



Accelerating
the future
of aerospace

Promising first deployments of hydrogen-powered aircraft operations in the European commercial flight network

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Problem



Airlines require assurance of adequate infrastructure before investing in hydrogen aircraft



Airports require long-term airline commitments before investing in hydrogen infrastructure

Which origin-destination (OD) airport pairs have the highest potential to become early adopters of hydrogen aircraft operations in the timeframe of 2035?

- What criteria are essential?
- How does the potential evolve in 2040?

TRANSCEND Aircraft⁶

2035+

Regional



Based on the ATR 42-600

| Metric | Value |
|--------------|-----------|
| Design Range | 1000 km |
| Seats | 50 |
| EIS | 2035 |
| Hydrogen | Fuel Cell |

Small Medium Range
Single Aisle



Based on the A321-Neo

| Metric | Value |
|--------------|------------------------|
| Design Range | 2000 NM |
| Seats | 176 |
| EIS | 2035 |
| Hydrogen | Combustion + Fuel Cell |

2040+

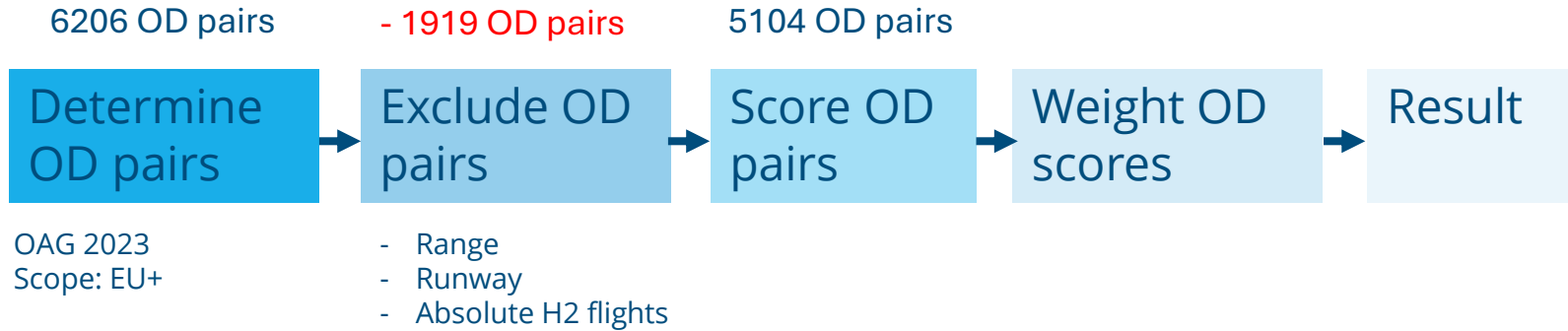
Small Medium Range
Twin Aisle



Based on the B787-8

| Metric | Value |
|--------------|------------|
| Design Range | 2000 NM |
| Seats | 300 |
| EIS | 2040 |
| Hydrogen | Combustion |

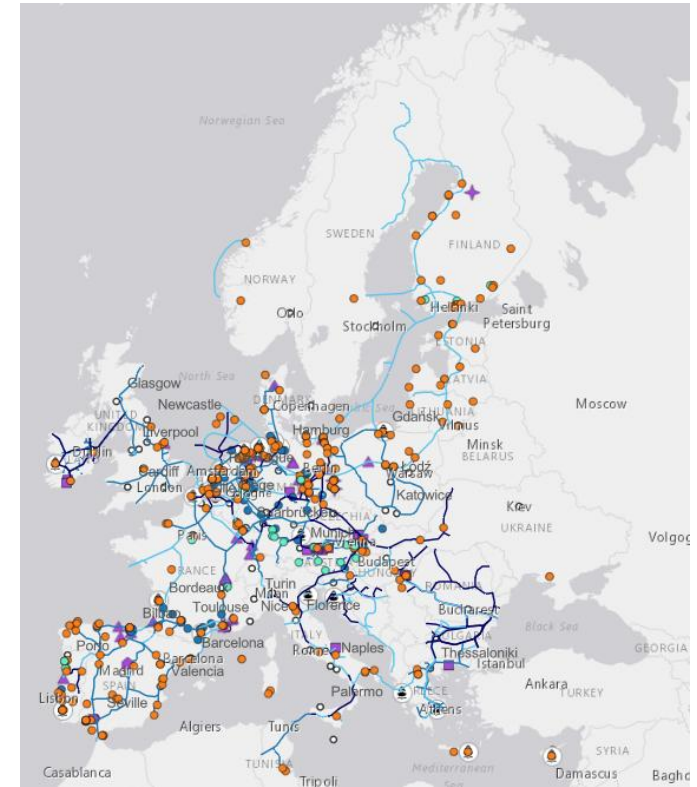
Method



- Publicly available/licensed data on
 - Flights (OAG 2023¹)
 - Airports (OurAirports²)
 - Kerosene and Hydrogen aircraft (CIRIUM³, TRANSCEND⁴)
 - Future hydrogen infrastructure projects (Hydrogen Infrastructure Map⁵)

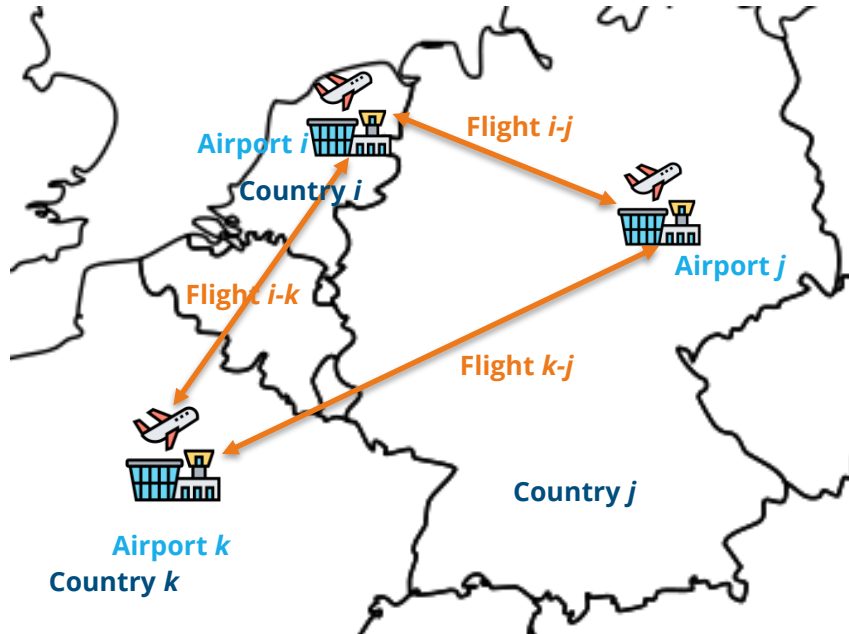
Infrastructure

- Hydrogen infrastructure locations and EIS from European Hydrogen Backbone (EHB):
 - Pipelines
 - Production facilities
 - Storage facilities
 - Distribution facilities
- From 2035+:
 - All airports will be supplied hydrogen using trucks.
 - Pipelines are not considered.
- From 2040+:
 - Small airports will be supplied by hydrogen trucks.
 - Medium & large airports can also be supplied by pipelines



European Hydrogen Backbone⁵

Scoring criteria



Flight-level scoring:
 $\text{Score}(\text{Flight } i-j)$

Airport-level scoring:
$$\frac{\text{Score}(\text{Airport } i) + \text{Score}(\text{Airport } j)}{2}$$

Country-level scoring:
$$\frac{\text{Score}(\text{Country } i) + \text{Score}(\text{Country } j)}{2}$$

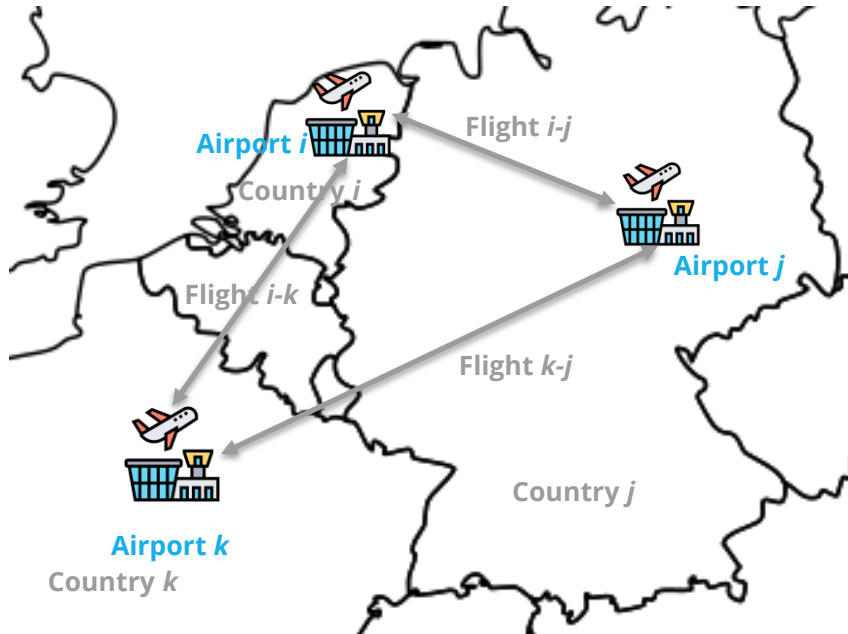
Scoring criteria



Flight-level scoring:
Score(Flight *i-j*)

- Absolute number of hydrogen flights (**H2 Flights**)
- Compatibility between flight and hydrogen aircraft (**Flight Compatibility**)
- Airline commitment to hydrogen operations (**Airline Commitment**)
- Missing revenue-passenger-kilometres and slot-constrained airports (**Missed RPK and slots**)

Scoring criteria

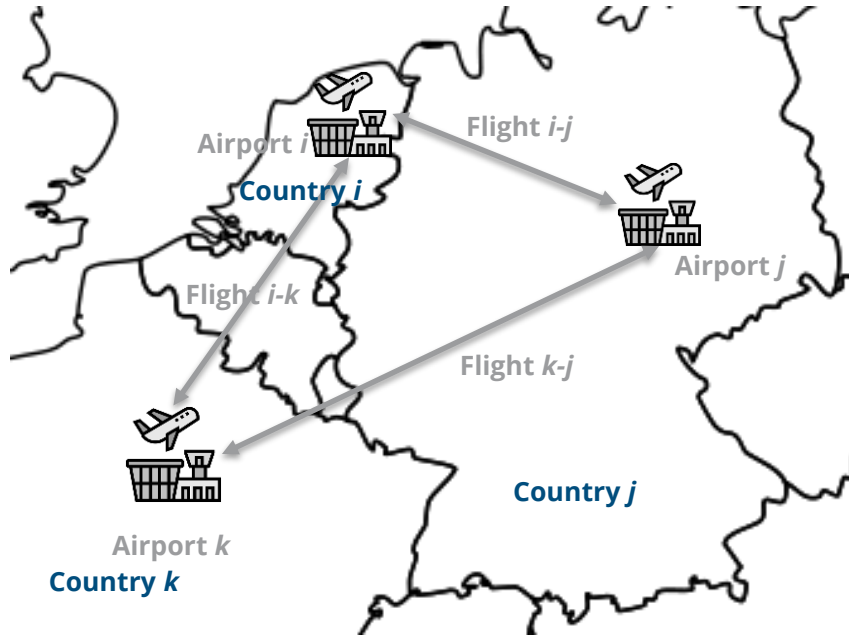


Airport-level scoring:

$$\frac{\text{Score}(\text{Airport } i) + \text{Score}(\text{Airport } j)}{2}$$

- Percentage of hydrogen flights departing from the airport (**% H2 Departures**)
- Distance from airport to hydrogen infrastructure (**H2 Infra Distance**)
- Available surface area for hydrogen operations at the airport (**H2 Infra Area**)
- Airport commitment to hydrogen operations (**Airport Commitment**)

Scoring criteria



Country-level scoring:

$$\frac{\text{Score}(\text{Country } i) + \text{Score}(\text{Country } j)}{2}$$

- H2 production cost in airport country (**Production Cost**)
- Available renewable electricity per country departing passengers (**Renewable Electricity**)

Criteria weighting



Objective

vs.



Subjective

- Objective: Criteria Importance Through Intercriteria Correlation (CRITIC)
- Subjective: Rank Sum (RS)

| RS Rank | Criteria | RS Rank | Criteria |
|---------|----------------------|---------|-----------------------|
| 1 | Flight Compatibility | 6 | Missed RPK and slots |
| 2 | H2 Infra Distance | 7 | Production Cost |
| 3 | H2 Flights | 8 | Renewable Electricity |
| 4 | % H2 Departures | 9 | Airline Commitment |
| 5 | H2 Infra Area | 10 | Airport Commitment |

Results 2035: Score card

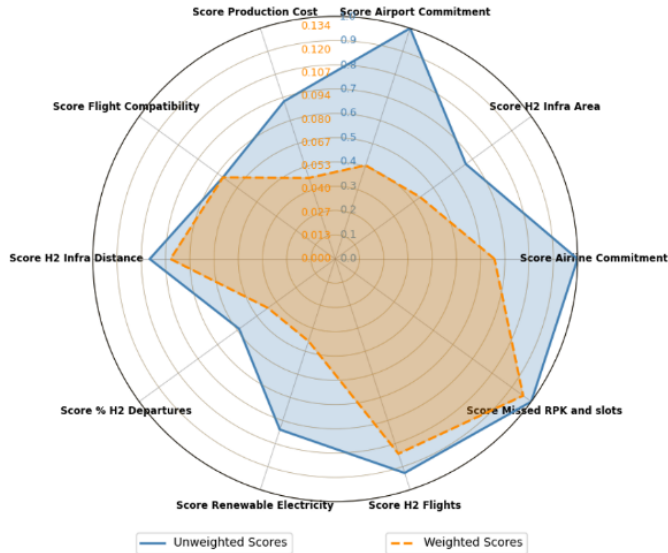
Rank

1

Score
0.782

ESSA - LFPG

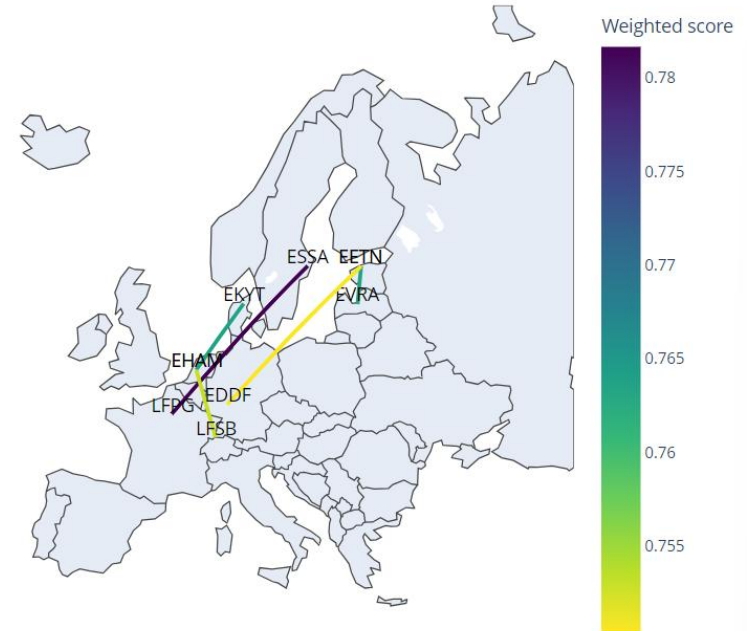
Stockholm Arlanda Airport (Sweden) – Charles de Gaulle Airport (France)



Key Figures 2035

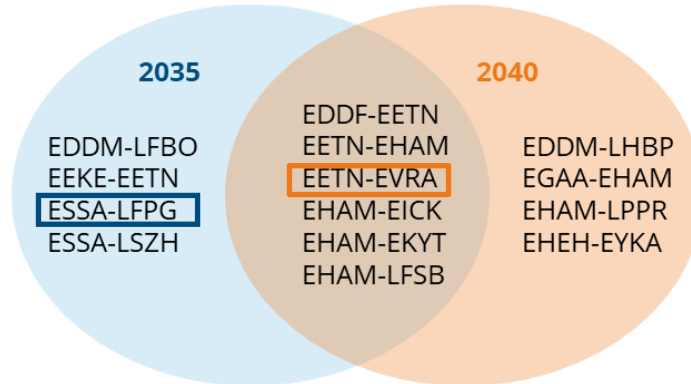
| | ESSA | LFPG | In top x percentile |
|---|---|--------------------------|---------------------|
| Absolute number of hydrogen flights | 3055 | | 7% |
| Compatibility between flight and hydrogen aircraft | Possible H2 aircraft: SMR SA. Regional range too short | | 66% |
| Airline commitment to hydrogen operations | 100% of flights performed by committed airlines | | 1% |
| Missing revenue-passenger-kilometres and slot-constrained airports | No missed RPK, H2 aircraft can take over all demand between ESSA-LFPG | | 1% |
| Percentage of hydrogen flights departing from the airport | 80.7% | 61.5% | 62% |
| Distance from airport to hydrogen infrastructure | 136.0 km | 33.7 km | 36% |
| Available surface area for hydrogen operations at the airport | 1.33 pax/km ² | 1.39 pax/km ² | 42% |
| Airport commitment to hydrogen operations | Yes | Yes | 1% |
| H2 production cost in airport country (2030) | 100.6 EURO | 118.8 EURO | 16% |
| Available renewable electricity per country departing passengers | 8943 kWh | 2447 kWh | 18% |

| Rank | OD Airport pair | Airport names | Weighted score |
|------|-----------------|--|----------------|
| 1 | ESSA-LFPG | Stockholm Arlanda Airport (Sweden) Charles de Gaulle Airport (France) | 0.782 |
| 2 | EHAM-EKYT | Amsterdam Schiphol Airport (Netherlands) Aalborg Airport (Denmark) | 0.764 |
| 3 | EETN-EVRA | Tallin Airport (Estonia) Riga International Airport (Latvia) | 0.763 |
| 4 | EHAM-LFSB | Amsterdam Schiphol Airport (Netherlands) EuroAirport Basel Mulhouse Freiburg (France) | 0.753 |
| 5 | EDDF- EETN | Frankfurt Airport (Germany) Tallinn Airport (Estonia) | 0.750 |



Results 2040

- Extra hydrogen aircraft in service with higher seat class
- Distribution of hydrogen through pipelines for larger airports
- Additional hydrogen infrastructure
- More renewable electricity
- Top #1: EETN-EVRA (Tallin Airport – Riga International Airport)



Conclusions



ESSA-LFPG (Stockholm Arlanda Airport – Charles de Gaulle Airport)



EETN-EVRA (Tallin Airport – Riga International Airport)



Routes from and to EHAM (Amsterdam Schiphol Airport) are present frequently

Methodology prioritises:

- Compatibility between flight and hydrogen aircraft characteristics
- Impact on passenger volumes (RPK & slots)

Constraining criteria:

- Absolute number of hydrogen flights

Starting point for additional investigation to determine opportunities/challenges at these airports

Recommendations

Model:

- Adjustments in flight network
- True origin-destination demand
- Passenger travel preferences
- Updates on actual hydrogen aircraft and infrastructure
- ...



Airport- and route-specific studies to determine opportunities and challenges at specific airports.





Thank you!



References

1. [Flight Schedules Data | Airlines Schedules Data | OAG](#)
2. [Dataset formats @ OurAirports](#)
3. [Aviation Data Sets – Cirium](#)
4. [Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains | TRANSCEND | Project | Fact Sheet | H2020 | CORDIS | European Commission](#)
5. [H2 Infrastructure Map Europe](#)
6. Novel propulsion and alternative fuels for aviation towards 2050 : Promising options and steps to take (TRANSCEND Deliverable D3.2)



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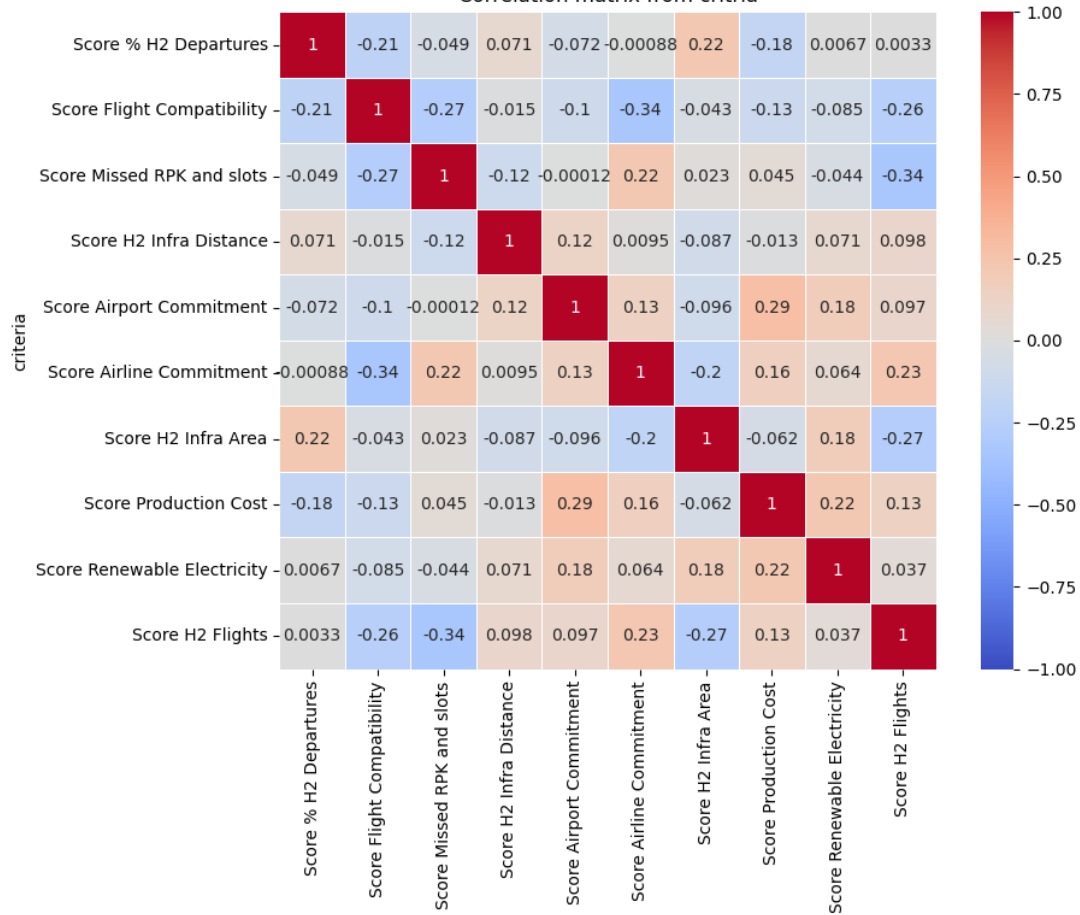
Voorsterweg 31
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Additional slides

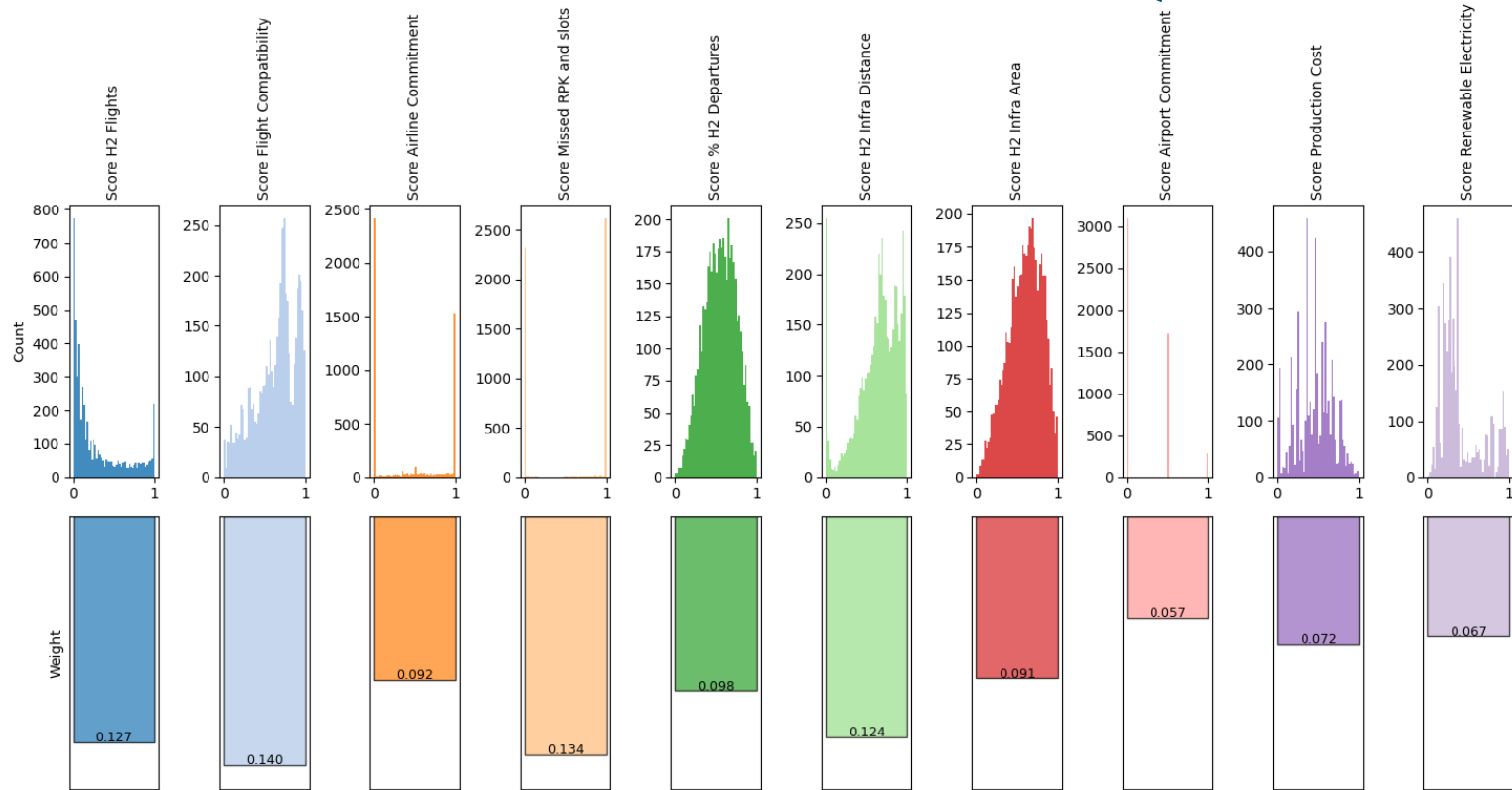
Correlation matrix from criteria





Results 2035

Binary data
limitation



Rank

2

Score
0.764

EHAM - EKYT

Amsterdam Schiphol Airport (Netherlands) – Aalborg Airport (Denmark)



Key Figures 2035

| | EHAM | EKYT | In top x percentile |
|---|---|--------------------------|---------------------|
| Absolute number of hydrogen flights | 2405 | | 10% |
| Compatibility between flight and hydrogen aircraft | Possible H2 aircraft: SMR SA. Regional range too short | | 96% |
| Airline commitment to hydrogen operations | 100% of flights performed by committed airlines | | 1% |
| Missing revenue-passenger-kilometres and slot-constrained airports | No missed RPK, H2 aircraft can take over all demand between EHAM-EKYT | | 1% |
| Percentage of hydrogen flights departing from the airport | 68.4% | 91.5% | 29% |
| Distance from airport to hydrogen infrastructure | 9.1 km | 57.2 km | 14% |
| Available surface area for hydrogen operations at the airport | 1.95 pax/km ² | 0.09 pax/km ² | 25% |
| Airport commitment to hydrogen operations | Yes | No | 6% |
| H2 production cost in airport country (2030) | 89.1 EURO | 78.3 EURO | 1% |
| Available renewable electricity per country departing passengers | 14451 kWh | 3055 kWh | 6% |

Rank

3

Score
0.763

EETN - EVRA

Tallin Airport (Estonia) – Riga International Airport (Latvia)



Key Figures 2035

| | EETN | EVRA | In top x percentile |
|---|--|--------------------------|---------------------|
| Absolute number of hydrogen flights | 3029 | | 8% |
| Compatibility between flight and hydrogen aircraft | Possible H2 aircraft: Regional and SMR SA | | 85% |
| Airline commitment to hydrogen operations | 100% of flights performed by committed airlines | | 1% |
| Missing revenue-passenger-kilometres and slot-constrained airports | 443k yearly missed RPK, no slot constrained airports | | 54% |
| Percentage of hydrogen flights departing from the airport | 83.2% | 80.3% | 23% |
| Distance from airport to hydrogen infrastructure | 5.5 km | 9.4 km | 1% |
| Available surface area for hydrogen operations at the airport | 0.67 pax/km ² | 2.54 pax/km ² | 54% |
| Airport commitment to hydrogen operations | Yes | Yes | 1% |
| H2 production cost in airport country (2030) | 87.7 EURO | 98.3 EURO | 2% |
| Available renewable electricity per country departing passengers | 6168 kWh | 3346 kWh | 23% |

Rank

4

Score
0.753

EHAM - LFSB

Amsterdam Schiphol Airport (Netherlands) – EuroAirport Basel Mulhouse Freiburg (France)



Key Figures 2035

| | EHAM | LFSB | In top x percentile |
|---|---|--------------|---------------------|
| Absolute number of hydrogen flights | 3783 | | 6% |
| Compatibility between flight and hydrogen aircraft | Possible H2 aircraft: SMR SA. Regional range too short | | 91% |
| Airline commitment to hydrogen operations | 100% of flights performed by committed airlines | | 1% |
| Missing revenue-passenger-kilometres and slot-constrained airports | No missed RPK, H2 aircraft can take over all demand between EHAM-LFSB | | 1% |
| Percentage of hydrogen flights departing from the airport | 68.4% | 73.7% | 62% |
| Distance from airport to hydrogen infrastructure | 9.1 km | 21.8 km | 5% |
| Available surface area for hydrogen operations at the airport | 1.95 pax/km2 | 0.80 pax/km2 | 43% |
| Airport commitment to hydrogen operations | Yes | No | 6% |
| H2 production cost in airport country (2030) | 89.1 EURO | 118.8 EURO | 11% |
| Available renewable electricity per country departing passengers | 14451 kWh | 2447 kWh | 7% |

Rank

5

Score
0.750

EDDF - EETN

Frankfurt Airport (Germany) – Tallinn Airport (Estonia)



Key Figures 2035

| | EDDF | EETN | In top x percentile |
|---|---|--------------------------|---------------------|
| Absolute number of hydrogen flights | 1235 | | 22% |
| Compatibility between flight and hydrogen aircraft | Possible H2 aircraft: SMR SA. Regional range too short | | 50% |
| Airline commitment to hydrogen operations | 100% of flights performed by committed airlines | | 1% |
| Missing revenue-passenger-kilometres and slot-constrained airports | No missed RPK, H2 aircraft can take over all demand between EDDF-EETN | | 1% |
| Percentage of hydrogen flights departing from the airport | 63.8% | 83.2% | 53% |
| Distance from airport to hydrogen infrastructure | 24.1 km | 5.5 km | 4% |
| Available surface area for hydrogen operations at the airport | 2.14 pax/km ² | 0.67 pax/km ² | 44% |
| Airport commitment to hydrogen operations | No | Yes | 6% |
| H2 production cost in airport country (2030) | 117.1 EURO | 87.7 EURO | 9% |
| Available renewable electricity per country departing passengers | 3145 kWh | 6168 kWh | 23% |