

# THE CLEAN SKY 2 TECHNOLOGY EVALUATOR 1ST GLOBAL ASSESSMENT

ICAS 2022

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[www.clean-aviation.eu](http://www.clean-aviation.eu)

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33RD CONGRESS  
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OF THE AERONAUTICAL SCIENCES  
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2022  
SWEDEN

# Acknowledgements

## ➤ DLR (Köln):

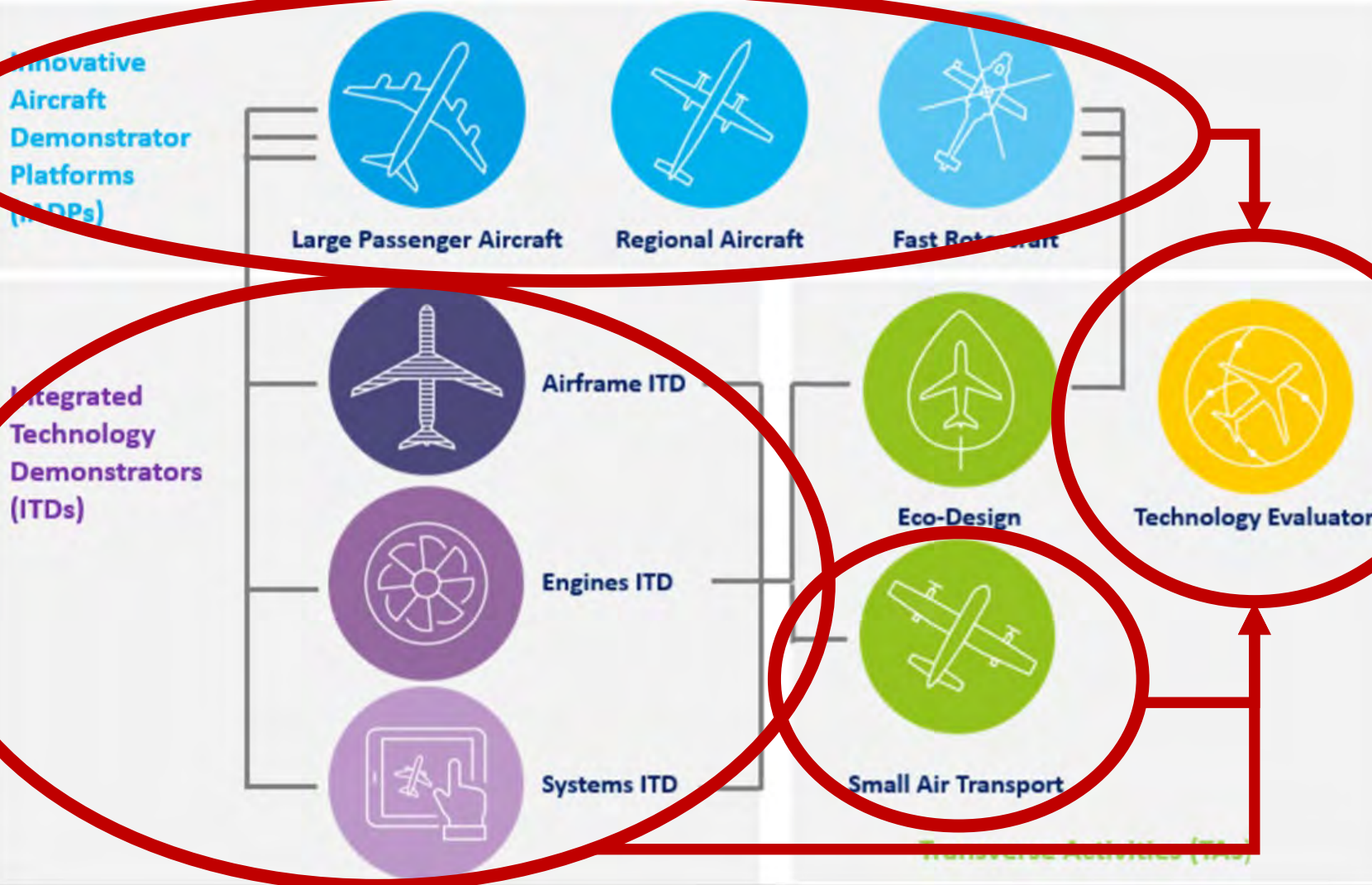
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- Giorgio Vicenzotti (Leonardo Helicopters)
- Julien Guitton (Airbus Helicopters)

# Technology Evaluator

IADPs



ITDs

- Clean Sky 2 Structure -



## Key Messages

First Global Assessment covers 2 major aspects:

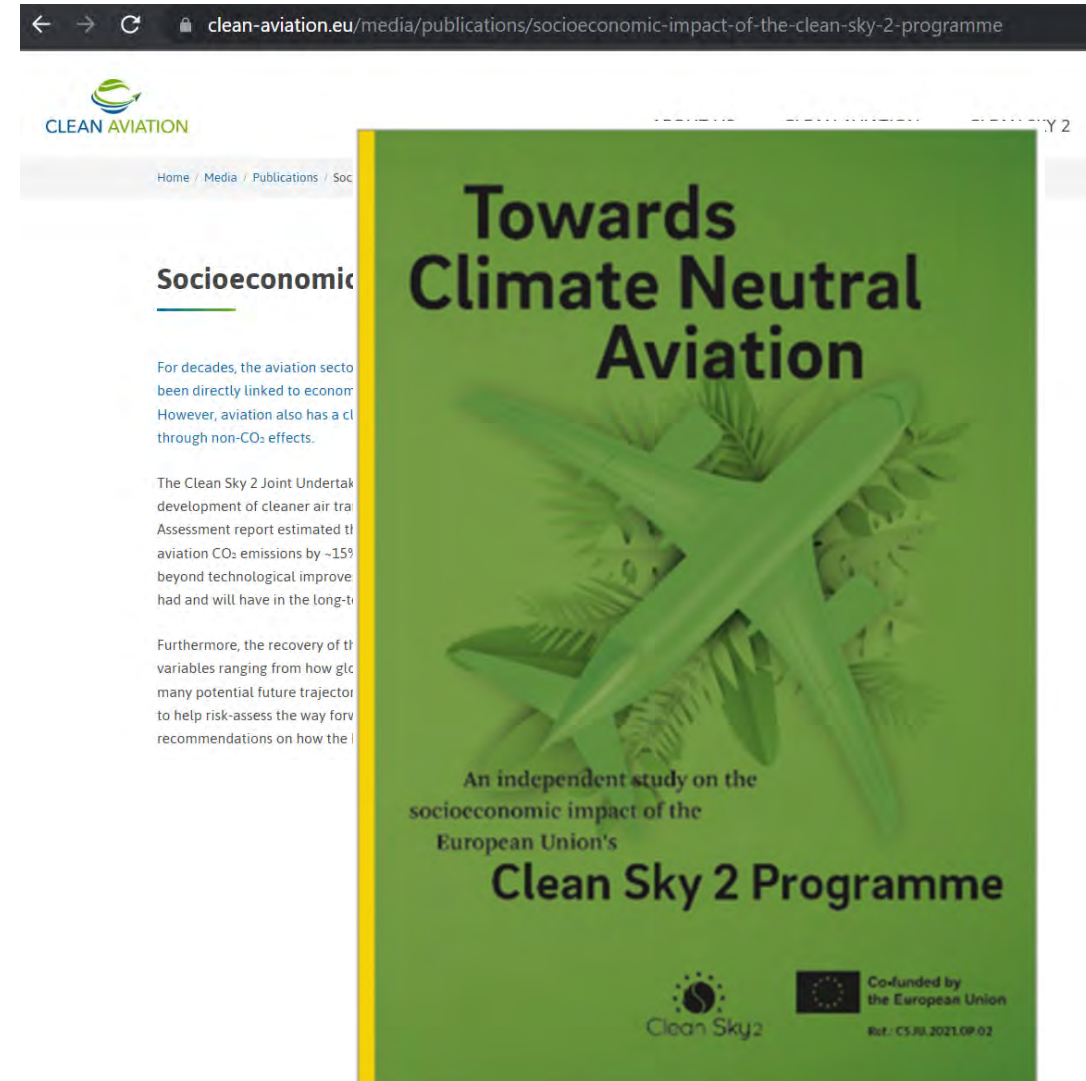
- the **environmental impact assessment**
- the ***socio-economic impact assessment***

First Global Assessment was performed before/during the outbreak of the pandemic.

**COVID-19 Impact not considered.**

See Note in Section 7 (Report) on potential impacts.

See R&B/OE Study available on web.



The screenshot shows a web browser displaying the Clean Aviation website. The URL is [clean-aviation.eu/media/publications/socioeconomic-impact-of-the-clean-sky-2-programme](https://clean-aviation.eu/media/publications/socioeconomic-impact-of-the-clean-sky-2-programme). The page features the Clean Aviation logo and a navigation menu. The main content area is titled "Socioeconomic" and contains a summary of the report. The report cover is prominently displayed on the right side of the page. The cover is green and features the title "Towards Climate Neutral Aviation" in large, bold, black letters. Below the title, it says "An independent study on the socioeconomic impact of the European Union's Clean Sky 2 Programme". The cover also includes the Clean Sky 2 logo and the European Union flag, along with the text "Co-funded by the European Union" and the reference number "Ref.: CS.10.2021.09.02".

Home / Media / Publications / Socioeconomic

### Socioeconomic

For decades, the aviation sector has been directly linked to economic growth. However, aviation also has a climate impact through non-CO<sub>2</sub> effects.

The Clean Sky 2 Joint Undertaking's development of cleaner air traffic management. The Assessment report estimated that aviation CO<sub>2</sub> emissions by ~15% beyond technological improvements had and will have in the long-term.

Furthermore, the recovery of the aviation sector is a key variable ranging from how global economic recovery to many potential future trajectories to help risk-assess the way forward. Recommendations on how the industry can contribute to the recovery of the aviation sector are provided.

## Towards Climate Neutral Aviation

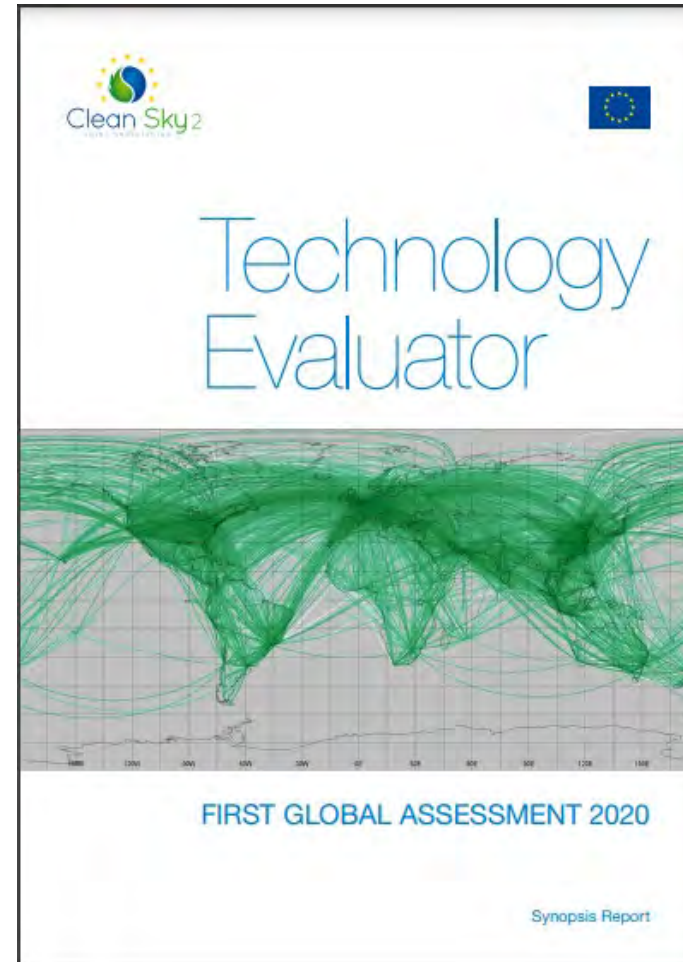
An independent study on the socioeconomic impact of the European Union's Clean Sky 2 Programme

Clean Sky 2 Co-funded by the European Union Ref.: CS.10.2021.09.02

## Key Messages

First Global Assessment is available as an **interim progress report** (showing interim results) at CS2 programme mid-term (**2020**) before the final assessment at programme end, in **2024**.

First Global Assessment is available as a **synopsis report** of the full technical deliverable submitted by TE (DLR) July 2020. It contains a high level Executive Summary.



Publication of 2 documents:

- Executive Summary -> Short Synopsis (16 pages + images & graphs)
- Synopsis Report -> Technical Report (122 pages)



# ASSESSMENT METHODOLOGY FORECAST & SCENARIOS

# Methodology (1/4)


	<p><b><u>Innovation potential at Mission level</u></b></p> <p>Clean Sky 2 Concept Aircraft are compared with 2014 Reference Aircraft on relevant missions regarding emissions and noise. The results are the basis to quantify the success level versus the CS2 environmental goals.</p>	
	<p><b><u>Realistic impact at Airport level</u></b></p> <p>A typical day at representative EU-airports (fleet mix from 2014 historical and 2035/2050 forecast data) is compared for a fleet with and without Clean Sky aircraft and analysed regarding emissions and noise.</p>	
	<p><b><u>Aviation footprint at Air Transport System (ATS) level</u></b></p> <p>A year with all global flights (fleet mix from 2014 historical and 2035/2050 forecast data) is compared for a fleet with and without Clean Sky aircraft and analysed regarding emissions and noise.</p>	

Figure 4 - Assessment levels.

# Methodology (2/4)

World Population  
(in billion)

8.5 / 9.2 / 9.7  
(2030 / 2040 / 2050)

United Nations (2019): World Population Prospects 2019

GDP growth rates  
(p.a. in %, from  
2014)

1.98 / 1.98 / 1.97  
(2030 / 2040 / 2050)

IHS Global Market (2017): Global GDP Growth Rates

Population growth  
rates (p.a. in %, from  
2014)

1.05 / 0.93 / 0.86  
(2030 / 2040 / 2050)

United Nations (2019): World Population Growth Rates

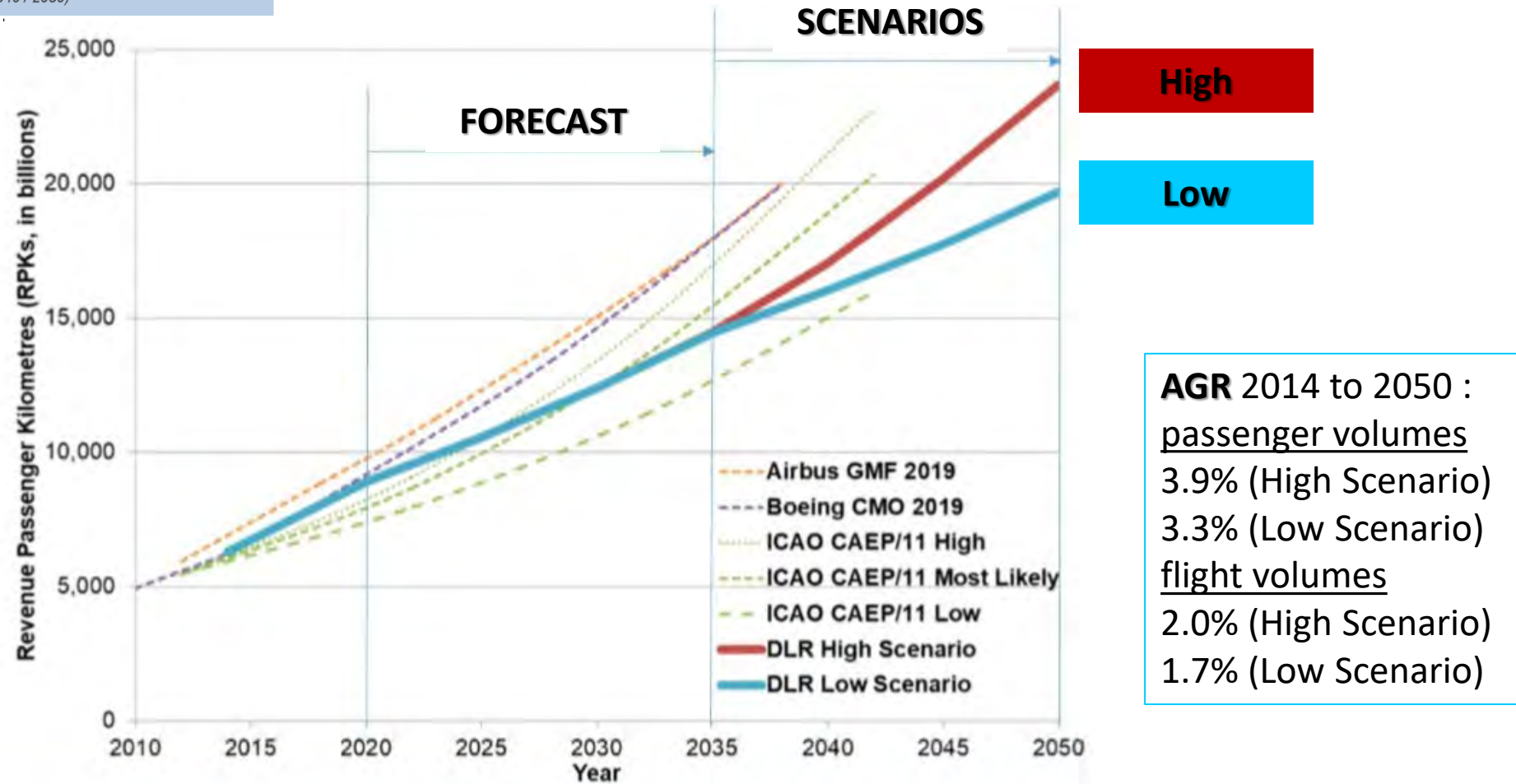


Figure 5 - Comparison of Forecast and Scenarios to other available air traffic predictions.





## Overall Assumptions:

- Economic conditions remain static (no war, **no COVID ...**)
- Key drivers:
  - income per capita, GDP, population, airfare dvlpt.
- Tech. diffusion models to neighbouring seat classes (TeDiMo)
- A/C Retirements (ICAO model)
- Passenger Load Factors 80% -> 88% (ICAO model)
- Airport Hub Structure unchanged
- No SAF (TRANSCEND)
- No Policies (GLIMPSE2050)
- No Retrofit
- No UAV & No SST (OASyS)
- Airport Capacity Constraints
  - new (additional) runways
  - runway extensions deliver little additional capacity
  - probability of a runway expansion modelled differently across the world (India, China)
  - No new airports.

**Key Message**

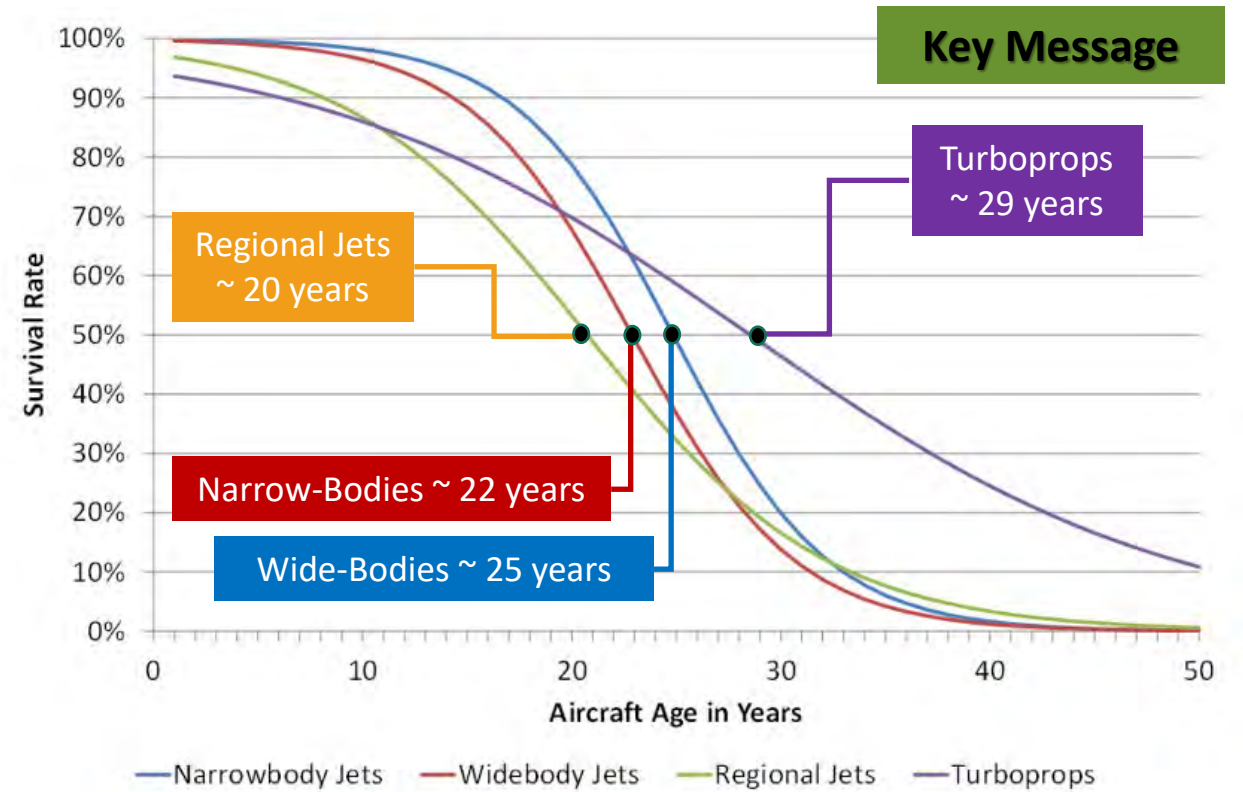


Figure 6 – Aircraft retirement curves.

**Key Message**

➔ **4 Full Fleet Calculations for 2050**

- DLR Unconstrained – High
- DLR Unconstrained – Low
- DLR Constrained – High
- DLR Constrained - Low

# Methodology (4/4)

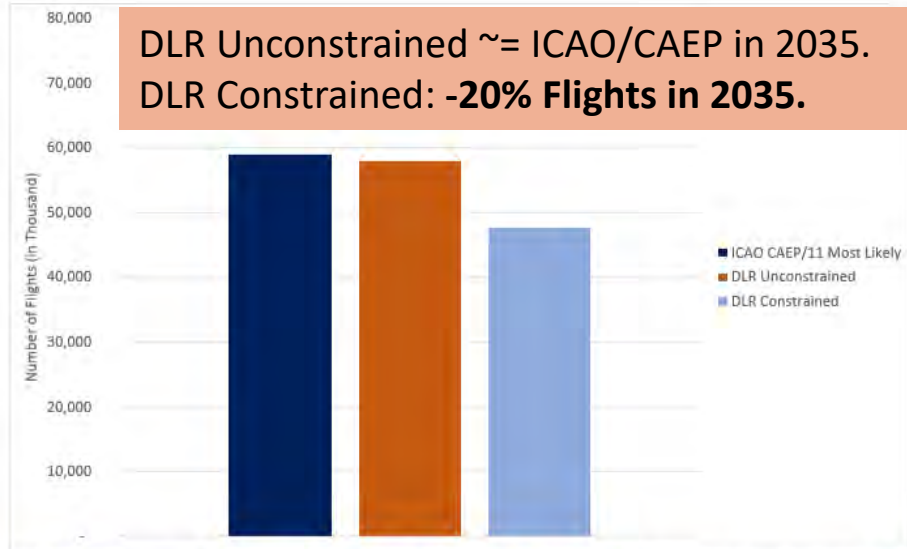


Figure 7 - 2035 DLR Forecast vs. ICAO CAEP/11 Forecast in terms of number of flights.

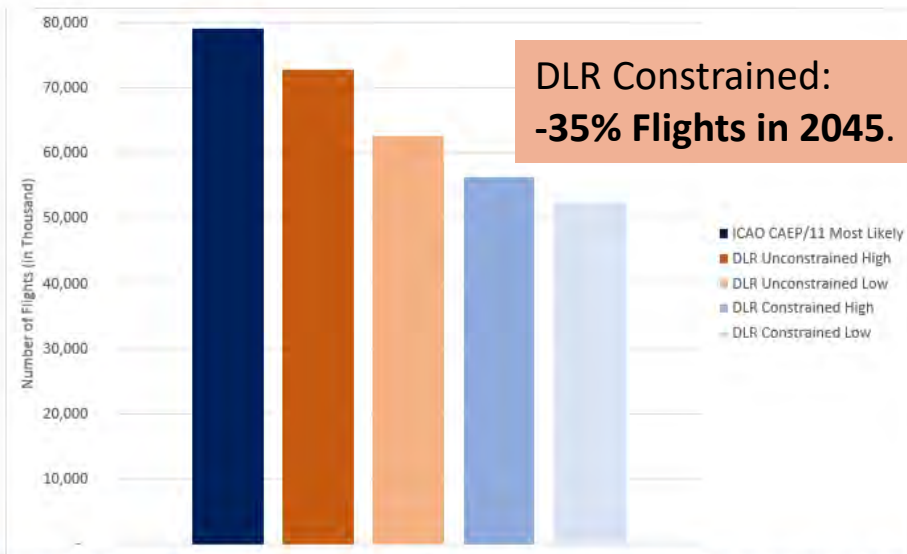


Figure 8 - 2045 DLR Scenarios vs. ICAO CAEP/11 Forecast in terms of number of flights.

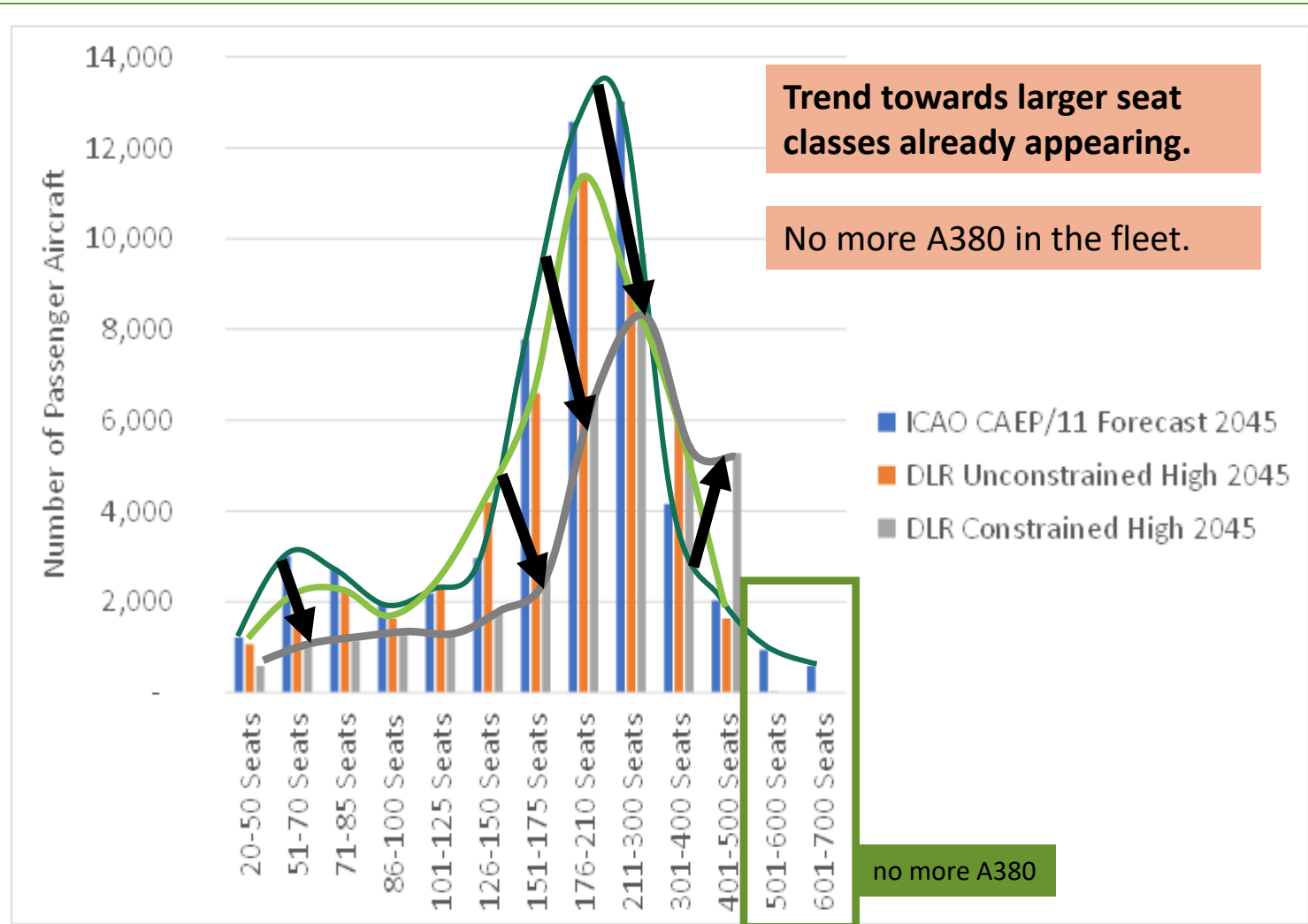


Figure 9 - 2045 DLR Scenarios vs. ICAO CAEP/11 Forecast in terms of in-service passenger aircraft by seat classes.

# Take-Away (1)



## AIRPORT TRAFFIC CONGESTION

Congested airports are already a reality today. **An overall reduction of 30% in terms of flight volumes** can be expected if *airport capacity constraints* are taken into account in the forecast model. This is an important novelty of the DLR methodology compared to other models dealing with air transport today.

# Take-Away (2)

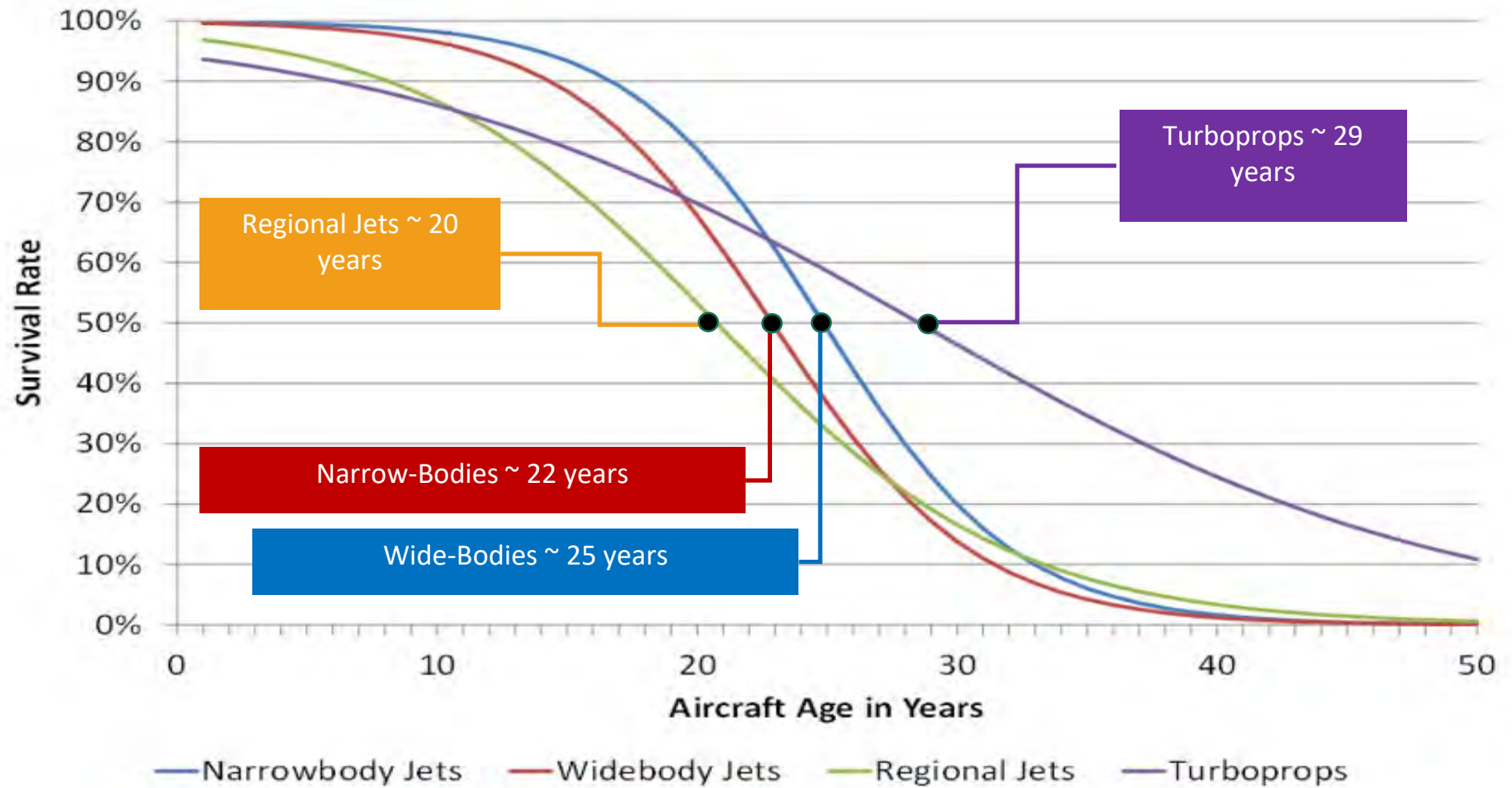


Figure 6 – Aircraft retirement curves.



# **ENVIRONMENTAL IMPACT**

## **AIRCRAFT (MISSION) LEVEL**



# AIRCRAFT CONCEPTS

# Aircraft Concepts

The current fleet divided into several market segments:

- **Mainliners (4)** (covering **Long Range** and **SMR**),
- **Regional aircraft (3)** (different mission targets),
- **Small Air Transport (1)** (19 seats)
- **Business Jets (1)**,
- **Fast Rotorcraft (2)**



## Key Messages

Concept definition  
Based on selection of technologies  
**> TRL3 in 2018**

Concept EIS

- a few concepts EIS **2025+**
- next earliest EIS is **2030 (Adv.)**
- **2035+** for Ultra-Adv. concepts.

SPD	Concept Aircraft				Reference Aircraft				Clean Sky 2 Environmental Goals			EIS* Window	TRL Target** @ CS2 close
	Concept Vehicle	Range nm	Cruise speed	# PAX	Reference Vehicle	Range nm	Cruise speed	# PAX	ΔCO <sub>2</sub>	ΔNO <sub>x</sub>	Δ Noise		
LPA	Advanced Short-Medium Range SMR+	2000	0.78 Ma	200	SMR 2014 A321neo	2800	0.78 Ma	200	-20%	-20%	-20%	2030	5
	Ultra-Advanced Short-Medium Range SMR++	2000	0.75 Ma	200								2035+	4
	Advanced Long Range LR+	6700	0.85 Ma	315	LR 2014 A350-900	6700	0.85 Ma	315	-20%	-20%	-20%	2030	4
	Ultra-Advanced Long Range LR++	6700	0.85 Ma	315								2035+	3
REG	Advanced Turboprop 90 PAX	1200	0.56 Ma at 20 kft	90	Innovative Turboprop 130 PAX	1600	0.62 Ma at 20 kft	130	-20%	-20%	-20%	2025+	5
	Regional Multi Mission Turboprop 70 PAX	1200	0.56 Ma at 20 kft	70								2035+	4
	Transport Airline	1600	0.62 Ma at 20 kft	130	2035+	4							
SAT	19 PAX Com	800	0.34 Ma	19					-20%	-20%	-20%	2025	4-5
AIR	Low Sweep Busine	2900	0.75 Ma	12	Assault Falcon 2000 like	2900	0.75 Ma	12	> -30%	> -30%	> -30%	2035	≥ 4
FRC	Airbus Helicopters Compound (RACER)	290	114 kTAS	12	Twin-Engine Medium Baseline (TEM-B) generic helicopter	290	114 kTAS	12	-20%	-20%	-20%	2030	6
	Leonardo Helicopters Tiltrotor (NGCTR)	<1000	250 kTAS	24	Leonardo Helicopters AW139 like	570	145 kTAS	15	-50%	-14%	-30%	2030+	6

✓ Concept Aircraft defined (TLARs)  
 ✓ Reference Aircraft defined  
 ✓ Environmental Goals set  
 ✓ Target EIS set  
 ✓ TRL @ CS2 closure set

\*All key enabling technologies at TRL 6 with a potential entry into service five years later.

\*\*Key enabling technologies at major system level.



# Reference Aircraft

## Key Message

Choice of Reference Aircraft may be difficult.

- Ok for mainliners (A321 neo EIS2016 – A350-900 EIS2015).
- Regional needs upscaling of ref. a/c. (ATR-72-500 is 70 pax -> 90 pax).
- REG TP 130 (USF) compared CS-300 (GTF).
- REG MM TP 70 (EADS-CASA) compared to C-295 (50 pax) upscaled but Flying Test Bed #2 in AIR.
- SAT -> generic 19-seat SoA 2014 model created
- BJ -> ref 2000 -> ref 2020 (2<sup>nd</sup> Assessment)
- FRC no existing match for reference vehicle ! (Range, Cruise Speed, #PAX, max ceiling)

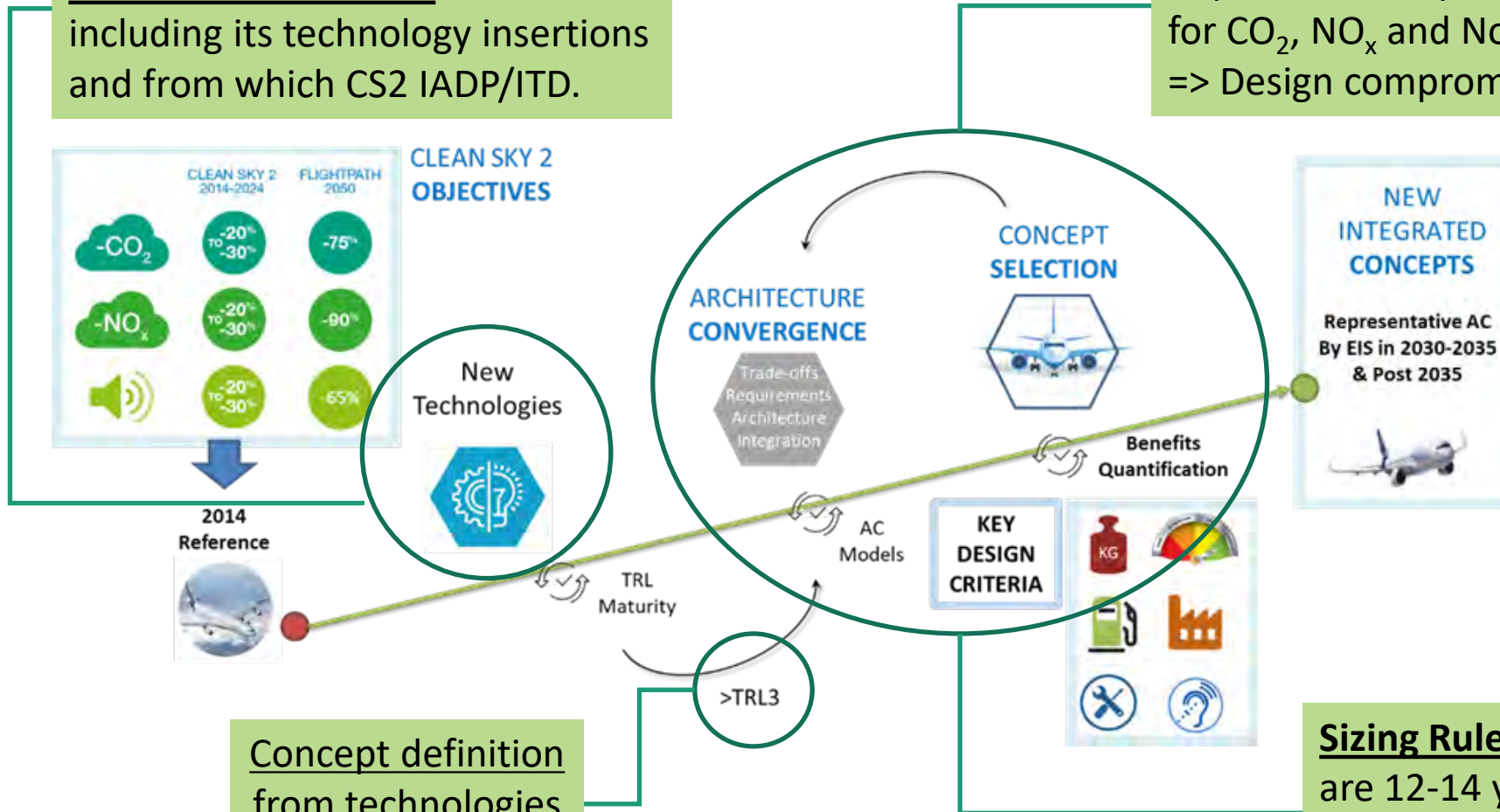
SPD	Concept Aircraft				Reference Aircraft				Clean Sky 2 Environmental Goals			EIS* Window	TRL Target** @ CS2 close
	Concept Vehicle	Range nm	Cruise speed	# PAX	Reference Vehicle	Range nm	Cruise speed	# PAX	ΔCO <sub>2</sub>	ΔNO <sub>x</sub>	Δ Noise		
FRC	Airbus Helicopters Compound (RACER)	<350	220 kTAS	12	Twin-Engine Medium Baseline (TEM-B) generic helicopter	290	114 kTAS	12	-20%	-20%	-20%	2030	6
	Leonardo Helicopters Tiltrotor (NGCTR)	<1000	250 kTAS	24	Leonardo Helicopters AW139 like	570	145 kTAS	15	-50%	-14%	-30%	2030+	6

# Mission Level Calculations

## Key Messages

**Each Aircraft Concept is described in detail.** including its technology insertions and from which CS2 IADP/ITD.

**Complex Design Optimisation !** Impossible to optimize *simultaneously* for CO<sub>2</sub>, NO<sub>x</sub> and Noise. => Design compromise !



**Concept definition from technologies > TRL3 in 2018**

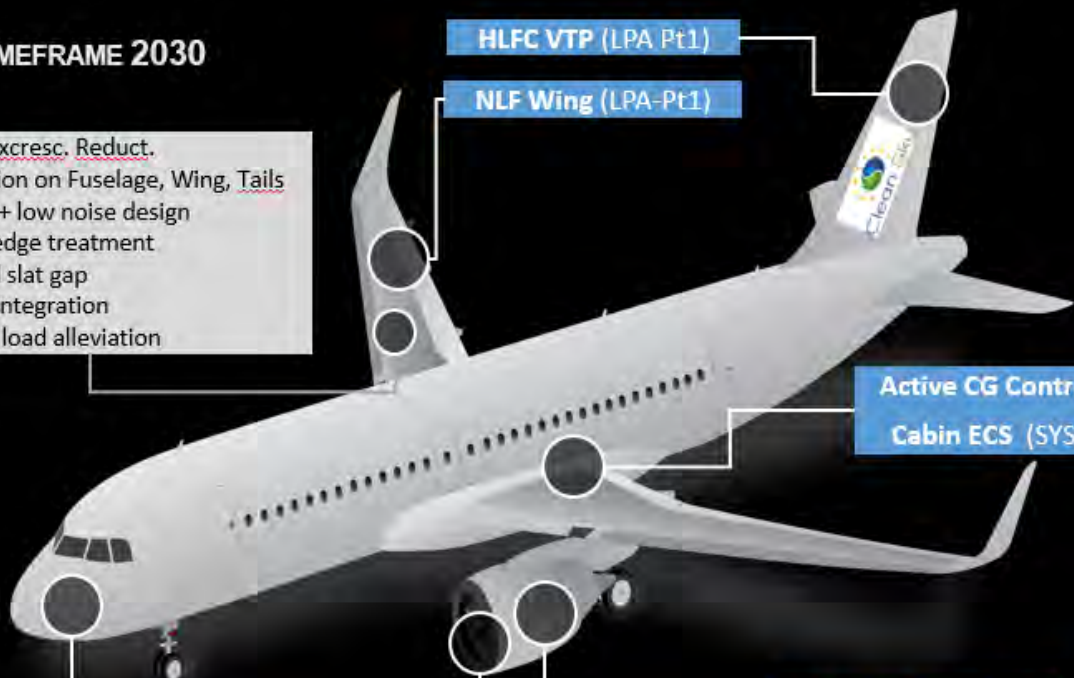
**Sizing Rules (#PAX – Range)** are 12-14 years old. To be updated for alignment with 2030 market expectations.

## Advanced Small-Medium Range (SMR+) Aircraft Concept

2,900 nm (5,370km) - Mach 0.78 - 200 PAX - MTOW 87 t

EIS TIMEFRAME 2030

- Riblets / Excrec. Reduct.
- Optimisation on Fuselage, Wing, Tails
- LG fairing + low noise design
- Flap side edge treatment
- Optimised slat gap
- Electrical integration
- Advanced load alleviation



**Ultra-High Propulsion Efficiency Turbofan**  
-9% to -12% CO<sub>2</sub> (ENG-WP2)

Ref. SMR 2015 – A321neo  
2,800 nm - Mach 0.78 - 200 PAX - MTOW 87 t

Benefits vs Platforms	SMR + Dec 2019		
	SFC	Mass (tons)	Drag
<b>PERFORMANCE</b>			
<b>Aerodynamics</b> High & Low speeds	-	↗	↘↘
<b>Structure</b>	-	↘↘	-
<b>Systems</b>	↘	-	↘
<b>Improvements for noise</b>	-	↗	↘
<b>Engine</b>	↘↘	↗	↗
<b>Total Performance</b>	<b>-9.5%</b>	<b>-0.7t</b>	<b>-3.9%</b>
<b>Total IMPACTS</b> avg %Reduction vs Ref 2014	<b>CO<sub>2</sub> -17%</b>	<b>NO<sub>x</sub> -34%</b>	<b>NOISE TO<sup>o</sup> -15% AP<sup>c</sup> &lt; -20%</b>

TO : Take-Off  
AP : Approach / Certification ICAO annex 16 conditions



## Ultra-Advanced S/M Range (SMR++) Aircraft Concept

2,900 nm (5,370km) - Mach 0.75 - 200 PAX – MTOW 87 t

EIS TIMEFRAME 2035

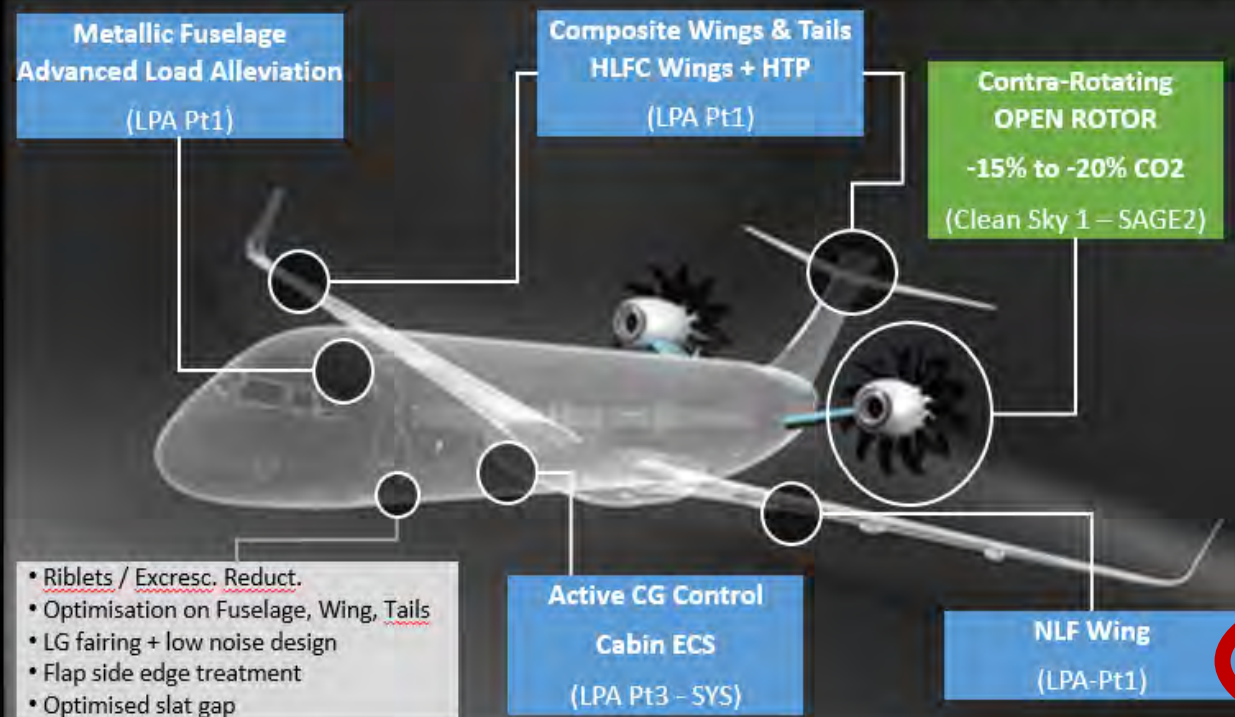


Image courtesy of Safran

Ref. SMR 2015 – A321neo

2,800 nm - Mach 0.78 - 200 PAX – MTOW 87 t

Techno benefits vs Platforms	SMR ++ CROR 2019		
PERFORMANCE	SFC	Mass	Drag
Aerodynamics	-	↗	↘↘
Structure	-	↘↘	-
Systems	↘	-	↘
Noise improvements	-	↗	↘
Engine	↘↘	↗	↗
<b>Total Performance</b>			
Technical issues			
MTOW Ref 2014: 93.5t		82.7t	
<b>Total impacts</b>	CO <sub>2</sub>	NO <sub>x</sub>	NOISE
ave %Reduction vs Ref2014			TO ~ +2.2db
<b>Iso Pax sizing</b>	-27%	-11%	AP ~ -3,4db

TO : Take-Off

AP : Approach / Certification ICAO annex 16 conditions

1<sup>st</sup> Assessment

2<sup>nd</sup> Assessment

2020

2024



SMR++ platform

CROR layout GEN2



2 possible paths under joint airframer/OEM assessment

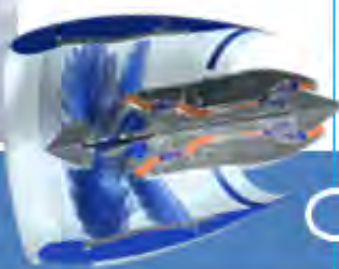
SMR++ v1

Pusher CROR layout  
Initial vision for 2035+,  
based on 2018 techno status

ORAS layout (front propeller with stator)



SMR++ final



SMR+ platform

2 possible paths under joint airframer/OEM assessment



UHBR-VPF : Integral drive variable pitch fan

SMR+ v1

Integral drive UHBR turbofan  
Initial forecast for 2030+,  
based on 2015 vision

SMR+ v2

Integral drive UHBR turbofan  
Updated with latest combustor emissions technologies



UHBR-ID : Integral drive turbofan

SMR+ final

## ADVANCED REGIONAL TURBOPROP CONCEPT 90 SEATS

1200 nm (2222km) - Mach 0.56 - 90 PAX – MTOW 32,5 t

EIS TIMEFRAME 2025



Ref. 2014 Resized ATR72

1200 nm - Mach 0.56 - 90 PAX – MTOW 35.6 t

Techno benefits vs Platforms	ADV TP 90 2019		
PERFORMANCE	SFC	Mass	Drag
Aerodynamics	-	↗	↘
Structure	-	↘	-
Systems	↘	-	-
Noise improvements	-	-	↘↘
Engine	↘↘	↘	-
<b>Total Performance</b>			
Technical issues			
<b>MTOW</b> Ref 2014: 35.6t		<b>32.5t</b>	
<b>Total impacts</b> avg %Reduction vs Ref2014	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
<b>Iso Pax sizing</b>	<b>-34%</b>	<b>-67%</b>	<b>CHAP14 - 15 epnDB</b>

# Regional TP130

## INNOVATIVE REGIONAL TURBOPROP CONCEPT 130 SEATS

1600 nm (2963km) - Mach 0.62 - 130 PAX – MTOW 51 t

EIS TIMEFRAME 2035



Ref. 2014 Ex Bombardier CS-300

3300 nm - Mach 0.78 - 130 PAX – MTOW 67.5 t

Techno benefits vs Platforms	ADV TP 130 2019		
	SFC	Mass	Drag
PERFORMANCE			
Aerodynamics	-	↗	↘
Structure	-	↘	-
Systems	↘	-	-
Noise improvements	-	-	↘
Engine	↘↘	↘	-
<b>Total Performance</b>			
Technical issues			
MTOW Ref 2014: 67.5t		<b>51.0t</b>	
<b>Total impacts</b>	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
avg %Reduction vs Ref2014			
<b>Iso Pax sizing</b>	-26%	-56%	CHAP14 -9 epnDB



# Interim Results (2020) at Mission Level

Category	Seats	Concept Aircraft				Clean Sky 2 Environmental Goals			EIS* Window	Clean Sky 2 1st Assessment Results			TRL Target** @ CS2 close	
		Concept Vehicle	Range nm	Cruise speed	# PAX	ΔCO <sub>2</sub>	ΔNO <sub>x</sub>	Δ Noise		ΔCO <sub>2</sub>	ΔNO <sub>x</sub>	Δ Noise		
SAT-FRC-BJ	0-19	19 PAX Commuter		300	0.34 Ma	19	-20%	-20%	-20%	2025	-21%	-27%	> -20%	4-5
		Low Sweep Business Jet		2900	0.78 Ma	12	> -30%	> -30%	> -30%	2035	-31%	-28%	-50%	≥ 4
		Airbus Helicopters Compound (RACER)		<350	220 kTAS	12	-20%	-20%	-20%	2030	+2 to +17% <sup>(4)</sup>	-24 to -36%	-16%	6
Regional (Extra-Small)	20-100	Leonardo Helicopters Tiltrotor (NGCTR)		<1000	250 kTAS	24	-50%	-14%	-30%	2030	-50 to -71% <sup>(5)</sup>	-12 to -50%	-86%	6
		Regional Multi Mission Turboprop 70 PAX	Transport Airline	1000	0.5 Ma	70	-20 to -30%	-20 to -30%	-20 to -30%	2025+	-20%	-59%	-20%	6
			Transport Freighter	1000	0.5 Ma	n/a								
			Search And Rescue (SAR)	400	0.5 Ma	15-25								
Advanced Turboprop 90 PAX		1200	0.56 Ma at 20 kft	90	-19 to -25%	-19 to -25%	-20 to -30%	2025+	-34%	-67%	-68%	5		
Small	101-210	Innovative Turboprop 130 PAX		1600	0.62 Ma at 30 kft	130	-35 to -40%	> -50%	-60 to -70%	2035+	-26%	-56%	-25%	4
		Advanced Short-Medium Range SMR+		2000	0.78 Ma	200	-20%	-20%	-20%	2030	-17%	-39%	-20%	5
		Ultra-Advanced Short-Medium Range SMR++		2000	0.75 Ma	200	-30%	-30%	-30%	2035+	-26%	-8% <sup>(3)</sup>	<-30%	4
Large - Medium	>300 / 211-300	Advanced Long Range LR+		6700	0.85 Ma	315	-20%	-20%	-20%	2035+	-13% <sup>(1)</sup>	-38%	<-20%	4
		Ultra-Advanced Long Range LR++		6700	0.85 Ma	315	-30%	-30%	-30%	2035+	-21% <sup>(2)</sup>	-45% <sup>(2)</sup>	n.a.	3

(\*) LR+ CO2 reduction (-13%) is made versus the A350-900 as reference aircraft, EIS 2015, a very highly optimized platform.

(\*\*) LR++ engineering assumption of an additional -8% on CO2 reduction and -7% on NOx reduction versus LR+ concept. LR++ not yet modelled.

(\*\*\*) SMR++ (-8% NOx) as CROR core engine model does not yet include low NOx combustor technology, unlike SMR+ model (-39%).

n.a. - not yet available  
n/a - not applicable

Key Messages

**Substantial progress** has already been achieved !

Most of the concepts **achieve or exceed their targets.**

FRC results preliminary: Issue of reference vehicle.

**The Clean Sky 2 Programme is well on-track.**

Not yet modelled





# ENVIRONMENTAL IMPACT

## AIRPORT LEVEL

# Airport Level Assessment

Noise impacts were estimated by comparing the noise performance of future airport-traffic scenarios with and without CS2 technologies in the year 2050 for the above mentioned airports. **The reductions for 2050 in surface area of Lden contours for relevant noise levels (60-65 dB(A)) are about 10-15%** (Figure 56).

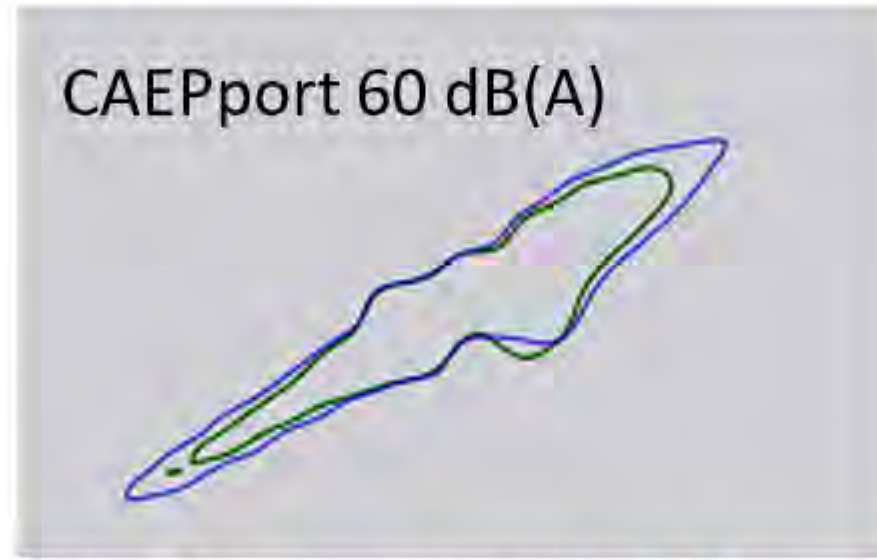


Figure 56 - Surface area reduction for 60 dB noise level.



## Key Messages

For the same noise levels (i.e. 60-65 dB(A) Lden) the noise results also highlight **significant reductions in 2050 of population exposed and population highly annoyed, i.e. in the range of 10-25%**.

In 2050, **reductions of CO<sub>2</sub> emissions amount to about 8-13.5% for the European airports considered, while the associated NO<sub>x</sub> reductions are roughly in the range 6.5-10.5%.**

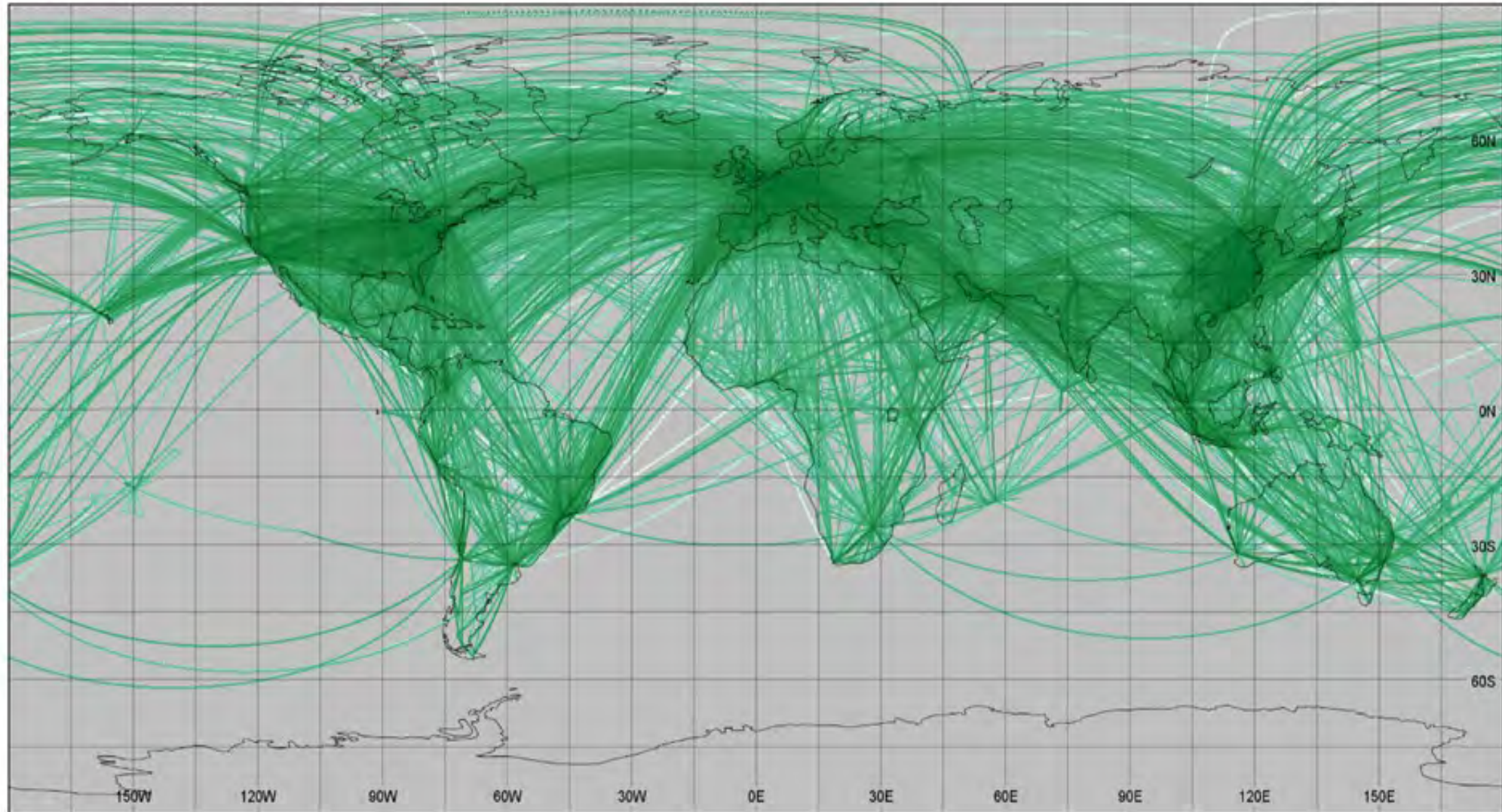


# **ENVIRONMENTAL IMPACT**

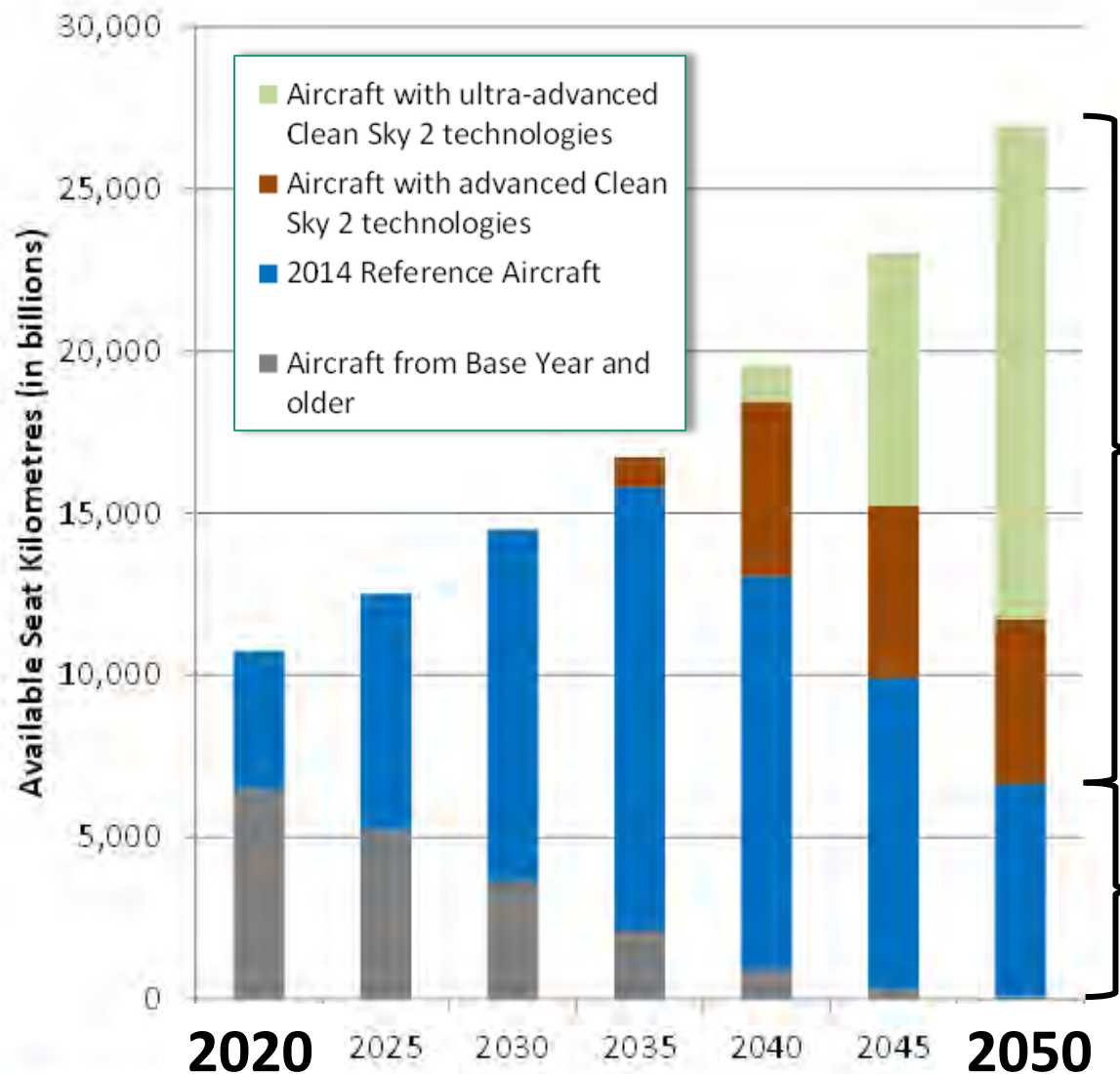
## **FLEET LEVEL**

# Fleet Level Assessment (ATS)

2050 Clean Sky high scenario traffic network



# Fleet Replacement



75%\* (70%) of Fleet replaced by CS2 a/c by 2050 :  
 → -15% (14%) CO2 reduction/ASK  
 -31% (29%) NOx reduction/ASK  
 25%\* (30%) of Fleet still SoA 2014 aircraft.  
 \*High (Low) Scenarios

75% of the fleet is replaced by CS2 a/c

25% remaining legacy a/c

## Key Messages

*it is crucial to target the **earliest entry into service date** for the next generation of aircraft.*

*urgent need to **accelerate the technology maturation process** by promoting and supporting research investments, in order to **“skip a generation”***

Figure 57 - Evolution of fleet replacement by CS2 aircraft up to 2050.



# Towards Larger Aircraft ...

**Key Message**

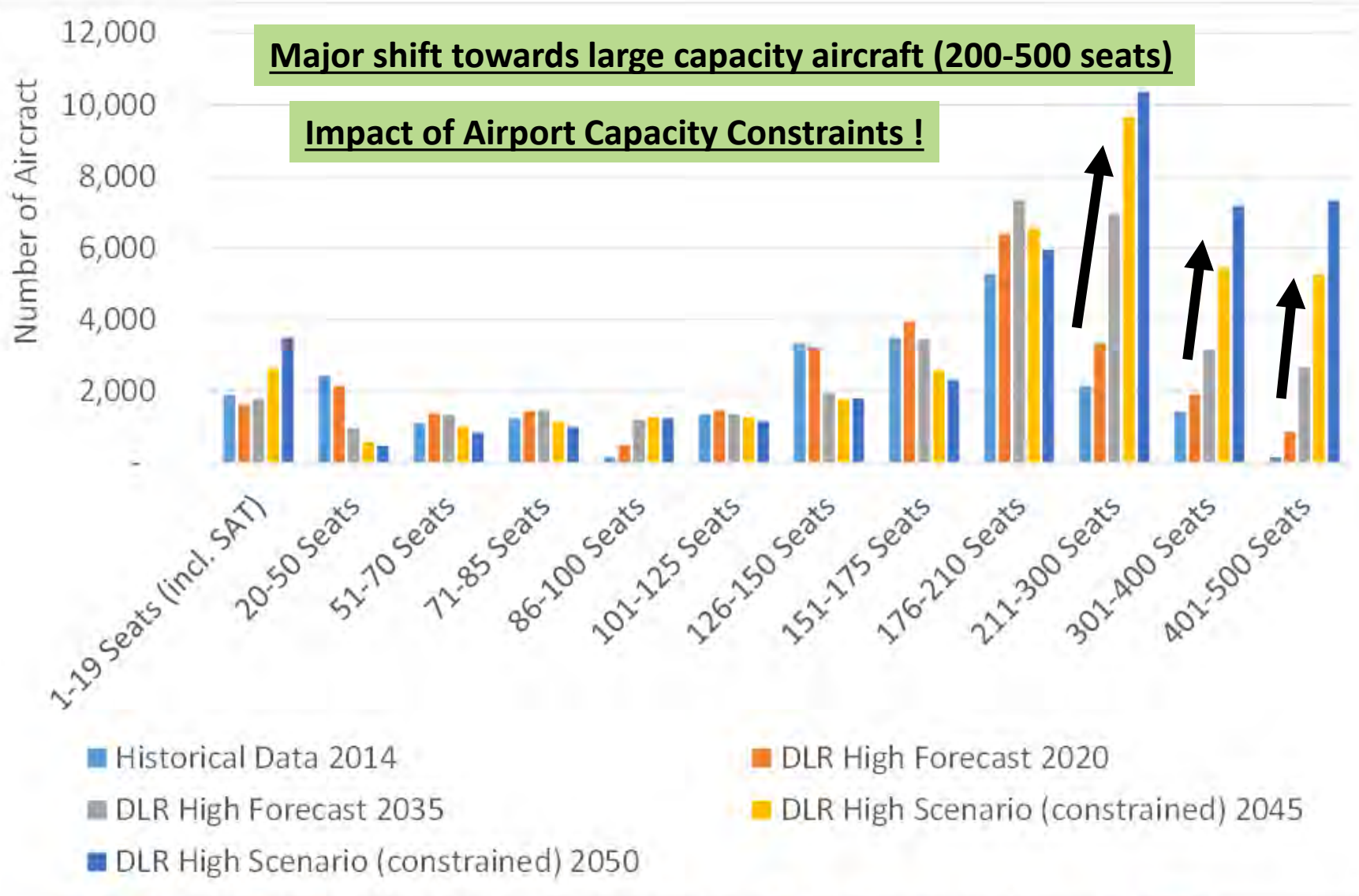


Figure 59 - Fleet evolution in terms of number of aircraft by seat class up to 2050.



Today ...

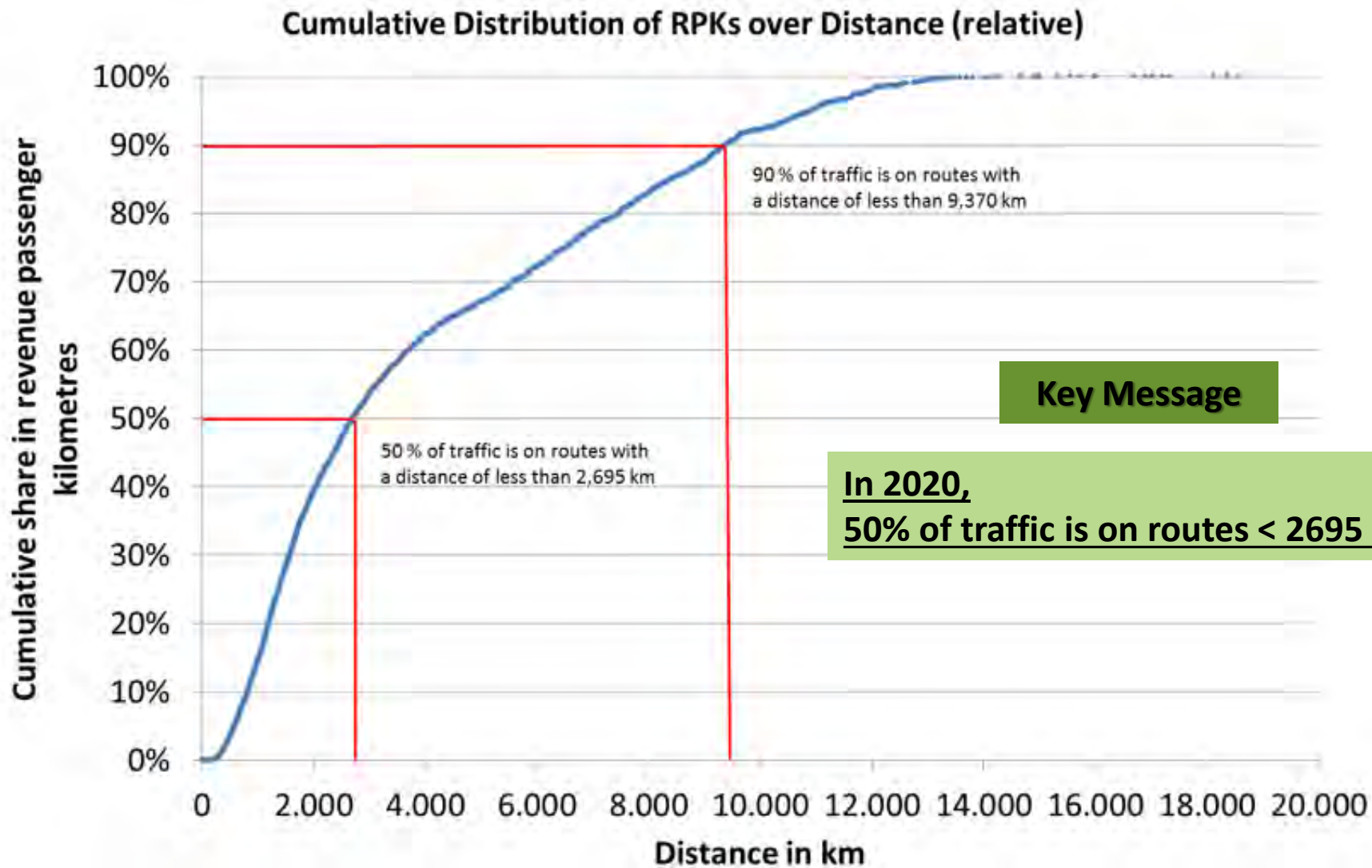


Figure 61 – Cumulative distribution of RPKs versus distance flown (Sabre Market Intelligence).



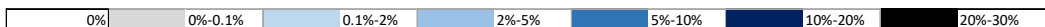
Aircraft Class	Seats	Flight Distance (km)											CO2	Flights	Passenger-km	
		0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000				
Commuter	0-19													0,08%	2,0%	0,03%
Extra-Small	20-100													4,3%	23,1%	3,6%
Small	101-210													37,3%	58,9%	41,9%
Medium	211-300													25,6%	10,3%	24,5%
Large	>300													32,7%	5,6%	29,9%
CO2		17%	22%	12%	8%	5%	5%	6%	5%	5%	5%	9%	Share of total in 2020			
Flights		55%	28%	9%	3%	1%	1%	1%	1%	0%	0%	1%				
Passenger-km		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%				

**2020**

Aircraft Class	Seats	Flight Distance (km)											CO2	Flights	Passenger-km	
		0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000				
Commuter	0-19													0,04%	1,5%	0,01%
Extra-Small	20-100													1,1%	9,6%	0,8%
Small	101-210													11,7%	33,7%	12,3%
Medium	211-300													26,8%	28,1%	22,0%
Large	>300													60,3%	27,2%	64,8%
CO2		19%	26%	14%	8%	4%	5%	5%	4%	4%	4%	6%	Share of total in 2050			
Flights		54%	28%	8%	3%	1%	1%	1%	1%	1%	1%	1%				
Passenger-km		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%				

**2050**

Share of total flights



## Key Message

**In 2050,**  
**Flight Volumes are shifted**

- **To large seat classes**
- **On short routes < 3000 km**

## AIR TRAFFIC CARBON EMISSIONS IN 2050



*In 2050, more than 55% of CO<sub>2</sub> emissions will come from medium and large aircraft on short-medium haul flights (<4000km). These two aircraft categories will account for about 55% of flights, compared to 15% in 2020.*



		Flight Distance (km)													
Aircraft Class	Seats	0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000	CO2	Flights	Passenger -km
Commuter	0-19												0,08%	2,0%	0,03%
Extra-Small	20-100												4,3%	23,9%	3,6%
Small	101-210												37,3%	58,3%	41,9%
Medium	211-300												25,6%	10,2%	24,5%
Large	>300												32,7%	5,6%	29,9%
<b>CO<sub>2</sub></b>		17%	22%	12%	8%	5%	5%	6%	5%	5%	5%	9%	<b>Share of total in 2020</b>		
<b>Flights</b>		55%	28%	9%	3%	1%	1%	1%	1%	0%	0%	1%			
<b>Passenger-km</b>		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%			
													<b>2020</b>		


**Key Message**

**In 2050,**  
**CO2 emissions are shifted**

- **To large seat classes**
- **On short routes < 3000 km/4000km**

		Flight Distance (km)													
Aircraft Class	Seats	0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000	CO2	Flights	Passenger -km
Commuter	0-19												0,04%	1,5%	0,01%
Extra-Small	20-100												1,1%	9,6%	0,8%
Small	101-210												11,7%	33,7%	12,3%
Medium	211-300												26,8%	28,1%	22,0%
Large	>300												60,3%	27,2%	64,8%
<b>CO<sub>2</sub></b>		19%	26%	14%	8%	4%	5%	5%	4%	4%	4%	6%	<b>Share of total in 2050</b>		
<b>Flights</b>		54%	28%	8%	3%	1%	1%	1%	1%	1%	1%	1%			
<b>Passenger-km</b>		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%			
													<b>2050</b>		

Share of total CO2 emissions: 0% 0%-0.1% 0.1%-2% 2%-5% 5%-10% 10%-15%

**A VERITABLE “SKY-BUS” “People Mover”** 

Like the famous London double-deckers, high passenger capacity will be key to responding to air traffic demand in the future, especially on short-haul routes (<4,000km). As a result of airport capacity constraints, a veritable “aerial autobus” of large capacity will be required to move passengers from city to city mostly on intra-continental flights.

- Overall Timeline, Technology Mapping and Update of Existing Models
  - All SPDs (Mapping) – All Concepts
- New/Updated Reference Vehicles
  - FRC (RACER / NGCTR)
  - BJ
- New Engine and Aircraft Models
  - SAT: Serial Hybrid-Electric Concept + SAT Conv TP (SAFRAN)
  - REG: Reg. 130 pax GTF – MTU (ADORNO)
  - SMR+: New Config. + New engine (VPF)
  - SMR++ update
  - LR++
  - **WB-SR (~500pax - ~3000/4000km) – People Mover**
- New/alternative assumptions for forecast and scenarios (COVID)
- Updated Socio-Economic Impact – See Roland Berger Study.
- Updated Environmental Impact



# Take-Away (3)

## Technology Evaluator First Global Assessment 2020

### FIRST GLOBAL ASSESSMENT RESULTS – 2020

MISSION LEVEL ASSESSMENT			
CONCEPT MODEL	-CO <sub>2</sub>	-NO <sub>x</sub>	NOISE
Long Range	-13%	-38%	< -20%
Short-Medium Range	-17% to -26%	-8% to -39%	-20% to -30%
Regional	-20% to -34%	-56% to -67%	-20% to -68%
Commuter and Business Jet	-21% to -31%	-27% to -28%	-20% to -50%
AIRPORT LEVEL ASSESSMENT			
	-CO <sub>2</sub>	-NO <sub>x</sub>	NOISE AREA
Airport Level	-8% to -13.5%	-6.5% to -10.5%	-10% to -15%
FLEET LEVEL ASSESSMENT			
	-CO <sub>2</sub>	-NO <sub>x</sub>	FLEET RENEWAL
Global Fleet Level	-14% to -15%	-29% to -31%	70% to 75%**

\*\* Percentage of aircraft replaced by Clean Sky 2 technology aircraft concepts by 2050

# Skip-a-Generation !

The  
**MOST  
EXCITING  
TECHNOLOGICAL  
DECADE**  
for AERONAUTICS  
IS  
**BEGINNING**

- »»»»»»»» **Clean Sky 2 is well on-track > Substantial Progress already made**
- »»»»»»»» **Keep pushing the envelope > ‘traditional’ aeronautical sciences**
- »»»»»»»» **Non-traditional sciences > key enablers**
- »»»»»»»» **Replacing ~75% of the global fleet by 2050**
- »»»»»»»» **Simulation, digital twin and innovative certification**
- »»»»»»»» **Life-cycle aspects and recyclability**



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Co-funded by  
the European Union

# Hybrid-Electric & Hydrogen ?

Ref: Awa2021-0207536 - 03/04/2021

10<sup>th</sup> EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUROCAST)

## Hydrogen-powered propulsion aircraft: conceptual sizing and fleet level impact analysis

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**Abstract**  
 The development of hydrogen-powered aircraft has recently become a topic of major interest, presenting the opportunity to eliminate CO<sub>2</sub> emissions. This paper describes the potential impact of introducing hydrogen (H<sub>2</sub>) power, both at aircraft and fleet level. Three passenger aircraft for varying ICAO seat classes were modelled with future entry-into-service (EIS) and with H<sub>2</sub>-powered propulsion. The modelling results were applied in a global fleet level analysis with varied traffic development scenarios. The analysis and results in terms of gross energy consumption and emissions (CO<sub>2</sub>, NO<sub>x</sub> and H<sub>2</sub>O) are detailed.

**1. Introduction**

Anthropogenic climate change and environmental impact are increasingly addressed by governments, international bodies, and industry. In the 2015 Paris Agreement [1], the participating countries set the goal of limiting the global temperature increase well below 2°C above pre-industrial levels and pursuing efforts to limit this to 1.5°C. This means that net CO<sub>2</sub> emissions should be reduced to zero by 2070 or 2050, respectively [2]. In 2019, the European Commission through its Green Deal announced the objective of Europe to become the first climate-neutral continent by 2050 – a target that has subsequently been implemented in the legally binding European Climate Law [3],[4]. This further stipulates a reduction of CO<sub>2</sub> emissions of 55% across the European industry by 2030, compared to levels in 1990.

For aviation specifically, Europe set environmental goals as part of Flightpath 2050, launched in 2011 [5]. Through successive technology research programmes - such as Clean Sky and Clean Sky 2 (CS2) - Europe is accelerating the progress towards the Flightpath 2050 with high level objectives for reduction of CO<sub>2</sub>, NO<sub>x</sub>, and noise emissions to be achieved through development of new aircraft and propulsion technologies [6],[7],[8]. Recently, aviation industry's commitments towards net-zero CO<sub>2</sub> have grown, as exemplified in Europe by Destination 2050 [9] and the Clean Aviation Strategic Research and Innovation Agenda [10], and addressed globally by work of the Air Transport Action Group and the International Air Transport Association [11],[12].

Recently, the development of hydrogen-powered aircraft has become a topic of major interest, presenting the opportunity to eliminate CO<sub>2</sub> emissions. Hydrogen (H<sub>2</sub>) for propulsion cannot be used in current transport aircraft, e.g. because of the absence of adequate H<sub>2</sub> storage systems. Disruptive technologies to enable H<sub>2</sub>-powered aircraft are investigated in one of the three pillars in Clean Aviation [10]. Novel aircraft propulsion concepts are being studied either with H<sub>2</sub> combustion engines, H<sub>2</sub> fuel cells (FC) or a combination of both (e.g. [13], [14], [15]). In particular the so-called use of Liquid Hydrogen (LH<sub>2</sub>) is under investigation, taking advantage of its more compact storage potential in comparison to compressed Gaseous Hydrogen (GH<sub>2</sub>).

The CS2 Coordination and Support Action TRANSCEND [16] (Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains [7]) has investigated what alternative energy sources for aviation and novel aircraft propulsion can contribute to mitigating climate change and achieving the environmental goals for 2050. This paper addresses the potential environmental impact of aircraft propulsion based on H<sub>2</sub> as studied in TRANSCEND. The performance and emissions potential were assessed for regional and short medium range (SMR) flights, both at aircraft and fleet level. For three different ICAO seat classes within the 20-300 seats range, H<sub>2</sub>-powered configurations were conceptually sized and assessed in terms of mission energy consumption and emissions. Propulsion based on H<sub>2</sub> combustion in gas turbines, on H<sub>2</sub> FC electric power and on combinations of these two using parallel hybrid electric propulsion (HEP), were addressed.

The remainder of this paper is structured as follows: Section 2 summarizes the approach followed for H<sub>2</sub>-powered aircraft and fleet modelling. In section 3, the H<sub>2</sub>-powered aircraft conceptual sizing process, as well as the main sizing

<sup>1</sup> More information about TRANSCEND is available at the project website, <https://transcend.ris.allissonline.nl/>.

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AN AVIATION CLEAN SKY 2

Carbon / climate-neutral system over the next 10-20 years. **Integration with hydrogen technologies can help to meet the drastic reduction target**

on hydrogen's potential for use in aviation, water transport, and **Patrick Child**, Deputy Director-General, in addition to leading industry **David Burns** (VP Global Business Development, Airbus), **Andreas Hartmann** (Chief Technology Officer, German Aerospace Centre - DLR).

use hydrogen in thermal (gas turbine) engines or as a building block for hydrogen-powered aircraft. Costing **less than €18 [\$20] extra per seat**, hydrogen-powered aircraft could play a key role in the future mix of aircraft and propulsion technologies.

development of fuel cell technology and liquid hydrogen-powered aircraft. This paper addresses the potential environmental impact of aircraft propulsion based on H<sub>2</sub> as studied in TRANSCEND. The performance and emissions potential were assessed for regional and short medium range (SMR) flights, both at aircraft and fleet level. For three different ICAO seat classes within the 20-300 seats range, H<sub>2</sub>-powered configurations were conceptually sized and assessed in terms of mission energy consumption and emissions. Propulsion based on H<sub>2</sub> combustion in gas turbines, on H<sub>2</sub> FC electric power and on combinations of these two using parallel hybrid electric propulsion (HEP), were addressed.

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## Hydrogen-powered aviation

A fact-based study of hydrogen technology, economics, and climate impact by 2050

May 2020

consequently sufficient investment