenger kilometer for conventional airplanes (rough estimation CROW), no emissions for eSTOL/eCTOL and no emissions for ground transport (since cars will also be electric)

x% Estimated ramp up to 2050 rate in given year

1) Ranges <250 km ignored since air traffic movements in this range are limited

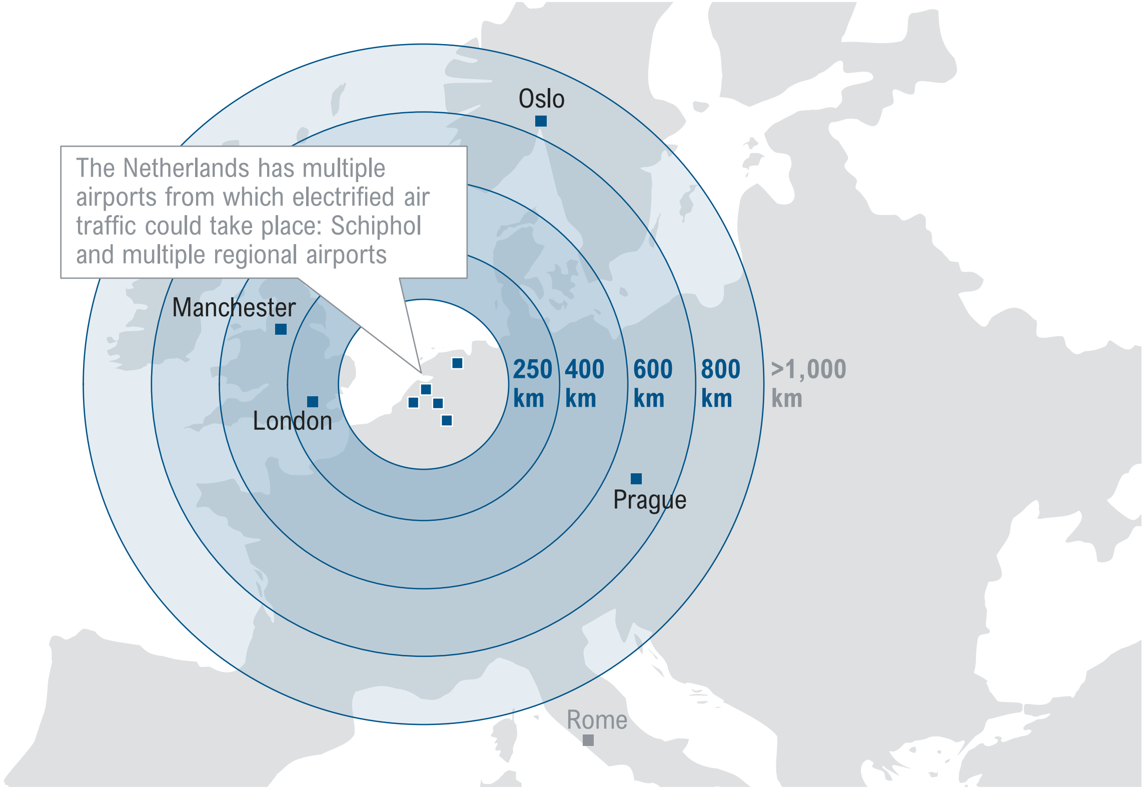
Source: CBS, Expert interviews, CROW, Groene11, Desk research, Roland Berger

The addressable area for eSTOL and eCTOL is up to 1,000 km – Cities such as London, Manchester, Prague and Oslo would be in range

Addressable area and associated movements: Air Traffic Electrification

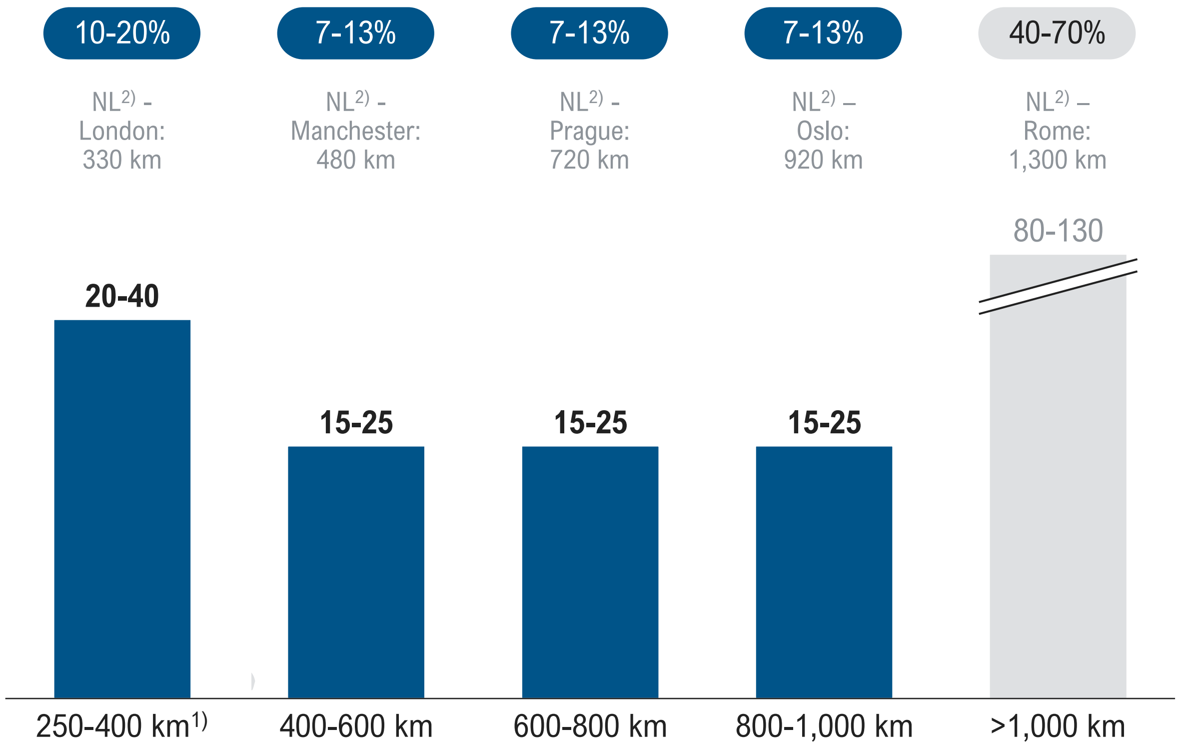
Estimation – Assumptions apply

Addressable area of a station in Utrecht



Addressable eSTOL/eCTOL | Not addressable

Movements air traffic from and to the Netherlands [k/day]



Addressable eSTOL/eCTOL | Not addressable

1) Ranges <250 km ignored since air traffic movements in this range are limited; 2) Calculation based on Schiphol

Source: CBS, Expert interviews, Desk research, Roland Berger

The demand in 2040 is estimated to be 2.5-12 k passengers per day based on the current number of movements and a switch rate between 0% and 20%

Market sizing movements (demand): Air Traffic Electrification

! Uncertainty: adoption strongly influenced by regulation

Estimation – Assumptions apply

Range	Movements air traffic [k/day]		Example travel	Assumed aircraft	Estimated switch rate	Est. demand 2040 [k movements/day]
250-400 km[2)]	20-40	10-20%	NL[3)] - London: 330 km, 65 min	eSTOL	5-20%	1.5-6
400-600 km	15-25	7-13%	NL[3)] - Manchester: 480 km, 80 min	eSTOL	5-15%	1-3
600-800 km	15-25	7-13%	NL[3)] - Prague: 720 km, 85 min	eCTOL	1-10%	0.2-2
800-1,000 km	15-25	7-13%	NL[3)] - Oslo: 920 km, 110 min	eCTOL	0-5%	0-1
>1,000 km	80-130	40-70%	NL[3)] - Rome: 1,300 km, 130 min	Conventional aircraft	0%	0
Source	Based on 72 m air traffic passengers in the Netherlands in 2019 (CBS) and ~10% share per range assumed[1)]		Time based on current time required for a direct flight according (website KLM)	Assumption: <600 km: eSTOL (more landing flexibility), >600 km: eCTOL (less energy consumption)	Assumed (excluding potential regulation effects)	

∑ 2.5-12 k

1) ~15% for 250-400 km assumed because of large volumes between Amsterdam and London; 2) Ranges <250 km ignored since air traffic movements in this range are limited; 3) Calculation based on Schiphol

Source: CBS, KLM, Expert interviews, Desk research, Roland Berger

60-260 required eSTOLs and eCTOLs are expected for Air Traffic Electrification in 2040 based on the estimated 2.5-12 k eSTOL and eCTOL movements in 2040

Market sizing required aircrafts (supply): Air Traffic Electrification

! Uncertainty: adoption strongly influenced by regulation

Estimation – Assumptions apply

Range	Est. demand 2040 [k movements/day]	Assumed aircraft	Capacity [passenger]	Occupancy at peak	Turn around time [min]	Required aircrafts in 2040
250-400 km[1]	1.5-6	eSTOL	8	80%	45	30-130
400-600 km	1-3	eSTOL	8	80%	45	30-80
600-800 km	0.2-2	eCTOL	16	80%	45	3-30
800-1,000 km	0-1 (∑ 2.5-12 k)	eCTOL	16	80%	45	0-20 (∑ 60-260)
>1,000 km	0	Conventional aircraft	n.a.	n.a.	n.a.	0
Source		Assuming <600 km eSTOL (landing flexibility) and >600 km: eCTOL (range, energy consumption)	8 for eSTOL assumed, 16 for eCTOL (expert interview and Desk research)	Average occupancy of air flights in 2019 (CBS)	~30-60 minutes for charging (expert interviews)	

1) Ranges <250 km ignored since air traffic movements in this range are limited

Source: CBS, Expert interviews, Desk research, Roland Berger

D. Required actions for the government and the top sectors

Ministerie van Infrastructuur
en Waterstaat

The government's key responsibilities are regulation, infrastructure and social-cultural factors while the top sectors must focus on technology and economics

AAM adoption drivers and different roles

	1 Social-cultural	2 Technology	3 Infrastructure	4 Economics	5 Regulation & certification
Criteria	Match with **values, views, expectations** of consumers, citizens and other stakeholders	Technological development of the **aircraft**, the **propulsion** and the **control** of it	Development of **infrastructure** (physical and digital) and **ground transport integration**	Development of **unit economics** compared to alternatives	Maturity of AAM **regulation** and **certification** across regions
Role	**Government[1)]**	Government[1)]	**Government[1)]**	Government[1)]	**Government[1)]**
	Top sectors	**Top sectors**	Top sectors	**Top sectors**	Top sectors

Leading role (bold) | Smaller role (incl. no role)

1) Most likely via the Ministry of Infrastructure and Water Management

Source: Desk research, Expert Interviews, Workshops, Roland Berger

There is a longlist of actions required to successfully develop Advanced Air Mobility in The Netherlands and Western Europe

Identified actions

Area	Action	Gov.	Top sec.
1 Social-cultural factors	Facilitate **public debate** on AAM (e.g. by bringing the right parties together and communicate/inform about the topic)	Leading role	Leading role
	Engage with **local communities** and end-users to grasp everyone's interests and opinions	Leading role	Smaller role
	Enlarge **capacity** at the Ministry and provinces to increase knowledge	Leading role	Smaller role
	Ensure a **human capital agenda** to develop talent required for AAM (e.g. engineers)	Leading role	Leading role
2 Techno-logy	Work with high tech (e.g. HTSM[1]), energy, aviation and automotive industries to **promote innovations** in new aircraft technologies, lightweight materials and rapid aircraft charging	Smaller role	Leading role
	Monitor **technological developments** (e.g. hydrogen and e-fuels) to ensure usage of latest innovations	Smaller role	Leading role
	Ensure knowledge development by **building documentation**	Smaller role	Leading role
3 Infra-structure	Determine **required infrastructure** (e.g. vertiports, energy infrastructure) through the Netherlands that supports the realization of required infrastructure (incl. retaining current infrastructure)	Leading role	Leading role
	Examine how to **integrate different air traffic types** (i.e. slower vs fast air traffic: AAM vs. conventional aircrafts)	Smaller role	Leading role
	Realize **hubs** (e.g. vertiport Twente)	Leading role	Smaller role
	Connect stakeholders to **interlink road traffic and AAM**	Leading role	Leading role
	Leverage strong position of The Netherlands in specific areas (e.g. charging infrastructure)	Smaller role	Leading role
4 Economics	Stimulate (technology) **investments** into the field of AAM	Smaller role	Leading role
	Support innovations and scale to make AAM more **cost-competitive** versus other mobility types (e.g. via subsidies)	Leading role	Smaller role
5 Regulation & certification	Organize **international collaboration** to ensure safely adapting AAM aircraft certification and to develop AAM airspace policies and regulation	Leading role	Leading role
	Ensure **capacity at the regulatory bodies** (e.g. EASA) to smoothen and accelerate the regulatory approvals	Leading role	Smaller role
	Specify **required certifications and regulations** for AAM to be in The Netherlands and Western-Europe (e.g. eco-slots for part of the flight movements)	Leading role	Smaller role
1-5 Over-arching	Develop **scenarios** in more detail to define how and when AAM affects decision making (incl. effects of potential closure of airports on success of AAM)	Leading role	Smaller role
	Support the development of the **AAM ecosystem**	Leading role	Leading role
	Strengthen the position of **the Netherlands**, but cooperate internationally to leverage knowledge	Smaller role	Leading role
	Identify the **added-value** of each top sector to AAM	Smaller role	Leading role
	Determine the government's **directing function**	Leading role	Smaller role

Leading role | Smaller role (incl. no role)

1) High Tech Systems & Materials

Source: Desk research, Expert Interviews, Workshops, Roland Berger

Concrete next steps are identified for the government and top sectors to accelerate development of Advanced Air Mobility in the short-term

Concrete next steps for the government and top sectors

Action	Next steps	Gov.	Top sec.
Program further research on AAM	• Determine the government's directing function and long-term goals	Leading	Smaller
	• Define how and when AAM affects decision making	Leading	Smaller
	• Explore other use cases for AAM (e.g. Waddengebied)	Leading	Smaller
Research public opinion on AAM	• Facilitate public debate on AAM, by communicating and informing about the topic	Leading	Leading
	• Engage with local communities and end-users to grasp everyone's interests and opinions	Leading	Leading
	• Align ambitions with values, views, expectations of consumers, citizens and other stakeholders	Leading	Leading
Bring together relevant stakeholders to accelerate AAM technology development	• Identify the added-value of each top sector to AAM	Smaller	Leading
	• Triple Helix – academia and knowledge institutes, industry and government	Leading	Leading
	• Support development of the AAM ecosystem	Leading	Leading
Stimulate research on AAM	• Support innovation to accelerate AAM development by subsidies	Leading	Smaller
	• Map existing subsidies that can be used for AAM	Leading	Smaller
	• Stimulate (technology) investments into the field of AAM	Smaller	Leading
Develop required AAM regulations with EASA	• Dutch government can take the lead in Europe regarding AAM regulation & certification	Leading	Leading
	• Ensure uniform regulations within Europe	Leading	Leading
Map infrastructure requirements for AAM in NL	• Determine required infrastructure through the Netherlands	Leading	Smaller
	• Build a roll-out plan that supports the realization of required infrastructure	Leading	Smaller

x Leading role x Smaller role (incl. no role)

Source: Desk research, Expert Interviews, Workshops, Roland Berger

Roland Berger