Towards Climate Neutral Aviation

An independent study on the socioeconomic impact of the European Union’s Clean Sky 2 Programme
THIS STUDY WAS COMMISSIONED BY THE CLEAN SKY 2 JOINT UNDERTAKING AND WAS PREPARED BY ROLAND BERGER AND OXFORD ECONOMICS, AND WAS CONDUCTED WITH INPUTS AND CONTRIBUTIONS FROM A WIDE ARRAY OF STAKEHOLDERS ACROSS THE AEROSPACE AND AVIATION ECOSYSTEM IN EUROPE AND GLOBALLY. THE FINDINGS REPRESENT AN AGGREGATION OF THE VIEWS GATHERED THROUGH INTERVIEWS WITH INDUSTRY LEADERS, INDUSTRY EXPERT SURVEYS, AS WELL AS PROJECT EXPERIENCE AND KNOWHOW FROM ROLAND BERGER AND OXFORD ECONOMICS, COUPLED WITH DETAILED ANALYTICAL MODELLING AND SCENARIO-BASED FORECASTS.

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Aviation makes a significant economic contribution through the operation of airlines and airports, and through aerospace manufacturing and services. It also enables tourism and has broader impacts through associated supply chain and worker spending effects. We estimate that aviation accounted for 4.5% of European GDP and employment as of 2019 — and is expected to support up to 18.5 million European jobs by 2050.

Beyond its own economic footprint, aviation also brings benefits to almost all parts of the economy by supporting international trade, investment, and knowledge transfer. This ultimately enhances economic competitiveness. Continued connectivity growth beyond 2025 levels could enable annual productivity increases of EUR 5,300 per worker in 2050.

Concurrently, there is a need to reduce the environmental costs of aviation and the Clean Sky 2 (CS2) programme is investigating how technology can be used to achieve this. Our modelling suggests that CS2 research could deliver economic benefits worth EUR 8.6 billion to Europe — equivalent to 3.4 times the investment in the programme — by increasing productivity in aerospace and related sectors, and by making European aerospace more attractive to foreign investors (all values calculated in real, present value terms).

While harder to quantify and attribute, our modelling suggests that incorporating CS2 technologies into the global aircraft fleet could deliver environmental benefits worth a central estimated value of EUR 320 billion out to 2050, of which 60% is due to CO₂ reduction and 40% due to NOₓ reduction (with further health benefits also likely to arise from reduced NOₓ and noise).

Although COVID-19 is having a major impact on aviation, the long-term socioeconomic benefits of CS2 should be largely unchanged. Post-COVID-19, aviation is expected to continue growing and double in size over 2019–2050 to ~20 trillion Revenue Passenger Kilometres (RPKs), ~25–30% less than pre-COVID-19 forecasts (these figures exclude the impact of the Ukraine crisis, for which it is still too early to determine the long-term impact). Despite delays caused by COVID-19, all CS2 work is expected to be back on schedule by 2023. Thus, despite the overall impact of COVID-19, no material effect is forecast for CS2’s socioeconomic additionality (<0.5% on estimated productive potential.

The Clean Aviation Joint Undertaking (CAJU) has been established under a new Council Regulation within Horizon Europe to build on results from Clean Sky, CS2, and other R&I programmes and establish a disruptive breakthrough towards climate neutral aviation. It will develop aircraft, their propulsion and other key systems to “enable net CO₂ reductions of up to 90% when combined with the effect of sustainable ‘drop-in’ fuels, or zero CO₂ emissions in flight when using hydrogen as energy source”; this target builds on ambitions set in Destination 2050 and is in accordance with the European Green Deal.

Under the evolutionary assumptions in our Baseline trajectory, 2050 European net CO₂ emissions reduce by ~45–50% vs. 2019 levels despite an almost doubling of RPKs. This falls significantly short of the ambitions of “net zero European aviation” set out in Destination 2050, and aspirations for “climate-neutral aviation”. Nevertheless, our analysis demonstrates that it is indeed possible to approach climate neutrality through significant adoption of hydrogen-powered aircraft and 100% Sustainable Aviation Fuel (SAF) uptake by 2050. The CAJU has set the right priorities and resources to develop clean and efficient 2030+ Entry into Service (EIS) aircraft (including hyper efficient conventional aircraft, hydrogen aircraft, hybrid-electric aircraft, and battery-electric aircraft) and is thus playing its part in achieving this ambition. However, further action (beyond the scope of the mandate of the CAJU) is required. Thus, in addition to the efforts by CAJU, we believe that six key recommendations should be prioritised:
1. Shorten design, development, and certification cycles
2. Accelerate adoption of 2030+ EIS aircraft
3. Reconfigure aviation and ATC infrastructure
4. Boost availability of sustainable fuels and feedstocks, including hydrogen
5. Enable the adoption of new airline network strategies
6. Develop and implement effective mitigation strategies for non-CO₂ effects

*IF EUROPE SUCCESSFULLY IMPLEMENTS THIS PLAN, IT WILL HAVE PAVED THE WAY TO CLIMATE NEUTRALITY FOR GLOBAL AVIATION*
Introduction

For decades, the aviation sector has seen sustained growth. As a driver of globalisation and commerce, the connectivity of nations has been directly linked to economic performance — with global air traffic often being cited as being tethered to global economic growth. In Europe alone, it is estimated that aviation contributed EUR 725 billion to the GDP of the EU-27 and UK, while supporting 11 million jobs in 2019 — representing 4.5% of European GDP and employment.

However, aviation also has a clear and present negative externality in the form of radiative forcing generated from carbon dioxide emissions and through non-CO₂ emissions-related effects. The total contribution of aviation to global CO₂ before the COVID-19 crisis stood at ~1 billion tonnes of CO₂, representing approximately 2.5–3% of global CO₂ emissions. Aviation also produces non-CO₂ climate forcing effects, including from nitrous oxides (NOₓ), water vapour, particulates, contrails, and contrail cirrus/aviation induced cloudiness. Though scientific understanding of these effects remains low, the total climate forcing of aviation may be 2–4x as much as CO₂ alone.

The Clean Sky 2 Joint Undertaking, a public-private partnership under the umbrella of Horizon 2020, was thus set up to “accelerate the development of cleaner air transport” technologies for earliest possible deployment. That means integrating, demonstrating, and validating technologies capable of reducing CO₂, NOₓ, and noise emissions. Besides improving the environmental impact of aeronautical technologies, including those related to small aviation, the objective of Clean Sky 2 is also to develop a strong and globally competitive aeronautical industry and supply chain in Europe.1

The 2020 Technology Evaluator First Global Assessment report estimated that by 2050, technologies arising from Clean Sky 2 programmes could ultimately help to reduce global aviation CO₂ emissions by ~15% and NOₓ emissions by ~31% per seat kilometre vs. 2014 levels. However, the impact of Clean Sky 2 goes beyond technological improvements and it is also important to quantitatively measure the socioeconomic impact that Clean Sky 2 has had and will have in the long-term — and thus be able to estimate the return on investment that funding into Clean Sky 2 represents for Europe.

However, this evaluation must be done in the context of the ongoing global SARS-CoV-2 (COVID-19) pandemic, which caused the most significant short-term shock in the history of global aviation. The recovery of the aviation sector post-COVID-19 is still ongoing, with many potential future trajectories, and is further compounded by additional uncertain variables ranging from how global regulatory regimes may develop, to the technological evolution of sustainable technologies, to how passenger preferences and expectations may evolve.2

This evaluation can then also help risk-assess the way forward for the Clean Sky 2’s successor body, the Clean Aviation Joint Undertaking (CAJU), as well as provide recommendations on how the European aviation ecosystem can chart its path to climate neutrality. This report is thus broken into three parts:

Chapter 1
Assesses the socioeconomic impact of the Clean Sky 2 Joint Undertaking so far, and more specifically the estimated and projected attainments of the Clean Sky 2 programme.

Chapter 2
Analyses the impact of the COVID-19 pandemic and forecasts how the aviation landscape may evolve post-COVID-19, including how the socioeconomic impact of Clean Sky 2 may be impacted.

Chapter 3
Develops an outlook for the aviation sector’s environmental impact, risk-assesses the Strategic Research and Innovation Agenda (SRIA) of the Clean Aviation Joint Undertaking, and provides recommendations for the European ecosystem to achieve climate neutrality.
Chapter 1
Socioeconomic impact of the Clean Sky 2 programme
Section summary

THE ECONOMIC IMPORTANCE OF AVIATION TO EUROPE
We estimate that aviation contributed EUR 725 billion to the GDP of the EU-27 and the UK and supported 11 million jobs in 2019, including from aviation-enabled tourism.
- This is equivalent to approximately 5% of European GDP and employment
- Based on low and high traffic growth assumptions from the CS2 Technology Evaluator, aviation could contribute between EUR 1.3 trillion and EUR 1.8 trillion to European GDP by 2050, and support 14–18.5 million European jobs (equivalent to 6–8% of total employment and GDP)

Air connectivity is an important promoter of international trade, investment, collaboration, and knowledge transfer, and therefore boosts the competitiveness of the European economy.
- Increases in Europe’s international air connectivity between 2025 and 2050 could boost productivity by EUR 4,000 to EUR 5,300 per employee by 2050 (in real terms and compared to a scenario in which connectivity remained unchanged from 2025)

THE IMMEDIATE ECONOMIC IMPACT OF CLEAN SKY 2
CS2 is an important source of knowledge-intensive activity for the European economy.
- CS2 projects supported by public funds and participants’ in-kind contributions will contribute an average of EUR 350 million per year to Europe’s GDP and support an average of 4,900 jobs between 2015 and 2024

CROWDING IN OF ADDITIONAL R&D DUE TO CLEAN SKY 2
The EUR 1.7 billion of public funding distributed through CS2 would, on average, be expected to stimulate an additional EUR 2.3 billion of private R&D.
- This additional private R&D may take place within aerospace, or across other parts of the economy as CS2 innovations find other applications
- The role of CS2 in stimulating private R&D could therefore be substantially greater than the EUR 940 million of in-kind private operational contributions to CS2 research projects

THE OUTCOMES OF CLEAN SKY 2 RESEARCH
The total economic benefit of CS2 to Europe’s productive potential is estimated to be 3.4 times greater than the total public and private investment in the programme.
- We estimate the economic benefits of CS2 to be EUR 8.6 billion in real, present value terms, assuming a 20-year return period and a discount rate of 4%
- This compares to the EUR 2.5 billion of public grants and in-kind private contributions invested in the programme (again, in real discounted terms)
- The economic benefits of CS2 result from the increased competitiveness of European aerospace as a result of CS2 innovations; productivity benefits spilling over to other European industries as CS2 innovations find other applications; increased foreign investment in aerospace, and broader impacts resulting from supply chain and workers’ spending

CS2 technologies are also expected to deliver substantial environmental benefits, although the value of these and the extent to which they can be attributed to CS2 is highly uncertain.
- The global social value of reduced CO₂ emissions resulting from the cleaner aviation technologies assessed in the Technology Evaluator’s study could be worth approximately EUR 200 billion between 2035 and 2050, based on an average of estimates for the value of CO₂. A further EUR 120 billion is added to this once reductions in NOx emissions are included
- The estimated environmental benefits reflect the potential impact of CS2 technologies but cannot be solely attributed to CS2 for two reasons. Firstly, commercialising and incorporating these technologies into the global fleet will require further investments outside of the CS2 programme. And secondly, the TE assumptions are based on a counterfactual in which technology remains at its 2014 level and does not progress in the absence of CS2
The aviation industry makes a significant contribution to the European economy through the operations of airlines, airports, aerospace manufacturers, and their supply chains. Connectivity enabled by air transport also promotes trade, investment, tourism, the transfer of knowledge and ideas and, ultimately, boosts Europe’s productivity and competitiveness. We start this chapter by assessing the value of these economic contributions.

At the same time, the world faces an increasingly urgent need to reduce carbon emissions and limit the harmful effects of climate change. The scale of this challenge is particularly acute for aviation, which remains heavily reliant on fossil fuels. For the aviation industry to continue to grow, and to support the growth and competitiveness of the European economy, while meeting environmental objectives, it needs to rapidly develop clean aviation technologies. The CS2 programme is an important element of Europe’s R&D efforts in this space.

To contextualise the role of CS2 and help inform the future focus of aerospace R&D, the second part of this chapter assesses the innovativeness and competitiveness of European aviation in relation to that of its two major aerospace competitors: the US and China.

We then turn to the socioeconomic impact of CS2 itself. We first consider immediate benefits, in terms of the jobs and GDP supported by the CS2 research programme. We then estimate the value of additional private R&D investment that is “crowded in” by the public funding contribution of CS2. The ultimate outcomes of CS2 are its contribution to the competitiveness of Europe’s aviation industry, and economy, more widely. To assess this we undertake econometric modelling to estimate the degree to which Europe’s GDP could increase as a result of CS2. The final part of our analysis considers the environmental benefits of CS2.

1.1 The economic importance of the aviation sector in Europe

Europe is an important global hub for aviation. In 2019, prior to the disruption caused by the COVID-19 pandemic, Europe had the second largest regional share of total passenger traffic, at 26.8%, just ahead of North America (22.2%) but behind Asia Pacific (34.7%).

Europe is also one of the world’s dominant forces in aerospace manufacturing, with the EU-27 and UK producing nearly a quarter of all world output in the sector in 2019, second only to the 50% of world output produced by the US in that year.

These major European industries generate a significant amount of value for the region’s economy in both the short- and the long-term. Each year these industries support jobs and GDP, directly, through their supply chains and workers’ spending, as well as through the international tourism spending facilitated by air travel. Over the longer term, the connectivity made possible by the aviation sector helps to bring economic advantages, facilitating trade and collaboration.

In this section, we demonstrate the prominent status of European aviation on the world stage by quantifying its economic footprint, both in recent years and in projections out to 2050. We also highlight the broader contribution that aviation makes through its impact on connectivity.

1.1.1 The economic footprint of the global aviation sector

To estimate the global economic footprint of the aviation sector, Oxford Economics used a standard means of analysis known as an “economic impact assessment”. This considers the economic impact of an industry across three core channels of impact:

- **The direct impact** of the sector itself, which here incorporates the activities of airlines, airports, and aerospace manufacturers
- **The indirect impact** within the aviation sector’s supply chains. For example, airlines’ purchases of fuel, aerospace manufacturers’ purchases of components, etc.
- **The induced impact** which arises as those employed in aviation and its supply chains spend their wages in
the wider economy. This particularly benefits consumer-facing sectors such as retail, hospitality, and leisure.

- On top of these core contributions, the aviation sector has a further impact through the international tourism it enables. Visitors arriving in a country by air spend money in their destination country, supporting direct economic impacts in sectors such as accommodation, restaurants, and shops. These expenditures also have wider impacts through supply chain and worker spending effects. We refer to this as the tourism catalytic impact.

Adding together these four channels of impact provides the total economic footprint of the aviation sector.6

Our estimates were developed using Oxford Economics’ Global Economic Impact Model. This is based on an approach known as “input-output” modelling and uses underlying data from the OECD. This type of model is similar to that used in previous economic impact studies for the aviation sector, including those for the US Federal Aviation Administration,7 the Air Transport Action Group (ATAG),8 and the International Air Transport Association (IATA).9 Further detail is provided in the Appendix.

### 1.1.1 The economic footprint of the global aviation sector in 2019

We define the aviation sector for this study as passenger and freight air transportation; airports, including ground handling, air traffic control, and other on-site services such as retail and food service, and the civil component of aerospace manufacturing (excluding space).

We estimate that in 2019, the aviation sector, including the tourism catalytic impact that the sector enables, contributed EUR 3.0 trillion to global GDP. Of this, the sector’s own operations had a direct impact of EUR 750 billion, meaning that for every EUR 100 that aviation directly contributed to global GDP, a further EUR 310 was supported elsewhere in the economy.

The aviation sector in the EU-27 plus the UK supported EUR 725 billion in GDP, a little below the contribution of the US aviation sector at EUR 885 billion.

As well as the contribution to global GDP, we estimate that the worldwide aviation sector supported a total of 90 million jobs, including a direct impact of 11 million jobs. This means that for every 100 jobs supported directly by the aviation sector, a further 700 jobs were supported elsewhere in the economy. → A

### 1.1.2 Forecasts of the footprint of the global aviation sector to 2050

As lower-income countries continue to develop and grow richer, we expect to see increasing demand for aviation services in the years ahead. In particular we expect to see faster growth in the economic contribution of airlines and airports in lower-income countries outside of Europe and the US due to faster economic expansion in these nations.

Similarly, while only a relatively small number of countries have significant aerospace manufacturing sectors, China is one nation with a developing capability in this area and it is expected to slowly take market share from Europe and the US in the decades to come.

We project aviation’s global economic footprint out to 2050, based on air traffic forecasts from Technology Evaluator (TE) analysis, which includes both a high and a low scenario for air traffic.10

In the low scenario, global aviation passengers are forecast to rise from 4.5 billion in 2025 to just over 9.2 billion by 2050, equivalent to 2.9% growth p.a. By comparison, global aviation passengers are forecast to grow at 4.1% p.a. in the high scenario, rising to 12.2 billion in 2050. The high scenario therefore incorporates 3 billion more passengers globally by 2050 than the low scenario.

We used these passenger growth assumptions as a basis for projecting growth rates for the direct impact of each aviation sub-sector (airlines, airports, aerospace).
We used the direct impacts in each year to estimate the indirect and induced impacts for the respective sub-sector. We also used the passenger growth assumptions to forecast tourism catalytic impacts. \(^\text{11}\)

To develop forecasts of the aviation industry’s economic impact, we need to apply “driver variables” from the TE forecasts to grow forward our 2019 estimates. The table below summarises our approach to growing the direct impact of each of the three sub-sectors in our model. \(\rightarrow \text{B}\)

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**A Total economic contribution of the global aviation sector, by region, 2019**

GDP contribution, 2019 prices [EUR bn]

<table>
<thead>
<tr>
<th>Region</th>
<th>Direct</th>
<th>Indirect</th>
<th>Induced</th>
<th>Tourism catalytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>165</td>
<td></td>
<td>725</td>
<td>885</td>
</tr>
<tr>
<td>EU-27 and UK</td>
<td>725</td>
<td></td>
<td>885</td>
<td>1,265</td>
</tr>
<tr>
<td>USA</td>
<td>1,265</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest of world (RoW)</td>
<td>1,265</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**B Growth drivers used to forecast the economic impact of the global aviation industry**

**AIR TRANSPORT**
Direct GDP is grown in line with terminal revenue passenger kilometres (RPKs) from the TE forecasts.

**AIRPORTS**
Direct GDP is grown in line with terminal passengers from the TE forecasts.

**AEROSPACE MANUFACTURING**
In the short-term (out to approximately 2025) we use Oxford Economics’ in-house forecasts for the civil aerospace industry which are, in turn, based on the published order books of major aerospace manufacturers. Beyond 2025, we grow output in line with global air traffic volumes from the TE study.

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Source: Oxford Economics, Roland Berger

Source: Roland Berger
On this basis, the worldwide GDP contribution of aviation is estimated to increase from EUR 3.0 trillion in 2019 to EUR 8.4 trillion in 2050 in the Technology Evaluator’s high scenario, or EUR 6.3 trillion in the low scenario.12 These results are based on all channels of economic impact, including the tourism catalytic effect. Similarly, the global aviation sector is estimated to support a total of approximately 190 million jobs in 2050 in the high scenario, or approximately 140 million jobs in the low scenario. The breakdown by geography and impact for the high scenario is illustrated Figure C.

The total GDP contribution of the aviation sector in the EU-27 and UK is estimated to rise from EUR 725 billion in 2019 to nearly EUR 1.8 trillion in 2050 in the Technology Evaluator’s high scenario, or over EUR 1.3 trillion in the low scenario. These figures are equivalent to approximately 8% and 6% of forecast GDP in that year respectively. By 2050, the global aviation sector is projected to support 18.5 million jobs in Europe in the high scenario, or 14 million in the low scenario (again, approximately 8% and 6% respectively of total European employment in 2050). 

1.1.2 The catalytic connectivity impacts of the aviation sector

Beyond the economic contribution of its own operations and tourists’ spending, aviation brings much wider benefits to almost all parts of the European economy through the international connectivity it provides. The ability to travel swiftly between countries fosters international trade, investment, competition, the exchange of knowledge and ideas and, ultimately, enhances Europe’s long-term productive potential.

The CS2 R&D programme is designed to help reduce the environmental impact of aviation. In a world where environmental regulation is increasingly restrictive, these technology improvements could conceivably mean that more flights may operate within an acceptable environmental footprint than might
otherwise be the case. To the extent that CS2 research is successful in reducing the environmental footprint of aviation, it could help Europe to realise stronger connectivity growth than would have occurred without the research, delivering productivity benefits to the European economy.

In this section, we investigate the potential value to Europe of continued growth in connectivity if aviation can continue to expand in line with forecasts from the Technology Evaluator study.

1.1.2.1 Approach to assessing the economic value of air connectivity

There are many ways to measure the extent and importance of an aviation network, but the degree to which it connects a country with the rest of the world economy is among the most important. This concept of connectivity measures how easy it is for passengers to reach other economic centres from a particular airport, country, or region. In this study, we measured Europe’s connectivity with an Air Connectivity Index based on an approach developed by the World Bank\(^\text{13}\) that considers the degree to which each country is connected to the world economy (see Air Connectivity Index box and Appendix A for more details on the approach taken).

We undertook econometric modelling to estimate the contribution of air connectivity to labour productivity across a panel of countries, holding other factors constant. From that model we obtained a coefficient that enabled us to estimate the potential impact of changes in air connectivity on labour productivity.

For this study, we estimated changes in Europe’s air connectivity between 2025 and 2050 based on TE forecasts. This part of the process took into account

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### How air connectivity increases productivity

**DIRECT EFFECT ...**

- Increased trade
- Increased Foreign Direct Investment (FDI)

**... CREATES NEW CONDITIONS ...**

- Bigger markets for domestic producers
- Increased competition for domestic producers
- Increased transfer of know-how and technology

**... YIELDING DYNAMIC BENEFITS**

- Increased domestic innovation
- Lower-cost, higher-quality goods and services
- More-skilled workforce

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Source: Roland Berger
Air Connectivity Index

Our approach to measuring connectivity is based on existing literature, and is grounded in network analysis methods and a gravity-like model commonly used in international trade studies. This approach accounts for the hub-and-spoke nature of global air transport in a way that aggregating flights or seats data would not. Our measure of connectivity is global and aims to capture relationships between all network nodes even when there is no direct flight connection between them. Our model uses annual data for the period from 2015–2019. In contrast to many previous studies, which were based on weekly data, the use of annual data allows us to avoid biases due to seasonality or any one-off factors, such as major sporting or cultural events. We follow a two-step approach to creating our Air Connectivity Index:

1. **Estimating the connectivity value of each origin-destination pair.** To do this we use econometric analysis to determine the connectivity value of each country as an origin and as a destination against each of the other countries. Each origin-destination pair’s connectivity value is a function of its economic size, the distance between the countries, and any special characteristics (e.g., historic links between Commonwealth countries). This approach isolates any non-systematic factors that may have caused an increase in flights in some years (e.g., the Olympics). The econometric model uses data between 191 origin and destination countries.

2. **Combining the connectivity values for each origin-destination pair into an Air Connectivity Index value for each country.** We combine the estimated connectivity values from the previous step into an Air Connectivity Index for each country to account its connections to all other countries. This index value is calculated as the sum of the connectivity values for each origin-destination pair that includes that country. Our calculations to estimate the Air Connectivity Index are identical to those in the World Bank study.

Air connectivity between different European countries, and between Europe and the rest of the world (we exclude domestic flights from the analysis). Combining our estimated change in Europe’s air connectivity with the coefficients from the econometric model enabled us to estimate the contribution of expected air connectivity growth to Europe’s labour productivity growth.

We compared our findings to an alternative scenario in which European air connectivity remained unchanged at its 2025 level. The rest of the world was assumed to continue growing as projected through this time period in this counterfactual. We chose 2025 as the starting point for our analysis to avoid the period of disruption caused by the COVID-19 pandemic, during which the estimated relationship between connectivity and productivity may not hold. We have assumed this relationship returns to its pre-pandemic form in the 25 years following 2025. That is, we assume that COVID-19 does not have any lasting impact on the relationship between connectivity and productivity.

### 1.1.2.2 Connectivity impact results

We find that under the TE high traffic scenario, which features rapidly increasing connectivity, European GDP would be 5.3% higher in 2050 than if connectivity remained at 2025 levels. This is equivalent to a real terms increase in productivity per worker of EUR 5,300 in 2050. Over the whole period 2025–2050, cumulative GDP would be 2.2% higher.

Under the TE low traffic scenario, where connectivity increases more slowly, European GDP would be 4.1% higher in 2050 than if connectivity had remained at 2025 levels. This is equivalent to a real terms increase in productivity per worker of EUR 4,000 in 2050. Over the whole period 2025–2050, cumulative GDP would be 1.7% higher.

In both cases, the benefits build over the analysis period as the effects of increasing air connectivity propagate through the economy. For example,
connectivity may enable a new business contact to be made, but it may take some time for that to translate into business transactions. →

While the full value of the productivity benefit cannot be attributed to CS2, the CS2 programme seeks to accelerate the development of clean aviation technologies and secure a faster reduction in aviation’s environmental footprint. To the extent that this occurs, CS2 may enable faster connectivity growth than would otherwise be the case and unlock substantial economic value.  

1.2 The competitiveness and innovativeness of the European aerospace industry

A central objective of Clean Sky 2, and its successor Clean Aviation, is to enhance the innovativeness and competitiveness of the European aerospace industry such that it may continue to compete internationally and sustain and grow its contribution to the European economy. In considering future areas of focus for Europe’s aerospace R&D it is informative to take stock of the current level of innovativeness and competitiveness of the industry in comparison to its main international competitors.

In this chapter, we highlight how Europe performs against the US, its main competitor in the civil aerospace sector, as well as emerging competition from China. We do so by reviewing a set of indicators across the domains of competitiveness and innovation by adapting a framework developed in a previous study for the European Commission. More detail on the approach we took to adapt this framework is provided in the Appendix.

We find that Europe often outperforms the US in terms of innovativeness, but the US tends to be stronger in the competitiveness dimension. Both of
these regions are ahead of China on most measures, although labour costs are significantly lower in China than in either Europe or the US.

1.2.1 Benchmarking the competitiveness of European aerospace

We benchmark Europe’s competitiveness in aerospace manufacturing against the US and China across eight indicators. These indicators, and the rationale for their inclusion, are given below.

1.2.1.1 Indicators used

- **SME share of aerospace business population**: the share of small and medium-sized enterprises (SMEs) businesses within a sector can be indicative of the level of competition. A strong presence of SMEs may indicate lower barriers to entry and less market dominance by larger players
- **Sector business population growth**: growth in the total number of businesses within a sector also reflects the level of barriers to entry and hence scope for competitive pressures
- **Regional share of global aerospace exports**: a high share of global exports for a particular product category indicates that the region is internationally competitive. Changes in export share over time can also provide insights into whether competitiveness is growing or declining
- **Imports of inputs**: a sector that is highly reliant on imported goods may be less resilient to supply shocks. A higher reliance on imported inputs may also indicate lower competitiveness in domestic downstream sectors. A lower reliance on imported inputs and components may reflect a region’s greater capacity for domestic end-to-end aerospace production
- **Labour productivity**: higher output per worker can indicate greater competitiveness. It will typically be influenced by the level of capital and technology available to workers
- **Region’s share of global aerospace gross value added (GVA)**: a higher share of world GVA for the sector indicates greater productive capacity, suggesting a strong source of demand and potential economies of scale

Calculating an index for benchmarking

The indicators used throughout this benchmarking analysis capture a range of different concepts and are measured using different units. To provide a single, unified comparison across the different indicators, values need to be “normalised” to a consistent index scale.

To do so we calculated indicator scores as the ratio of the region’s indicator value to the best performing region. This means that the best performing region always scores 100, and the other two regions score some fraction of this figure. For instance, a region achieving a value that is 80% of the highest-scoring region would be given an index value of 80.

Depending on the indicator, the “best performing” score might represent the highest value in the underlying dataset (such as a large market share) or it might represent the lowest value in the underlying dataset (such as labour costs or emissions).

Note that in some cases it was not possible to obtain the precise data points needed for the aerospace manufacturing sector. For certain indicators we therefore report data pertaining to a broader industry, such as the “air, rail and sea transport equipment manufacturing” sector within which aerospace is classified under standard industrial definitions, or in some cases, the total manufacturing sector. This is indicated on the charts that follow.
• **Trade balance in aerospace goods:** a larger trade surplus in a category of goods indicates demand for a region’s products in the international market, suggesting greater competitiveness

• **Unit labour costs:** these reflect the ability of firms in a sector to produce goods or services at a low cost relative to productivity and profitability and therefore be price competitive in international markets. A rise in an economy’s unit labour costs represents an increased reward for labour’s contribution to output. However, a rise in labour costs higher than the rise in labour productivity may be a threat to an economy’s cost competitiveness if other costs are not adjusted in compensation.

### 1.2.1.2 Results

We find that business dynamism is a relative strength of Europe’s aerospace manufacturing industry, when measured in terms of the share of SMEs amongst the sector’s firms. The relatively high share of SMEs in Europe suggests potentially lower barriers to entry than in other markets. Data were available for the aerospace manufacturing sector for Europe and the US with SMEs accounting for 93% of European aerospace manufacturing businesses, compared to 90% in the US.

A further indication of dynamism is that Europe experienced a faster rate of growth in the number of businesses operating in the transport manufacturing sector from 2012 to 2018 (again relying on the broader rail, sea and air transport manufacturing sector due to lack of data availability).

Europe trails behind the US on five of the competitiveness indicators reviewed, including its share of global gross value added, its share of global exports, and the value of its trade balance. For the first two indicators, Europe has maintained its market share at a relatively constant level. It has, nonetheless, achieved faster growth than the US in its trade balance for aircraft and spacecraft since 2015, suggesting an element of catching up. In contrast, the growth of labour productivity in European aerospace manufacturing failed to keep pace with the US from 2013 to 2019, and so Europe is losing ground on this indicator.

Overall manufacturing labour costs as a share of GVA in China remain significantly below those in Europe and the US. While data for labour costs in aerospace manufacturing were not available for China, figures for Europe and the US show that labour costs for European aerospace manufacturing were almost 50% higher (as a share of GVA) than their US counterparts.

### 1.2.2 Benchmarking on innovativeness

In this section we benchmark Europe’s innovativeness in aerospace manufacturing against the US and China across nine indicators. The approach taken is consistent with that applied previously for competitiveness. The indicators selected for the innovativeness benchmarking, and the rationale for their inclusion, are outlined below.

#### 1.2.2.1 Indicators used

- **R&D personnel:** a higher share of R&D workers within an industry indicates a greater focus on innovation, as well as a willingness and ability to invest in new technologies.
- **Engineering graduates:** a higher share of engineering graduates within total university graduates indicates a greater capability to develop and implement new technologies.
- **Share of innovating firms:** high-level measures of sector innovation such as total R&D spend will be influenced by the largest players. Looking at the share of businesses that have engaged in innovative activity can give an indication of how widespread innovative efforts are.
- **Aerospace engineering patents:** patents are used as a measure of output from the innovation process. As such, a greater rate of patenting relative to industry size suggests a higher level of innovation.
### Summary of aerospace manufacturing sector competitiveness indicators

Index values (highest scoring region = 100)

<table>
<thead>
<tr>
<th>SECTOR OF ANALYSIS</th>
<th>EU Region</th>
<th>USA</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>SME share of population</td>
<td>Rail, sea, and air transport manufacturing</td>
<td>Europe: 95, USA: 82, China: 100</td>
<td>Europe: 95, USA: 82, China: 100</td>
</tr>
<tr>
<td>Business population growth</td>
<td>Rail, sea, and air transport manufacturing</td>
<td>Europe: 100, USA: 0, China: 3</td>
<td>Europe: 100, USA: 0, China: 3</td>
</tr>
<tr>
<td>Share of global exports</td>
<td>Aerospace products</td>
<td>Europe: 62, USA: 100, China: 3</td>
<td>Europe: 62, USA: 100, China: 3</td>
</tr>
<tr>
<td>Imported share of total inputs</td>
<td>Rail, sea, and air transport manufacturing</td>
<td>Europe: 59, USA: 49, China: 100</td>
<td>Europe: 59, USA: 49, China: 100</td>
</tr>
<tr>
<td>Labour productivity</td>
<td>Aerospace manufacturing</td>
<td>Europe: 52, USA: 18, China: 100</td>
<td>Europe: 52, USA: 18, China: 100</td>
</tr>
<tr>
<td>Share of global GVA</td>
<td>Aerospace manufacturing</td>
<td>Europe: 42, USA: 6, China: 100</td>
<td>Europe: 42, USA: 6, China: 100</td>
</tr>
<tr>
<td>Trade balance</td>
<td>Aerospace products</td>
<td>Europe: 40, USA: 0, China: 100</td>
<td>Europe: 40, USA: 0, China: 100</td>
</tr>
<tr>
<td>Labour cost</td>
<td>Total manufacturing</td>
<td>Europe: 25, USA: 17, China: 100</td>
<td>Europe: 25, USA: 17, China: 100</td>
</tr>
</tbody>
</table>

Source: Oxford Economics, Roland Berger
### Summary of Innovativeness Indicators

Index values (highest scoring region = 100)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Europe</th>
<th>USA</th>
<th>China</th>
<th>Sector of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D personnel as share of workforce</td>
<td>59</td>
<td>94</td>
<td>100</td>
<td>Rail, sea, and air transport manufacturing</td>
</tr>
<tr>
<td>Engineering graduates share of all graduates</td>
<td>67</td>
<td>33</td>
<td>100</td>
<td>All engineering</td>
</tr>
<tr>
<td>Share of innovating firms</td>
<td>85</td>
<td>99</td>
<td>100</td>
<td>Rail, sea, and air transport manufacturing</td>
</tr>
<tr>
<td>Aerospace patents per 1,000 workers</td>
<td>79</td>
<td>87</td>
<td>100</td>
<td>Aerospace</td>
</tr>
<tr>
<td>CO₂ emissions — Output ratio</td>
<td>32</td>
<td>17</td>
<td>100</td>
<td>Rail, sea, and air transport manufacturing</td>
</tr>
<tr>
<td>Energy use — Output ratio</td>
<td>40</td>
<td>55</td>
<td>100</td>
<td>Rail, sea, and air transport manufacturing</td>
</tr>
<tr>
<td>Aerospace climate change mitigation patents/1,000 workers</td>
<td>6</td>
<td>100</td>
<td>95</td>
<td>Aerospace</td>
</tr>
<tr>
<td>Number of aerospace engineering publications</td>
<td>65</td>
<td>84</td>
<td>100</td>
<td>Aerospace engineering</td>
</tr>
<tr>
<td>R&amp;D spend: GVA ratio</td>
<td>51</td>
<td>82</td>
<td>100</td>
<td>Rail, sea, and air transport manufacturing</td>
</tr>
</tbody>
</table>

Source: Oxford Economics, Roland Berger
• **Aerospace climate mitigation patents**: this factor looks at the output of innovation in greener aviation technologies. A higher rate of patenting in green technologies relative to industry size suggests a greater focus on environmental innovation

• **Manufacturing CO₂ emissions**: a lower ratio of CO₂ emissions to manufacturing output may point to a greater level of innovation in both manufacturing processes and energy production. While not specifically linked to aerospace, this indicator points to the wider environment of innovation in the technologies needed for the future

• **Energy efficiency**: pledges to reduce emissions mean that industries will need to shift towards more energy-efficient means of production. Regions with greater energy efficiency today could stand to gain a competitive advantage over their peers if energy prices rise in the future

• **Aerospace publications**: the share of academic publications on a given subject from a particular region out of the global total reflects the degree of high-level knowledge held within a region and as such, indicates the potential for a greater degree of innovation in the country

• **R&D spending intensity**: a higher level of R&D spending relative to output indicates a greater focus on innovation as well as willingness and ability to invest in new technologies

1.2.2.2 Results

The European aerospace manufacturing sector outperforms the US and China on six of the nine indicators reviewed in the field of innovativeness.

Europe leads the way with regards the share of R&D personnel in total employment in the rail, sea and air transport manufacturing sector (more specific data are not available for all three regions), as well as the flow of new engineering graduates needed to ensure a supply of labour in the future. While the US exceeds Europe in terms of the intensity of R&D spending in the broader rail, air and sea sector (included here due to limitations of data availability from China), when looking specifically at the aerospace sector, Europe is found to exceed the US on this metric.

The European aerospace manufacturing sector also has a strong relative performance with regards to innovative output, as measured by patents. However, recent trends show weakening performance in Europe compared to improving performance in the US and China. Europe slightly trails China with regards to the number of academic aerospace engineering publications, with the share of global publications from both regions remaining fairly constant since 2010. This contrasts with the US which has experienced a declining share of global aerospace publications since 2000.

With regards to environmental efficiency and innovation, Europe outperforms the US and China in both emissions and energy usage per unit of GVA in the broader rail, sea and air transport manufacturing sector, and there is evidence that Europe’s performance has been improving over recent years.

1.3 The immediate economic contribution of the Clean Sky 2 programme

While the CS2 R&D programme is aimed at bringing long-term environmental and economic benefits to Europe, CS2 research projects are themselves a source of jobs and revenues for participants, often in advanced, high-value activities. In this part of the study we estimate the immediate economic impact of CS2 research. To do this we adopt a similar economic impact assessment framework to that applied to the global aviation industry in Section 1.1.1.2 We therefore consider the economic impacts that CS2 projects support directly; through their procurement expenditures (indirect impact); and through workers’ spending (induced impacts). Once again, our estimates are based on Oxford Economics’ Global Economic Impact Model.
1.3.1 The scale of the CS2 programme

CS2 is a multi-year, European programme funded by public and private sources. From the beginning of the Joint Undertaking to the final call for participation, more than 940 organisations from 30 countries have been engaged across the entire aviation sector. Of these, 363 were small and medium-sized enterprises, 113 were research centres, 156 were universities and 308 were larger industrial partners.23

CS2 provides public grants to a broad spectrum of participants in the aviation industry, including aerospace manufacturers and their supply chains, as well as not-for-profit organisations, such as universities, and research and technology organisations (RTOs). These grants are used to fund research projects agreed jointly by the participating organisations. Private industry also makes contributions to the funding of the programme, through two channels:

- **In-kind operational (IKOP) contributions**: participating companies’ contributions to the projects they are working on. These reflect costs incurred to support the project’s operational activities, such as the value of labour and procurement costs incurred during the projects
- **In-kind additional activities (IKAA)**: costs incurred in the course of activities which fall outside of CS2’s work plan but which, nevertheless, contribute to the initiative’s objectives

Between 2014 and 2024, the total value of CS2 funding (public grants, IKOP, and IKAA) will reach EUR 3.9 billion in nominal terms, split between EUR 1.7 billion from CS2JU grants, EUR 940 million from IKOP and EUR 1.2 billion in IKAA. →

1.3.2 The in-year economic footprint of CS2 R&D activity

The most immediate benefit that CS2 funding and participation brings to the European economy is through the employment supported and the GDP contributed in the years that the R&D activity takes place.

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**CS2 funding by year and source**

Nominal [EUR bn]

<table>
<thead>
<tr>
<th>Year</th>
<th>Grants</th>
<th>IKOP</th>
<th>IKAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>226</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>438</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>456</td>
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<td></td>
</tr>
<tr>
<td>2019</td>
<td>526</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>502</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>392</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>318</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>318</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>318</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Oxford Economics, Roland Berger
1.3.2.1 The economic impact of R&D activity funded by grants and IKOP

**GDP CONTRIBUTION**

The R&D activities funded by CS2 grants and IKOP from 2015 to 2024 directly contribute an average of EUR 109 million per year to Europe’s GDP. This contribution reached EUR 182 million at its peak in 2020.

By combining the direct contribution of funding R&D activity with the supply chain and worker spending impacts, we estimate that the funding of R&D activity by CS2 grants and IKOP contributes EUR 315 million per year to European GDP from 2015 to 2024, on average. In 2020, the total GDP contribution peaked at EUR 533 million.

This means, in 2020, for every EUR 1 of GDP that CS2 research contributed directly, a further EUR 1.9 of GDP was supported elsewhere in the EU-27 and UK economies.

In line with the funding allocation, the average annual impact was mostly concentrated in Germany, France, Spain, Italy, and the UK.

**EMPLOYMENT CONTRIBUTION**

CS2 grants and IKOP contributions peaked in 2020. In that year, we estimate that more than 3,500 people worked on R&D activities funded by these two sources. In the period between 2015 to 2024, nearly 2,000 people worked on these activities each year, on average.

Bringing together the direct, indirect, and induced impacts, we estimate that CS2 grant funding and IKOP contributions supported an average of 4,900 jobs per year from 2015 to 2024. This means that for every 100 jobs directly supported by CS2 research, a further 150 jobs were supported elsewhere in the EU-27 and UK economies.

1.3.2.2 The economic impact of R&D activity funded by IKAA

The economic impact of the activities linked to the IKAA contributions was modelled separately as it cannot be directly attributed to CS2. These are activities that could have happened in the absence of CS2 but which member

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**Total GDP impact in the EU and the UK by impact channel**

By year, 2019 prices [EUR m]

<table>
<thead>
<tr>
<th>Year</th>
<th>Direct</th>
<th>Indirect</th>
<th>Induced</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>14</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>367</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>458</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>533</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>431</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>335</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>330</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2024</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>325</td>
</tr>
</tbody>
</table>

Source: Oxford Economics, Roland Berger
companies may count towards their in-kind contribution quotas as they have been determined to contribute to CS2’s broader objectives in parallel to the CS2 actions.

**GDP CONTRIBUTION**
The activities supported by the IKAA contributions from 2014 to 2024, directly contributed an average of EUR 75 million per year on average across 2014 to 2019 and EUR 11 million per year across 2020 to 2024.

By combining the direct contribution of IKAA with the supply chain and worker spending impacts, we estimate that IKAA contributed EUR 224 million per year on average from 2014 to 2019 and EUR 33 million on average from 2020 to 2024.

**EMPLOYMENT CONTRIBUTION**
In 2017, when IKAA contributions were highest, we estimate that more than 1,800 people worked on activities funded by these contributions. Across the period 2014 to 2019 the average annual direct employment contribution was 1,300, falling to 190 on average across 2020 to 2024.

Bringing together the direct, indirect and induced impacts, we estimate that IKAA contributions supported an average of approximately 3,300 jobs per year from 2014 to 2019 and 480 per year between 2020 and 2024.

**1.4 The outputs and outcomes of CS2**
Investments in science, technology, and innovation are critical drivers of economic growth and competitiveness. Indeed, the OECD finds that a 1% increase in R&D spending boosts economic productivity by up to 0.4%, which is important as it is thought that increasing productivity is “the only sustainable way to improve living standards in the long run”.

Investing in R&D brings benefits for the participating organisations, including the development of new products or more efficient processes that can help them to sustain or increase competitiveness, market share and, ultimately, profitability. R&D activity also delivers wider benefits for society as knowledge and know-how are disseminated to other industries and find other applications.

It is important to acknowledge that at the time of writing the CS2 research programme is still underway. Given the diffuse nature of benefits of R&D and time lags between technology development and the placement of new products on market it is too early to have a full understanding of what the programme will deliver. Our modelling therefore effectively represents an ex-ante assessment of the outcomes of CS2.

**1.4.1 Outputs from CS2 projects**
We start this section by reviewing management information to outline the research outputs generated by CS2 projects to date. The CS2 programme has involved more than 940 participating organisations, which on average have each participated in two projects (excluding any IKAA activity).

Between 2014 and June 2021, CS2 resulted in 2,028 research publications. These included more than 1,000 peer-reviewed papers, technical papers, books, and theses. A further 797 conference presentations were delivered.

Over the same period, a total of 271 patents were either awarded or in application stage, the majority of which were confidential. A further 148 other intellectual property (IP) applications and awards were made, across registered designs, trademarks and other IP.

**1.4.2 Private sector R&D crowded in by CS2 programme**
R&D expenditures are widely regarded as a “good thing” since they are expected to lead to greater innovation, a key driver of long-term productivity growth, and therefore living standards. For this reason, many governments have policy objectives designed to increase overall R&D investment.
One such policy is the public funding of R&D, one of the benefits of which is to stimulate additional private sector investment. This may be the case because public investment reduces the costs and risks to firms of undertaking R&D; the public sector may be willing to fund projects that are too risky or complex for private investors to finance on their own; and because public research may make new discoveries that stimulate private research in related fields.

Public funding to CS2 is designed to enable research that would otherwise not go ahead, or not go ahead at the necessary speed or scale, indicating that a large proportion of the private expenditure on CS2 projects is “crowded in”. In practice, however, there is no straightforward way to test how much of the private R&D taking place within CS2 would have occurred in a “no-CS2” counterfactual. Nonetheless, we can estimate the value of private R&D that we would expect to be crowded in using an economy-wide approach developed in previous research by Oxford Economics to investigate the impact of public R&D expenditures in “leveraging” additional private expenditures.28

For this study, we have built an econometric model that looks across a panel of European countries and estimates the extent to which variations in private R&D expenditures can be attributed to public R&D expenditures, controlling for other factors. This enables us to estimate the value of additional private R&D investment crowded in by each EUR 1 of public R&D investment. It is important to emphasise that our model is based on economy-wide data on public and private R&D expenditures, and thus is not specific to either CS2 or the aerospace manufacturing industry.29

We use the findings from our econometric model in conjunction with the value of public investment in CS2 research projects to assess the amount of further private sector R&D investment that we would expect to be stimulated by the public contributions to CS2.

Our modelling suggests that EUR 2.3 billion of private sector R&D activity is crowded in by the public grant funding to CS2. This is an economy-wide result:

<table>
<thead>
<tr>
<th>Total reported publications and total reported intellectual property applications and awards through CS2 programme, 2014–June 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conference presentations</strong></td>
</tr>
<tr>
<td><strong>Peer-reviewed papers</strong></td>
</tr>
<tr>
<td><strong>Technical papers</strong></td>
</tr>
<tr>
<td><strong>Confidential patents</strong></td>
</tr>
<tr>
<td><strong>Other publications</strong></td>
</tr>
<tr>
<td><strong>Other confidential IP</strong></td>
</tr>
<tr>
<td><strong>Public patents</strong></td>
</tr>
<tr>
<td><strong>Theses</strong></td>
</tr>
<tr>
<td><strong>Books</strong></td>
</tr>
<tr>
<td><strong>Other public IP</strong></td>
</tr>
</tbody>
</table>

Source: CS2JU, Roland Berger
some of the additional private spending will be within aerospace and some will be in other industries.

It is notable that the value of EUR 2.3 billion value is much greater than the EUR 940 million of IKOP, the CS2 private contribution that is likely to be most directly crowded in by the CS2 programme. To some extent IKAA expenditures might also be crowded in, but the conceptual link there is less direct since IKAA spending is related to, but not driven by, CS2 public grant contributions.

It is also important to highlight that while our estimate of EUR 2.3 billion of crowded in private expenditures is very similar to the sum of IKOP and IKAA, this is coincidental and our model does not seek to determine the degree to which IKOP or IKAA expenditures have actually been crowded in. In reality, some of the IKOP and IKAA expenditure may have happened in the absence of CS2, while some of the private expenditures crowded in by CS2 will accrue outside of CS2, either elsewhere in aerospace or in other industries.

While it is not feasible to assess the magnitude of each of these categories, the conceptual relationship between the various sources of expenditure can be summarised in the figure below. → K

### 1.4.3 The long-term economic impact of CS2 R&D programmes

In this section we look at the long-term impact of the R&D conducted under the CS2 programme on the economy of the EU-27 and UK. This comes through the three channels detailed in the following sections. Our overall objective from this analysis is to bring these effects together into one overall long-term net economic impact figure that may be compared to the cost of the CS2 programme.

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**K Illustrative representation of the relationship between crowded-in R&D spending and CS2 private contributions (not to scale)**

**CS2 PROGRAMME MANAGEMENT, CO-ORDINATION AND PUBLIC FUNDING**

Notes: 1 IKOP — In-kind operational contributions; 2 IKAA — In-kind additional activities

Source: Oxford Economics, Roland Berger
1.4.3.1 Contribution to the long-term competitiveness of European aerospace through new products and processes

The R&D activity that takes place within CS2 projects would be expected to lead to new or improved products and processes. These enhance the European aerospace industry’s offer and competitiveness, enabling European aerospace manufacturers to make a greater economic contribution than would otherwise have been the case.

These benefits may result directly from CS2 innovations, or indirectly as knowledge and know-how developed through CS2 research is disseminated across the industry and feeds into other innovations. Oxford Economics has previously developed an econometric model to explain how R&D expenditure in different sectors contributes to productivity growth by stimulating innovation and enhancing the skills of the labour force. To do so, we constructed a dataset comprising R&D expenditure by sector and country, over time. We supplemented this with data on total factor productivity (TFP) from the EU "KLEMS" dataset, as well as a set of control variables to control for differences in institutional factors and workforce skills. The resulting macro-econometric model enabled us to estimate the value of productivity uplift that would be expected to accrue to each sector as a result of a given amount of R&D investment within that same sector.

For this study we combined coefficients from that model with data on CS2 R&D spending to estimate the extent to which CS2 boosts productivity within the aerospace sector.

1.4.3.2 The wider contribution of CS2 to the European economy through spillovers

Knowledge and know-how developed through CS2 would be expected to “spill over” into other industries. As it does so it may stimulate further innovation and drive economic benefits for other parts of the European economy. In this way CS2 will contribute to Europe’s long-term productivity growth and economic competitiveness, outside of aerospace manufacturing.

To estimate the value of spillover benefits that R&D investment stimulates in other industries, we supplemented the TFP model described previously with information on the strength of supply chain relationships across industries and countries, based on input-output (IO) tables. This enabled us to estimate the degree to which R&D spending in one sector results in productivity benefits in the rest of the economy.

For this study we re-estimated the variable capturing the strength of supply chain relationships to align with the economic structure of the EU and UK economy. By combining this new variable with coefficients from the original model and CS2 spending data, we could estimate the value of productivity benefits stimulated by CS2 outside of aerospace manufacturing.

1.4.3.3 Contribution to the long-term competitiveness of European aerospace through increased foreign direct investment

The presence of a major programme of aerospace R&D would be expected to create “localisation” benefits as aerospace companies seek to locate in Europe to capitalise on the knowledge and skills developed through the programme.

Oxford Economics has previously investigated this using a model to estimate how R&D spending influences the decisions of firms to invest in an economy. This model is based on a micro-econometric framework to investigate the determinants of firm-level decisions regarding manufacturing projects across a variety of industries. One of the determinants in the model is R&D funding, which enables us to estimate the degree to which R&D investment within an industry leads to increased foreign direct
investment (FDI). We can use that initial FDI effect to estimate the impact on GDP.

For this study, we used that model in conjunction with data on the value of CS2 R&D investment to estimate the value of additional FDI in the European aerospace industry that arises as a result of spending on CS2 R&D. From there we could assess the degree to which CS2 could increase the economic contribution of European aerospace by making the industry more attractive to foreign investors through increased foreign investment.

1.4.3.4 The overall long-term contribution of CS2 R&D to the European economy

Each of the effects described previously increases profitability in aerospace and other related sectors, attracting further capital and labour to the sectors, driving their expansion. The increased size of those industries means that they increase procurement spending, while higher wages support higher levels of spending in the consumer-facing economy.

We use a “computable general equilibrium” (CGE) model to assess the total net contribution of these effects to European GDP. That is, within the CGE framework we simultaneously model the impact of increased competitiveness in the aerospace sector; spillovers to other industries; increased FDI; and the subsequent impacts in supply chains and through workers’ spending associated with each of these three effects. This enables us to estimate the overall net impact of CS2 on European GDP.

To estimate the full extent of all the benefits outlined here and report them as a single present value, we make several assumptions, set out in the box on this page.

On this basis, we estimate that over the 20-year benefit accrual period, CS2 R&D projects funded by public sector grants and by IKOP contributions could contribute a total of EUR 8.6 billion to the economy of the EU-27 and UK (in 2019 prices and discounted back to 2022). The majority of this impact (EUR 6.4 billion) results from R&D-driven productivity boosts in the aerospace industry and associated knock-on effects through the economy. Much of the remainder results from productivity benefits in sectors benefitting from technology spillovers, with a further small contribution from the impact of the aerospace industry attracting greater international investment.

Assumptions used in long-term benefit modelling

Benefits take 10 years to begin to materialise, reflecting the relatively early-stage focus of CS2 R&D and expected lags before the resulting new products and processes are adopted by the aviation industry. This assumption was supported by the findings of our econometric modelling.

Benefits accrue for 20 years following this “gestation” period, reflecting a conservative estimate of the period during which these innovations maintain a useful asset life. The 20-year period was selected to align with the typical production cycle for an aircraft.

A discount rate of 4.0% per year, in line with European Commission guidance for cost benefit assessments. This reflects that society places greater value on benefits that accrue nearer in the future.

A depreciation factor of zero is applied. Depreciation can be applied to represent an innovation losing relevance. However, we assume no loss of relevance during the relatively short time frame over which we assume benefits will accrue.
The EUR 8.6 billion economic impact compares to total IKOP and CS2JU grant contributions of EUR 2.5 billion on an equivalent basis. Overall, this means that economic benefits are 3.4 times greater than the value of public and private investment in the programme. If we also include private sector contributions through IKAA, this gives a total contribution of EUR 13.3 billion to the economy of the EU-27 and UK, in 2019 prices and discounted back to 2022. Comparing this figure to the total financial contributions of EUR 3.8 billion (CS2JU grants plus private sector IKOP and IKAA contributions in real, present value terms), indicates an economic benefit to cost ratio of 3.5.

This result reflects the quantifiable net economic benefits of CS2. A further potential source of economic benefit, which we were not able to quantify for this study, could arise if CS2 technologies enable stronger growth in Europe’s air connectivity than would otherwise have been possible within a given set of environmental constraints. To the extent this is the case, the economic benefits of CS2 could be greater than indicated here (as set out in Section 1.1.2).

**1.4.4 Environmental benefits arising from the CS2 programme**

**1.4.4.1 Global environmental impact of CO₂ reductions**

In addition to boosting the economic competitiveness of European aerospace and the economy more widely, CS2 research is expected to deliver new technologies that will make aviation greener in the decades ahead. In this section, we attribute monetary values to the environmental benefits expected to arise from CS2 R&D to provide a more comprehensive picture within our socioeconomic assessment.

The Technology Evaluator’s First Global Assessment Report projected CO₂ emissions reductions based on an aircraft fleet in 2050 that incorporates advanced clean technology arising from CS2 R&D activity. We used this published information in conjunction with updates provided to Oxford Economics by the TE study team to estimate CO₂ reductions from 2035 to 2050.
It should be noted that the counterfactual for this assessment is a global fleet based on technologies that were available in 2014, rather than the likely state of aviation technology in 2050 in a world where CS2 R&D was not performed. In addition, this counterfactual assumes further investment in R&D outside of CS2 to fully develop and commercialise the technologies, and subsequent investment by airlines to adopt the technologies. As such the emission reductions cannot all be attributed to CS2 and incorporated into the benefit-cost ratio for the programme. Nonetheless, the emission reductions illustrate the potential impact of research into cleaner aviation technology around the world, compared to a situation where the environmental impact of aircraft remains unchanged.

We use estimates of the value of carbon based on two concepts:

- The "social cost of carbon" (SCC) which aims to capture the present value of the damage costs associated with an additional tonne (1,000 kg) of CO₂ emissions; and
- The "shadow price of carbon" (SPC), an approach which estimates the cost to society from reducing CO₂ emissions in line with emission and climate change targets

We source these estimates from three major studies on the social cost of carbon, as well as six estimates of the shadow price of carbon from governments and non-governmental organisations. These studies provide estimates of the value of CO₂ in the years out to 2050, giving a range of values for 2050 CO₂ emissions from EUR 230 to EUR 840 (per tonne, in 2019 prices). The median of this sample gives a value of carbon dioxide emissions in 2050 of EUR 300, in 2019 prices. We have tested this figure with industry experts and believe it to be a suitable figure for the purposes of our analysis. However, given the uncertainty around the value of carbon to use, we present our results in the form of a range, taking the median purely as a central estimate of that range.

Applying the range of estimates for the value of carbon set out here to the CO₂ emission reductions estimated by the TE assessment produces estimated savings in the value of CO₂ emissions of between EUR 130 billion and EUR 490 billion. These figures are all discounted back into 2022 terms using the European Commission’s recommended 4.0% discount rate.

As indicated, given the uncertainty of the assumptions used in calculating these estimates, we take the median of these figures as a central estimate. This gives a central value of approximately EUR 200 billion for the CO₂ emissions reduced by CS2 technologies in comparison to a global fleet with technologies no newer than 2014.

1.4.4.2 Global environmental impact of NOₓ reductions

The findings outlined previously may be considered conservative since they only consider environmental benefits from reductions in CO₂ emissions. Further benefits are expected to accrue through a reduction in a group of nitrogen oxide gases known as NOₓ, which contribute indirectly to global warming by affecting the persistence of methane and by reacting with other gases to form ozone, both of which have direct warming effects. Cleaner aircraft technologies, such as those made possible by CS2 R&D activity, help to reduce NOₓ emissions.

As with the CO₂ evaluation, the TE’s impact assessment provides estimates of the reduction in NOₓ emissions in 2050. Based on further information supplied by the TE, we have updated these estimates for 2050 and also estimated reductions in the period from 2035 to 2050.

It is not straightforward to directly estimate the impact of NOₓ on global warming. Instead, we first convert NOₓ emissions into CO₂-equivalent (CO₂e) emissions. We do this based on academic literature that provides estimates of the weight of CO₂ and NOₓ emitted from one kilogram of jet fuel, as well as the respective global warming effects.
**Estimates of the value of global CO₂ emissions reduced between 2035 and 2050 by cleaner aircraft technology, compared to global fleet with technology no newer than 2014, based on TE high traffic scenario.**

Total value of carbon saved, 2019 prices [EUR]

<table>
<thead>
<tr>
<th>Source</th>
<th>Value (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIB high SCC</td>
<td>132</td>
</tr>
<tr>
<td>IWG high damage estimate SCC</td>
<td>140</td>
</tr>
<tr>
<td>Nordhaus central 2.5% discount SCC</td>
<td>149</td>
</tr>
<tr>
<td>EC central SPC</td>
<td>196</td>
</tr>
<tr>
<td>IPCC low overshoot</td>
<td>203</td>
</tr>
<tr>
<td>Median</td>
<td>204</td>
</tr>
<tr>
<td>UK BEIS central SPC</td>
<td>205</td>
</tr>
<tr>
<td>Norway government central SPC</td>
<td>288</td>
</tr>
<tr>
<td>Nordhaus central zero time preference rate SCC</td>
<td>387</td>
</tr>
<tr>
<td>Strategie France central SPC</td>
<td>434</td>
</tr>
<tr>
<td>EIB central SPC</td>
<td>490</td>
</tr>
</tbody>
</table>

Source: Oxford Economics, Roland Berger
**Estimates of the social cost saving of the global CO₂ and NOₓ emissions reduced between 2035 and 2050 by cleaner aircraft technology, compared to global fleet with technology no newer than 2014, based on TE high traffic scenario**

Total value of CO₂-equivalent saved, 2019 prices [EUR]

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Value of CO₂-Equivalent Saved (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIB high SCC</td>
<td>211</td>
</tr>
<tr>
<td>IWG high damage estimate SCC</td>
<td>223</td>
</tr>
<tr>
<td>Nordhaus central 2.5% discount SCC</td>
<td>237</td>
</tr>
<tr>
<td>EC central SPC</td>
<td>312</td>
</tr>
<tr>
<td>IPCC low overshoot</td>
<td>323</td>
</tr>
<tr>
<td>Median</td>
<td>324</td>
</tr>
<tr>
<td>UK BEIS central SPC</td>
<td>326</td>
</tr>
<tr>
<td>Norway government central SPC</td>
<td>458</td>
</tr>
<tr>
<td>Nordhaus central zero time preference rate SCC</td>
<td>615</td>
</tr>
<tr>
<td>Strategie France central SPC</td>
<td>691</td>
</tr>
<tr>
<td>EIB central SPC</td>
<td>780</td>
</tr>
</tbody>
</table>

**CO₂** | **NOₓ**

Source: Oxford Economics, Roland Berger
of these amounts of emissions. This allows us to establish a relationship between the two and hence estimate a CO₂ equivalency ratio. Upon the advice of expert stakeholders, emissions were translated into terms of “radiative forcing” (i.e., the extent to which they cause global warming) using a metric known as GWP50, or global warming potential over 50 years. While there is no generally-accepted approach for this conversion, the expert stakeholders we consulted with, suggested that the GWP50 approach is reasonable for the purposes of this study. Appendix C.3 gives more detail on the reasoning behind this choice.

Once we have established the amount of NOₓ emissions saved globally as a result of aviation R&D in CO₂e terms in the years from 2035 to 2050, we again apply a range of values for CO₂ to put a financial estimate on the value of these saved emissions.

Multiplying the estimates of NOₓ emission reductions from the TE assessment by the estimates of the value of CO₂ gives estimates of the impact of reducing emissions, which are then discounted back to 2022 values. These are added to the previously-calculated value of reductions in CO₂ itself.

These results highlight how looking solely at the impact of CO₂ reductions in aviation provides a conservative estimate. Adding the NOₓ emission reductions produces a figure that is approximately 60% higher than the CO₂ emissions alone. By taking the median of this sample, we obtain a central estimate of the total value of CO₂ and NOₓ emissions reduced of approximately EUR 320 billion.

1.4.4.3 Health impacts of NOₓ and noise reductions

Aside from the global climate change impacts of CO₂ and NOₓ emissions, aircraft emissions also have health impacts. In particular, NOₓ emissions cause respiratory health problems globally, and the noise emitted around airports has quality of life impacts. In this study, we do not seek to put a global value on these health impacts but instead we provide some illustrative evidence to indicate the scale that reductions in these emissions could have.

For instance, in a 2010 study, 8,000 premature mortalities per year globally were estimated to be attributable to the NOₓ emitted by aircraft at cruising altitude, and a further 2,000 to NOₓ emitted during take-off and landing. The UK government provides a “central” damage cost of approximately EUR 11,000 per tonne of NOₓ emitted by aircraft. In large part these costs are through increased mortality and decreased quality of life due to childhood asthma. Another academic study on the subject puts a global average cost on the air quality reductions caused by aviation NOₓ emissions at EUR 19,800 per tonne.

Although more detailed modelling would be necessary to robustly value the potential health benefits of NOₓ reductions that result from CS2 technologies, it is clear from the values ascribed per tonne of NOₓ as referenced here that this would likely represent a significant further source of benefit.

Similarly, noise emitted by aircraft during take-off and landing can have notable effects on quality of life for people exposed, such as annoyance from the noise or disturbance of sleep from night-time aircraft operations. Some studies suggest further knock-on effects, including reduced cognitive performance and reading ability in children, and stress-related heart disease in adults.

The European Environment Agency has previously estimated that across the 33 countries of the European Economic Area a total of 1 million people suffered from “high annoyance” due to aircraft noise and 250,000 from high levels of sleep disturbance.

The CS2 Technology Evaluator’s First Global Assessment found that across five European airports, the population living within areas affected by high noise (60–65 dB) could be 10% to 25% lower by 2050 if CS2 technologies are introduced into aircraft fleets, compared to a situation where fleets continued to use 2014 technologies. A significant reduction in the share of population affected by high aircraft noise would therefore represent further benefits attributable to the CS2 programme.
Chapter 2
Effect of COVID-19 on the aviation and aerospace sectors
No material effect of COVID-19 is forecast for the socioeconomic additionality of the Clean Sky 2 programme

The COVID-19 pandemic had a significant impact on the aviation and aerospace sectors, with demand dropping by ~60% (year-on-year) in 2020, sharply reduced production rates, severe financial pressure on both airlines and aerospace manufacturers; in addition, COVID-19 appears to have augmented concerns in Europe about the environment and therefore increased pressure to decarbonise travel.

Despite COVID-19, air travel demand is expected to continue growing in the long-term, with Revenue Passenger Kilometres (RPKs) expected to double by 2050 to ~20 trillion passenger-kilometers in our Baseline recovery trajectory; however, this represents a loss of ~1% p.a. in growth vs. pre-COVID-19 forecasts, mainly due to a worsened economic outlook, a sustained loss in business travel, and increased sustainability-related costs.

The Roland Berger Baseline RPK recovery trajectory is in line with independent projections, and is within the range of the Technology Evaluator’s low and high forecasts.

The 2050 passenger fleet is expected to consist of ~50,000 aircraft (of which ~75% are expected to be narrowbody aircraft), a ~25–30% reduction in the fleet size vs. pre-COVID-19 forecasts.

Despite this major impact on aviation, the long-term socioeconomic impact of CS2 is largely unchanged by COVID-19.

- Following delays caused by COVID-19, all CS2 work is expected to be back on schedule by 2023
- No material effect of COVID-19 is forecast for the socioeconomic additionality of the Clean Sky 2 programme (<0.5% on estimated productive potential)
2.1 Implications for the aviation sector

After the discovery of the SARS-CoV-2 virus in Wuhan, China in December 2019, governments globally imposed rigorous restrictions on public life to stem the spread of the virus through lockdowns and travel restrictions. This resulted in many industries slowing down or coming to a standstill, with real global GDP decreasing by 3.1% in 2020 compared to 2019. At the same time, demand for air travel was almost eliminated in April 2020, impacting both domestic and international air travel. The recovery since then has been a function of the emergence of new virus variants and global efforts to vaccinate against COVID-19.

The sudden drop in demand imposed a massive challenge operationally and financially for the aviation and aerospace industry. Airlines and flight infrastructure providers had to adjust operations to the reduced demand and incorporate bio-safety protocols, despite the lack of relevant historical data/precedence on which to base operational decisions (given the unique nature of COVID-19). This led to many airlines relying on financial support from governments, with global financial aid for airlines amounting to USD 243 billion by the end of September 2021. At the same time, aerospace OEMs and suppliers had to scale down production drastically, with deliveries in 2020 down by 36% for narrowbody, and 54% for widebody compared to 2019, paired with a decline in orders (~63% in 2020 vs. 2019), as well as operational challenges due to bio-safety standards, supply chain disruption. Aerospace manufacturers faced significant financial challenges, putting many jobs at risk.

2.1.1 The path to recovery

Roland Berger’s post-COVID-19 Baseline recovery forecast shows that the impact of COVID-19 on demand for passenger air travel could be as high as ~27% of 2050
RPKs, equivalent to a ~1% p.a. drop in growth rate from 2019 to 2050; the cause of this drop can be split into the following components:

- 5 years of “lost growth”, with demand for air travel only returning to 2019 levels in 2024
- A further series of factors directly related to COVID-19 including (in order of impact on 2050 RPKs): a ~20% reduction in business travel; lower economic growth post-COVID-19; and higher airline yields (i.e., ticket prices) in the short-term
- An increase in airline costs due to sustainability-related requirements (e.g., carbon prices, SAF uptake, etc.) also result in a further ~3% fall in 2050 RPKs compared to pre-COVID-19 forecasts.

Note that Roland Berger’s forecast is largely unconstrained with respect to airport capacity constraints. Only very high capacity and tightly constrained airports (mainly in Europe and North America) are treated as having limited growth potential; other regions globally are treated as being able to adapt to rapid growth, should it occur, through the development of new runways or additional airports in the region. Nevertheless, to ensure that the forecasting efforts were robust, an analysis was done to compare unconstrained and constrained versions of Roland Berger’s forecast against those from Technology Evaluator, and to judge the materiality of airport capacity constraints, finding that forecasting methodology was in line, and that the capacity constraints were not material for the forecast. See Section 2.1.3 and Figure R for a comparison of RB and Technology Evaluator forecasts.

Additionally, the effect of the ongoing Ukraine crisis, though extremely important, is not considered quantitatively in this report, with its conclusion and long-term effect highly uncertain at the point of writing (May 2022). A qualitative evaluation of the currently known effects of the Ukraine crisis is provided in Section 2.4.

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**Baseline recovery trajectory — post-COVID-19 global RPK forecast** [trillion passenger-km]

<table>
<thead>
<tr>
<th></th>
<th>CAGR 2019–50</th>
<th>CAGR 2030–50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-COVID-19</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>incl. sustainability</td>
<td>3.8%</td>
<td>3.8%</td>
</tr>
<tr>
<td>Post-COVID-19</td>
<td>2.8%</td>
<td>2.8%</td>
</tr>
</tbody>
</table>

Source: Roland Berger
2.1.2 Potential alternate recovery trajectories

However, despite widespread removal of lockdowns and opening of borders in many European countries at the time of writing (May 2022), the SARS-CoV-2 pandemic remains an ongoing concern, with new variants still regularly arising. Thus, the path to air traffic recovery is still subject to considerable uncertainty. To account for this uncertainty, we developed two alternative recovery trajectories in addition to the Baseline.

The Baseline recovery trajectory is a continuation of the pathway the world is currently on, with new variants after Omicron of similar or lower severity continuing to emerge for several years prompting short periods of restrictions, while roll-out of vaccines and deployment of boosters continues. Recovery to pre-COVID-19 levels of RPKs is achieved by 2024.

Conversely, the Rapid recovery trajectory assumes the world returns to pre-COVID-19 levels of RPKs by 2023 with new variants after Omicron having significantly lower severity, and not triggering restrictions, while vaccine roll-out and deployment of boosters is accelerated.

Finally, the Setback trajectory assumes that new COVID-19 variants of concern keep appearing, and at least one future variant reduces vaccine effectiveness substantially (requiring the development of brand new vaccines) or has significantly higher severity than Omicron, triggering a new wave of travel restrictions and vaccine re-development, thereby delaying the recovery of RPKs to pre-COVID-19 levels to 2026.

The exact nature of the post-COVID-19 recovery varies significantly between these trajectories, each of which remains possible at the time of writing. 2050 RPKs are ~7% higher in our Rapid trajectory or ~10% lower in in our Setback trajectory. This is a result of different assumed travel restrictions, levels of short-term economic development, sustained loss in business travel and consumer behaviour.\(^4\) 

![Recovery trajectories — post-COVID-19 RPK forecast](source: Roland Berger)
2.1.3 Comparison against other notable post-COVID-19 forecasts

The Roland Berger long-term Baseline COVID-19 recovery forecast remains below the 2040 Airbus and Boeing post-COVID-19 forecasts. Though a detailed numerical comparison was not possible at an assumptions level, the difference is likely to be driven by macroeconomic assumptions (GDP growth and post-COVID-19 short-term yield increase), sustainability cost forecasts (e.g., due to carbon pricing and SAF uptake) and expectations of consumer travel behaviour evolution (especially loss in business travel). The three Roland Berger trajectories are however within the range of the Technology Evaluator post-COVID-19 Low and High forecasts. \( \rightarrow \mathcal{R} \)

By contrast, the Roland Berger long-term trajectory is very much in-line with independent forecasts by IATA, ATAG/Waypoint, ICAO and IEA. In particular, the Roland Berger forecast predicts a level of RPKs almost exactly in-line with the ATAG/Waypoint scenario and the "central" IEA Sustainable Development Scenario. \( \rightarrow \mathcal{S} \)

From a regional perspective, the pandemic had a slowing effect on the shift of air traffic towards emerging countries. The region with highest growth is still expected to be China, with a 3.8% growth p.a. in RPKs from 2019 to 2050, while North America and Europe are still expected to grow at 2.3% and 1.8% p.a. respectively. Air traffic in Rest of World\(^6\) is expected to grow at 3.2% p.a. This leads to the share of North American and European air traffic of global volumes to reduce to 20% and 17% respectively. However, this actually represents a larger share of global RPKs in 2050 than expected in pre-COVID-19 forecasts, driven largely by the response of Europe and North America to the pandemic as well as non-COVID-19 related developments, knowledge of which was refined during the pandemic (especially the impact of climate change, which hit economies of emerging countries more, as encapsulated in changes in Oxford Economics’ GDP forecasts).
S  RB/IEA/IATA comparison — post-COVID-19 global RPK forecast [trillion passenger-km]

<table>
<thead>
<tr>
<th>Source</th>
<th>CAGR 2019–50</th>
<th>CAGR 2030–50</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEA — stated policies scenario</td>
<td>3.4%</td>
<td>3.4%</td>
</tr>
<tr>
<td>IATA</td>
<td>3.3%</td>
<td>3.3%</td>
</tr>
<tr>
<td>IEA — sustainable development scenario</td>
<td>2.8%</td>
<td>2.6%</td>
</tr>
<tr>
<td>RB Baseline</td>
<td>2.8%</td>
<td>2.9%</td>
</tr>
<tr>
<td>ATAG</td>
<td>2.8%</td>
<td>2.6%</td>
</tr>
<tr>
<td>IEA — net zero by 2050 scenario</td>
<td>1.8%</td>
<td>1.8%</td>
</tr>
</tbody>
</table>

Notes: Dotted lines indicate interpolation of RPK development — IEA, IATA and ATAG numbers are point forecasts that have been linearly interpolated; Comparison only possible at results level — exact underlying assumptions unknown.

Source: IATA, IEA, ATAG, Roland Berger
Considering the European region in particular, a notable recent post-COVID-19 forecast against which a comparison can be conducted is the Eurocontrol Aviation Outlook 2050 (April 2022). Unlike the Roland Berger analysis, Eurocontrol provides its output in total IFR movements per annum (i.e., approximately equal to total number of commercial flights). The Roland Berger forecast does not estimate this value for Europe in particular, making a comparison imperfect. However, comparing annual growth rates alone, in the Baseline recovery trajectory RB forecasts RPK growth of 1.8% p.a. over 2019–2050 in Europe. Considering RB’s expected changes in aircraft gauge (seats per aircraft), load factor and average distance per flight, this would resolve to an annual increase in movements of ~1.3–1.4% p.a.

By comparison, the Eurocontrol base scenario forecasts growth in movements of ~1.2% p.a. over 2019–2050, which is a very comparable degree of growth: only 0.1–0.2% p.a. apart.

Further detail is not available from the Eurocontrol forecast to dive deeper into the specifics to disaggregate the drivers of this difference, but it could include different assumptions on the evolution of average distance per flight, average aircraft gauge, and average load factor. The difference is unlikely to be driven by network evolution, as it is assumed to undergo only evolutionary changes in both forecasts.

Nevertheless, the delta of only 0.1–0.2% p.a. adds confidence that the Roland Berger European region forecast is predicting a comparable order of magnitude of flight movements and RPKs into 2050.

2.1.4 Note on air cargo

The impact of COVID-19 on air cargo is expected to be much more muted and estimated to cause a reduction of ~5% in terms of 2050 revenue tonne-kilometres (RTKs). This is much more a result of a slowdown in the overall economic outlook post-COVID-19 than due to any change in demand drivers, which are expected to have been largely unaffected.

One consideration partially slowing down the long-term RTKs outlook is the trend towards a more localised supply chain that industry and governments may strive for in light of the massive supply chain problems which arose during the pandemic. This is especially relevant for medical equipment and pharmaceuticals, of which a large part is transported via air. Conversely, a major trend expected to cause an increase in RTKs is the increased use of digital tools and thereby the shift of local to online retail, which has a higher need for quick delivery. This is however only expected to have a second-order impact on air cargo, since major e-commerce platforms use air cargo as only one part of their larger multi-modal logistics/warehousing/delivery operation (e.g., with fast delivery processes being handled much more on a last-mile basis, without the need for air cargo).

Net of these effects, COVID-19 is not expected to markedly change the outlook for air cargo to 2050.

2.2 Implications for the fleet and aerospace sector

We estimate that the global fleet of commercial passenger aircraft will double from ~25,000 aircraft in 2020 to ~50,000 aircraft in 2050, composed of ~75% narrowbody, ~15% widebody and ~10% regional aircraft. This represents a +5% p.p. increase of global fleet share for narrowbody aircraft vs. current levels, driven by the ongoing trend towards using newer narrow(er)body aircraft to replace (older) and less flexible widebody aircraft on appropriate routes. While the significance of regional jets is expected to reduce in the mid-term due to inferior economic and ecological performance, the launch of novel propulsion type regional aircraft (including hybrid, hydrogen-powered or even battery-powered regional aircraft) over 2030–2040 is expected to lead to a long-term increase back to 2020 levels of fleet share in the Baseline case.

Considering the 2020–2040 period in a comparison against Airbus and Boeing forecasts, the Roland Berger
### Expected fleet and annual deliveries

**New deliveries (annual)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Regional</th>
<th>Narrowbody</th>
<th>Widebody</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>0.1</td>
<td>1.4</td>
<td>0.2</td>
</tr>
<tr>
<td>2025</td>
<td>0.1</td>
<td>1.5</td>
<td>0.3</td>
</tr>
<tr>
<td>2030</td>
<td>0.2</td>
<td>1.8</td>
<td>0.4</td>
</tr>
<tr>
<td>2035</td>
<td>0.3</td>
<td>1.9</td>
<td>0.4</td>
</tr>
<tr>
<td>2040</td>
<td>0.3</td>
<td>2.1</td>
<td>0.5</td>
</tr>
<tr>
<td>2045</td>
<td>0.4</td>
<td>2.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**CAGR 2020–40**

- Boeing: 3.3%
- Airbus: 3.8%
- RB: 2.4%

**Source:** Roland Berger
Baseline recovery trajectory has a lower fleet growth: Airbus and Boeing forecast growth of 3.8% and 3.3% p.a., respectively, while Roland Berger forecasts a more modest growth of 2.4% p.a.. This lower growth of between 0.9–1.4% p.a. is in-line with the 1.1–1.2% p.a. slower RPK growth projected by Roland Berger, as compared against Airbus and Boeing forecasts, as discussed in Section 2.1.3. 

Further implications for the aerospace sector include a potential increase in interiors/cabin conversions, a reduced ability to self-invest in R&D, and partial supply chain localisation.

- Increase in interiors/cabin conversions in the medium-term, driven by the drop in business demand, airlines are expected to adapt their operating models towards serving an increased share of leisure travel, potentially including an adjustment of the cabin layout. This change is also expected to come in parallel with different pricing models, and potentially network changes, towards routes that are frequented more by leisure travellers, and away from routes with lower overall volumes that have historically been supported by higher yield business travellers.

- Reduced ability to self-invest in R&D in the short- and medium-term, driven by financial constraints resulting from increased debt taken on during the COVID-19 crisis, along with the working capital required to support the ramp-up in production post-COVID-19. These financial pressures may cause a reduced ability to self-invest in R&D by suppliers, with potentially harmful implications for innovativeness and slower development of aircraft incorporating new technologies.

- Partial supply chain localisation, as companies seek to mitigate risks of potential future supply chain disruptions of the type seen during the pandemic. In the aerospace sector, this is however seen as a minor effect, since the long-term structural reasons driving global supply chains (e.g., cost, offset requirements, and availability of a suitably skilled workforce) are expected to remain.

2.3 Implications for the socioeconomic impact of CS2

The COVID-19 pandemic had the potential to disrupt the CS2 R&D programme in several ways, including delaying milestone deliveries for particular projects, outright cancellations of projects, or even accelerated delivery for some projects, for instance to prevent layoffs or furloughs. We worked with CS2JU to understand the extent of these impacts, and spoke with senior programme leaders to understand the specific nature and impact of the delays that had occurred.

2.3.1 Impact of COVID-19 on CS2JU projects

Quantified in funding terms, out of the approximately EUR 3.9 billion in CS2 projects, approximately EUR 2.3 billion had already been completed before the pandemic began in March 2020 and EUR 0.9 billion was assessed not to be impacted at all by COVID-19 in terms of delivery expectations. Furthermore, no projects were cancelled due to COVID-19 and none were accelerated over the pandemic period.

The overall impact of COVID-19 on Clean Sky 2 projects and funding is thus mainly estimated to be delays impacting a limited number of projects. The estimated total value of these projects is EUR 688 million (across grant funding and in-kind contributions), calculated by using CS2JU data on grant funding delays and extrapolating that to IKOP and IKAA contributions. This is composed of 189 projects with an estimated delay of approximately 11 months on average.

However, delays only apply to a subset of the total funding of these delayed projects. We estimate that activity delayed due to COVID-19 relates to EUR 139 million of funding, i.e., 20% of the budget of the affected projects and just 3.5% of total CS2 funding.

The exact profile of these delays (measured in changes in funding received over time), on average a delay of 11 months, can be observed in Figure U. While funding in 2020 was lower than planned by approximately EUR 45
million, the shortfall is expected to have been levelled out by 2023, leaving no structural impact by the end of the programme. Again, this spending profile can be mapped equally to the IKAA and IKOP funding.

It is also important to assess the non-financial impact of the occurred delays, which may impact the CS2 planned goal achievement in terms of CO₂, NOₓ and noise. However, in line with the funding profile, no impact on the achievement of CO₂, NOₓ, and noise reductions is expected at the end of the programme.

- There have been nine demonstrators subject to COVID-19 related delays, but these are still expected to demonstrate the full emissions reduction potential by the end of the programme (as shown by the first assessment of the Technology Evaluator) and do not affect the overall project budget, and most demonstrator delays will be recovered by the programme end.
- The scope of only six demonstrators is reduced at completion (maturity level in 2023), linked to change of strategy of members due to the COVID-19 pandemic, where the 2023 technological maturity level achieved may reduce from, e.g., TRL4 to TRL3. However, none of these changes have a material impact on the overall CO₂, NOₓ or noise reductions enabled by CS2JU.

### 2.3.2 Impact of COVID-19 on the socioeconomic impact of CS2

The delays in 2020 and 2021 are expected to have no impact on the delivery date of technologies anticipated to reduce CO₂, NOₓ and noise emissions. Further, as there is no reduction or increase in the total amount of funding committed to CS2 R&D as a result of COVID-19, there is no impact in the total socioeconomic impact of CS2 in nominal terms.

However, the delays identified push a small amount of research backwards by a few months and so some of the socioeconomic impact would be slightly delayed within our models. Nonetheless, the discount rate that we apply means that benefits in future years are taken into consideration at a reduced rate compared to earlier years.
slightly reducing the total value of the benefits when expressed in present value terms. A similar, small effect is produced when accounting for inflation in future years.

As such, we estimate that the impact of COVID-19 on the total socioeconomic impact of the CS2 programme is EUR 25 million when expressed in real, present value terms, or only ~0.3% of the total EUR 8.6 billion impact.

2.4 Initial views on the impact of the Ukraine Crisis

On 24 February 2022, Russia invaded Ukraine in an escalation of the Russo-Ukrainian conflict that began in 2014. As of end-May 2022, the conflict is ongoing with a growing humanitarian crisis affecting millions of people. At the same time, the war has implications for air travel, and thus the aviation and aerospace industries, which have not been factored into the analysis presented in this report, since the crisis postdates the analysis conducted in this study. As of May 2022, the timing and nature of the conflict’s conclusion remain highly uncertain, and its long-term effects on aviation cannot yet be determined.

Nevertheless, key implications that can already be discerned in a qualitative manner are summarised below:

- **Air traffic**: the closure of European airspace to Russian aircraft and reciprocal measures, as well as the avoidance of Ukrainian/Belarussian airspace, is expected to initially reduce global air traffic by ~0.5%, with many routes lengthening by 15–50%. There are however valid wider concerns over how the conflict may further decrease air travel (e.g., traffic fell by 2.6% in First Gulf War in 1991 and fell again in Second Gulf War, albeit increased by 0.9% over 2003 overall). A more impactful driver of air traffic reduction may thus be a reduction in global or regional economic growth, given the ~1.3x multiplier linking economic growth with air traffic growth — however, this effect is highly uncertain as the impact of the crisis on global or regional economic growth remains unknown.

- **Fuel prices**: Jet-A prices have risen substantially; the mid-May Jet-A price of USD 1,160 per Mt represents a ~85% premium relative to average 2019 levels, equal to an increase in direct operating costs of ~20% for a typical low cost carrier. As a result, airlines’ emphasis on short-term operational improvements has increased, with airlines with newer (more efficient) fleets faring better.

- **Raw materials**: several key raw materials are sourced from conflict-impacted regions Russia, Ukraine and Belarus. Chief among these is titanium, with Russian supplier VSMPO believed to have a ~25% market share and being a significant supplier to Boeing/Airbus. Boeing is understood to have 1–2 years’ titanium inventory, leaving Airbus more exposed to any supply near-term interruptions. However, this threat has not yet materialised: titanium is still exempt from import sanction of import ban in Europe and Airbus is continuing to import titanium until a ban is imposed, while Boeing has stopped purchasing Russian titanium. Other raw materials such as nickel, aluminium and steel have seen price increases but no supply chain disruption as Russia is a minority producer.

- **Potential long-term geopolitical risk**: there remains a risk of a potential (re-)division of the world into a Western and Eastern bloc, driving de-globalisation, slower economic growth and continuation of major air traffic restrictions.

There are other impacts to consider as well, including the loss in aircraft deliveries to Russia, Belarus and Ukraine (e.g., ~2% of the 737MAX order book were aircraft earmarked for Russian operators which are now likely to be cancelled), the impact on leasing companies (given approximately 500 aircraft which are likely to be permanently taken over by the Russian government), and potential changes in R&D spending to favour defence (which may result in less spending on civil aerospace/aviation sustainability).

The ultimate extent of the impact of the Ukraine crisis remains highly uncertain given that the crisis is still unfolding. Thus, the previous remarks are provisional only and highly subject to change as the crisis develops.
Chapter 3
Ecosystem outlook and recommendations
Under Council Regulation (EU) 2021_2085, the CAJU must “integrate and demonstrate disruptive aircraft technological innovations able to decrease net emissions of greenhouse gases by no less than 30% by 2030, compared to 2020 state-of-the-art technology”. Building on this goal, the CAJU Governing Board has adopted the Strategic Research & Innovation Agenda (SRIA) which currently is targeting an aircraft energy efficiency improvement of 30% (for short-medium range aircraft) and 50% (for regional aircraft), that together with the use of drop-in sustainable aviation fuels (SAFs) and/or green hydrogen will lead to an aircraft level reduction in net CO₂ emissions of ~90%. Moreover, the CAJU is in the process of developing further targets for non-CO₂ greenhouse gases for its SRIA.

In the broader European context, the European Green Deal requires the transport sector as a whole (including air, rail, road, and waterborne transport) to achieve a 90% reduction in greenhouse gas emissions in 2050 vs. 1990.

While no specific breakdown is specified in the European Green Deal for the aviation sector in particular, through vehicles, such as Destination 2050, the European aviation sector has embraced net climate neutrality as a target for aviation by 2050.

In this report, we have thus looked at how the European aviation ecosystem can pave the way towards climate neutrality by 2050. While estimating the overall climate effects of all GHG species (GWP50 for CO₂eq), we have elected to focus on CO₂ given the relatively large and long-lasting contribution thereof to climate change, the current high levels of uncertainties related to non-CO₂ effects and the likelihood that a large share of these non-CO₂ effects can be countered through mitigation measures that do not require extensive aircraft technology or architectural changes.

However, our modelling demonstrates that in the Roland Berger Baseline trajectory, net CO₂ emissions in Europe reduce by only ~45–50% relative to 2019 levels; this Baseline trajectory is based on continued evolution in line with historical experience and assumes a Sustainable Aviation Fuel (SAF) uptake of ~50% (half bio-based, half Power-to-Liquid), and penetration of hydrogen-powered aircraft to 40% of the European fleet by 2050.

Relative to our Baseline trajectory, increasing SAF uptake to around 100% coupled with a 40–60% fleet share of hydrogen-powered aircraft would allow a 90% reduction in net CO₂ emissions; adoption of more hydrogen aircraft or a move to 100% PtL SAFs would further reduce net CO₂, potentially down to 95% vs. 2019 levels, thereby establishing Europe on the path towards climate neutrality.

Our analysis confirms that the CAJU is playing its part to achieve emissions reductions required for climate neutrality, and that the SRIA is fit-for-purpose. However, further intervention — beyond the scope of the mandate of the CAJU — is required to achieve the ambitious goal of 90% reduction in net CO₂ emissions by 2050. Six recommendations should be prioritised alongside the work of the CAJU, and Europe should:

1. Accelerate adoption of 2030+ EIS aircraft, including both hyper efficient conventional aircraft and novel aircraft with new propulsion technologies including hydrogen and electric
2. Shorten aircraft design, development and certification cycles to bring these aircraft to market as quickly as possible
3. Reconfigure aviation and Air Traffic Control (ATC) infrastructure to accommodate novel aircraft types and minimise the emissions of all aircraft
4. Boost availability of hydrogen and sustainable fuels, including their feedstocks, to ensure that Europe has access to hydrogen and sustainable fuels for aviation to meet the expected future demand
5. Enable the adoption of new airline network strategies that can fully take advantage of the capabilities of novel aircraft types
6. Develop and implement effective mitigation strategies for non-CO₂ effects, pursuing practical solutions on NOₓ, particulates and contrail mitigation that are backed up by science

IF EUROPE SUCCESSFULLY IMPLEMENTS THIS PLAN, IT WILL HAVE PAVED THE WAY TO CLIMATE NEUTRALITY FOR GLOBAL AVIATION
3.1 Emissions targets

Under Council Regulation (EU) 2021_2085, often referred to as the “Single Basic Act”, the CAJU must “integrate and demonstrate disruptive aircraft technological innovations able to decrease net emissions of greenhouse gases by no less than 30% by 2030, compared to 2020 state-of-the-art technology”, and “ensure that the technological and the potential industrial readiness of innovations can support the launch of disruptive new products and services by 2035, with the aim of replacing 75% of the operating fleet by 2050 and developing an innovative, reliable, safe, and cost-effective European aviation system that is able to meet the objective of climate neutrality at the latest by 2050”.

Building on this goal, and as a derivative of the high level objectives under Council Regulation (EU) 2021_2085, the mission of the CAJU is to develop aircraft for entry into service by 2035 that will “enable net CO₂ reductions of up to 90% when combined with the effect of sustainable ‘drop-in’ fuels”. This target is defined as a 90% reduction at the aircraft level vs. 2019 and in net CO₂ terms only, including the assumptions stated in the Clean Aviation Joint Undertaking Strategic Research and Innovation Agenda on adoption of SAF and hydrogen fuels.

Given the general objectives of the CAJU, as set out in the Regulation, “to contribute to reducing the ecological footprint of aviation ... therefore significantly contributing to the achievement of the general goals of the European Green Deal”, it is also important to understand the broader European context.

The European Commission White Paper preceding the EU Green Deal set the scene for all sectors to make important contributions to decarbonisation and more generally to drastic reductions in greenhouse gas emissions. Notably, this requires the transportation sector as a whole (including air, rail, road and waterborne transport) to achieve 90% reduction in greenhouse gas emissions in 2050 vs. 1990, expressed in CO₂e terms.

No breakdown is specified between the various transport modes in terms of contributions or speed of reductions in emissions, and indeed this 90%
reduction is not required in the policy to be proportional across modes. Nonetheless, since the publication of the White Paper and the subsequent proposal for the European Green Deal and EU Climate Law legislative acts, the European aviation sector committed to “net climate neutral” by 2050. Specifically, as part of Destination 2050, Airlines for Europe (A4E), the Civil Air Navigation Services Organisation, European Regions Airline Association, Airports Council International-Europe and the Aerospace & Defence Industries Association of Europe committed to net zero CO₂ emissions in 2050 on behalf of their members.

On this basis, in this report, we have looked at how the European aviation ecosystem can pave the way towards climate neutrality in 2050 through significant net CO₂ reductions vs. 2019 levels. In this report, we have interpreted this target of approaching climate neutrality as aiming for 90% or higher reductions in net CO₂, specifically excluding the impact of carbon offsets/removals on residual net CO₂ emissions.

Note that the importance of reducing the impact of non-CO₂ effects, above and beyond the important net CO₂ reductions targeted, cannot be understated. This report recognises the need to improve the level of scientific understanding of all non-CO₂ effects. Depending on what metric is used to quantify equivalence (as laid out in Appendix C.3), the total climate forcing of aviation may be 2-4x as much as CO₂ alone. However, given the highly uncertain nature of non-CO₂ effects and their mitigation, we do not assess a specific reduction target in CO₂e in the analysis presented here.

Please refer to Appendix C.2 for a mapping of relevant EU policies relevant to the discussion below.

3.2 Aviation emissions forecast

In the Roland Berger Baseline trajectory, where global RPKs are expected to grow to ~20 trillion by 2050, global net CO₂ emissions continue to increase to 2050 by approximately ~10–15% and net GHG emissions are expected to increase by ~20–25%, relative to pre-COVID-19 2019 levels. This modest growth in global emissions, ultimately flattens by the early 2040s due to interventions that include: carbon pricing, sustainable aviation fuel (SAF) uptake, and the introduction of novel aircraft supported by CAJU investments (including hyper-efficient conventional aircraft and hydrogen-propelled aircraft).

European emissions are expected to fall over the same time period: we expect emissions reductions of 45–50% to occur in the Baseline trajectory, despite continued growth in RPKs of ~75% by 2050.

As visualised in Figure W, this reduction is driven by four key levers: fleet rollover to NEO generation aircraft, introduction of hyper-efficient conventional aircraft (HECA), introduction of novel aircraft technologies (especially hydrogen-powered narrowbody aircraft), and use of SAFs (including both bio-based and Power-to-Liquid (PtL) SAFs). Together, we expect around half of this decoupling of emissions to be driven by the introduction of 2030+ EIS aircraft (HECA, hydrogen-powered aircraft, hybrid-electric aircraft, and battery-electric aircraft) which leverage the disruptive technologies developed by the CAJU. At the same time, non-CO₂ effects (as measured in GWP50 terms) are also expected to reduce in the Baseline trajectory, albeit by a smaller amount as both hydrogen- and SAF-powered aircraft are expected to continue producing non-CO₂ effects. Please refer to Appendix C.3 on the rationale for the selection of GWP50 as the key metric for this report vs. alternatives such as GWP20 and GWP100.

Compared against global emissions, Europe is able to achieve aviation net CO₂ emissions reduction in the Baseline trajectory driven by slower-than-global air traffic growth and faster new aircraft technology adoption.

All in all, this is a highly significant achievement for Europe: for air traffic growth to continue while
V European traffic and emissions in the Baseline trajectory, 2019–2050
Indexed, 2019=100

Notes: 1 Both CO₂ and non-CO₂ effects, including net NOₓ, Soot, Water, Sulfates and Contrails and Contrail Cirrus

Source: Roland Berger
**Baseline net CO₂ emissions trajectory** \(^1\) by reduction levers, 2019–2050

Indexed, 2019 = 100

![Graph showing baseline CO₂ emissions trajectory with reduction levers from 2020 to 2050.](image-url)

Notes: 1. Key assumptions underlying forecast: ~2% RPK growth over 2019–2050, adoption of 60% 2030+ EIS aircraft by 2050 of which half are hydrogen-powered, 50% SAF uptake (half bio-based, half PtL); 2. Introduction of novel aircraft technology includes hydrogen/electric/hybrid aircraft; 3. An improvement of ~1% by 2050 is equivalent to 2–4% improvement for average fleet performance in Europe (not including potential improvements enabled by Single European Sky via the SESAR programme, which are not factored into the Baseline trajectory); 4. Increasing 2050 SAF blend to 63% (in line with Refuel EU targets) reduces 2050 net CO₂ emissions by ~10% relative to 2019

Source: Roland Berger
has already highlighted the two major decarbonisation levers: the introduction of hydrogen aircraft into the fleet, and the uptake of SAFs to replace kerosene in conventionally propelled aircraft.

Considering these two main levers, we find that approaching 100% SAF uptake and significant fleet share of hydrogen-powered aircraft is required to achieve this highly ambitious reduction target.

Across the sensitivities we assessed, there are six that achieve a 90% or greater reduction in net CO₂ emissions. All of these sensitivities require high volumes of SAFs and hydrogen (as set out in Appendix C.4). Whilst it is theoretically possible to approach 90% net CO₂ reductions exclusively through SAFs or emissions reduce in absolute terms would make for an historic achievement — a true decoupling of emissions growth from air traffic growth. However, the 45–50% emissions reductions forecast for the Baseline trajectory still fall short of the goal to aim for climate neutrality by 2050, as set out in Section 3.1.

### 3.3 Approaching climate neutrality

Thus, approaching climate neutrality (interpreted by this report as targeting 90% reduction in net CO₂ or more without considering the impact of carbon offsets, as set out in Section 3.1) by 2050 relative to 2019 levels is extremely challenging. However, the analysis thus far
**Residual net CO₂ emissions sensitivity to SAF and hydrogen aircraft uptake, 2050**

[% delta vs. 2019 net CO₂ emissions]

### Hydrogen aircraft uptake

[2050 fleet share]

- **Rapid uptake (~80%)**
  - Baseline case
    - -25%
    - -50%
    - -60%
  - Outcomes that approach climate neutrality
    - -95%
    - -95%

- **High uptake (~60%)**
  - Baseline case
    - -25%
    - -50%
    - -60%
  - Outcomes that approach climate neutrality
    - -90%
    - -95%

- **Baseline (~40%)**
  - Baseline case
    - -25%
    - -50%
    - -60%
  - Outcomes that approach climate neutrality
    - -90%
    - -90%

- **No hydrogen aircraft**
  - -5%
  - -10%
  - -20%
  - Outcomes that approach climate neutrality
    - -80%
    - -85%

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**SAF uptake by 2050** [% of total jet fuel demand]

- **Downside** — 20% SAF (10% Bio, 10% PtL)
- **Baseline** — 50% SAF (25% Bio, 25% PtL)
- **ReFuel EU** — 63% SAF (35% Bio, 28% PtL)
- **ITRE** — 100% SAF (35% Bio, 65% PtL)
- **100% PtL**

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Notes: 1 All sensitivities have ~4 trillion RPKs in Europe, representing ~20% of global demand; 2 Hydrogen aircraft uptake fleet defined as Regional (50–100 PAX), Narrowbody and Widebody aircraft.

Source: Roland Berger
Approaching Climate Neutral Scenario\(^1\) net CO\(_2\) emissions reduction by reduction levers, 2019–2050
Indexed [Mt CO\(_2\)]

Notes: 1 Key assumptions underlying forecast: ~2% RPK growth over 2019–2050, adoption of 60% 2030+ EIS aircraft by 2050 of which half are hydrogen-powered, 50% SAF uptake (half bio-based, half PtL); 2 Introduction of novel aircraft technology includes hydrogen/electric/hybrid aircraft; 3 An improvement of ~3% by 2050 is equivalent to 10–14% improvement for average fleet performance in Europe (including expected improvements enabled by the implementation of the SESAR programme)

Source: Roland Berger
hydrogen, we expect the requirements imposed on the supply/value chain would not be realistic (e.g., requiring ~100% of the fleet to be hydrogen). As such, this report does not single out one specific scenario as the “right” one to pursue given uncertainties around market, cost and technology developments. Instead, we highlight six scenarios as being potentially regulatory-driven given their ambitious, but achievable, uptake of hydrogen-powered aircraft and SAFs, as given in the green box in Figure Y. As one potential illustration of how these scenarios could work, we have chosen one sensitivity (the ‘Approaching Climate Neutral Scenario’) to flesh out in the coming pages.

The ‘Approaching Climate Neutral Scenario’ is able to achieve a hugely significant 95% reduction in net CO₂ vs. 2019 through a variety of measures: switching to 2030+ EIS aircraft represents almost 50% of the emissions reductions achieved, while the use of PtL SAFs is responsible for a further 30%. This represents a groundbreaking scenario with several major changes assumed relative to the Roland Berger Baseline trajectory, including: earlier introduction of hydrogen aircraft, earlier introduction of hyper-efficient conventional aircraft, accelerated aircraft adoption rates, operational improvements through the implementation of the SESAR programme, and the uptake of a 100% PtL SAF blend.

3.4 Recommendations

Approaching climate neutrality for European aviation will require efforts to approach net zero carbon as a crucial step, and efforts beyond carbon, too; indeed approaching climate neutrality requires actions above and beyond what the Clean Aviation Joint Undertaking can do alone. To make this scenario possible, the entire European aviation and aerospace ecosystem would need to evolve and invest in a whole suite of new technologies, infrastructure, and operations — all built on a foundation of enabling policies and regulations.

...
3.4.1 Performance of the CAJU Strategic Research and Innovation Agenda

Our analysis confirms that the Strategic Research and Innovation Agenda (SRIA) is fit-for-purpose for the CAJU to play its part in helping European aviation approach climate neutrality. We have assessed that the CAJU has set the right priorities and resources to develop 2030+ EIS aircraft, and if it is sufficiently supported by other members of the European ecosystem, it is well-placed to achieve its mission.

To conduct this analysis and risk-assess the SRIA, we considered its performance against the Roland Berger Baseline trajectory, but also considered several further high impact/high uncertainty scenarios (see Appendix C.1 for details on our assessment approach). Overall, we assess that:

• The CAJU is well placed and correctly focused to achieve its mission, and the SRIA is generally well-positioned to enable this by consistently supporting aircraft with the requisite performance, which we expect to enter service by 2035, across the scenarios modelled.

• The ultra-efficient aircraft thrust performs strongly across all scenarios given consistently high 2050 fleet share and ability for investment to benefit other aircraft types, including hydrogen aircraft.

• The CAJU is well-positioned to support its targeted fleet replacement of 75% of the global fleet by 2050, as it is likely to only come through combination of HECA and hydrogen aircraft, both of which the SRIA prioritises.

• The SRIA takes a strong portfolio approach on novel aircraft types, with significant support provided to both hybrid and hydrogen aircraft, supporting all likely potential outcomes in high-risk/high-reward technologies.

However, while the success of the SRIA and the CAJU is necessary for the European ecosystem to approach climate neutrality, it is not sufficient. The likelihood of this being achieved can be substantially increased through the implementation of the six measures set out in Section 3.4.2.

3.4.2 Six key recommendations

On top of the work being conducted by the CAJU, we believe six key recommendations are required to push the European aviation ecosystem on to the required pathway towards climate neutrality.

These recommendations assume the fulfilment of the key actions by the Clean Aviation Joint Undertaking of developing clean and efficient 2030+ EIS aircraft in developing ultra-efficient conventional aircraft, and demonstrating feasibility of novel propulsion architectures (hydrogen, hybrid, and electric aircraft). It is further recognised that key enabling variables, such as the direct operating cost to airlines when adopting 2030+ EIS aircraft, are not solely the remit of any one stakeholder, and the entire aviation ecosystem must evolve to ensure cost effectiveness, which is in turn a core enabler for the rapid uptake of new aircraft. Indeed, direct operating cost reduction is influenced by not only the CAJU, but also at least Recommendations 1, 2, 3, and 4 in Figure BB, and is discussed in the details of the six specific recommendations below.

1. **Accelerate adoption of 2030+ EIS aircraft** including both hyper efficient conventional aircraft and novel aircraft with new propulsion technologies including hydrogen and electric.

The current typical commercial aircraft lifespan of 20–25 years, which represents a retirement rate of ~3% of the current fleet p.a., does not allow for sufficiently quick replacement of the fleet to achieve the CAJU target of replacing 75% of the global operating fleet by 2050 following the launch of disruptive new products by 2035. Based on a 2035 EIS, only 60% of the fleet would be replaced at this historical retirement rate, assuming the industrial ramp-up in production of a new type of aircraft in line
Recommendations already supported by CAJU

with historical precedents. The 90% reduction target requires European fleet replacement to approach 95% by 2050 — with a 2035 EIS of relevant aircraft, a replacement rate in Europe between 6–7% would be required, along with a capable supply chain able to support the delivery of the requisite new aircraft into the fleet. For any acceleration of adoption of new aircraft to be achievable, it will be necessary for these aircraft to be affordable and have strong commercial cases based on their performance and cost base. Thus, Europe should:

- Encourage retirement and new aircraft purchases through regulatory push or commercial pull (but with appropriate compensation for manufacturers which rely on an aftermarket business model and operators/lessors whose asset values will be significantly impacted)
- Support development and industrialisation of novel manufacturing technologies, in parallel to the CAJU’s investments
2. **Shorten aircraft design, development, and certification** to bring these aircraft to market as quickly as possible

At the same time, the sooner novel aircraft technologies can be introduced, the more likely they are to represent a large share of the fleet by 2050. To achieve the required European fleet replacement of 95% by 2050, an Entry into service (EIS) of 2030 or sooner would be required (assuming a retirement rate of 4%, although a somewhat later EIS may be possible with faster retirement as recommended previously). A key driver of the EIS year is the design & development timeline, which has steadily been increasing over the past few decades to 7–8 years for all-new aircraft types. A shortening of this timeline, of the order of magnitude of 50%, while maintaining safety standards, will be essential to meeting climate goals. Thus, Europe should:

- Encourage agile aircraft development, including the use of digital design, validation, and certification tools, and concurrent industrialisation of 2030+ EIS aircraft to facilitate a rapid ramp-up in production
- Ensure rapid certification for 2030+ EIS aircraft, while maintaining safety standards

3. **Reconfigure aviation and Air Traffic Control (ATC) infrastructure** to accommodate novel aircraft types and minimise the emissions of all aircraft

A full suite of new infrastructure will be required if Europe is to host a large fleet of hydrogen-propelled aircraft, while also supporting a base of PtL SAF-powered aircraft. In addition, significant operational improvements could be unlocked if the Single European Skies programme can be implemented; improvements to Air Traffic Control (ATC) will also allow adjustments to aircraft routes so as to minimise the effects of contrails and aviation-induced cloudiness. In order for the adoption of new aircraft to happen in parallel to this infrastructure reconfiguration, the operating costs of new aircraft including airport fees will need to be cost competitive to existing aircraft. Thus, Europe should:

- Support rollout of additional infrastructure necessary for SAFs and hydrogen
- Reconfigure ATC infrastructure to enable Single European Sky and contrail/aviation-induced cloudiness mitigation

4. **Boost availability of sustainable fuels and feedstocks** to ensure that Europe has access to hydrogen and sustainable fuels for aviation to meet the expected future demand

To achieve the ‘Approaching Climate Neutral Scenario’, Europe alone will require access to 45–50 Mt of SAFs and 15–20 Mt of liquid hydrogen fuel by 2050. Indeed, considering that the production of PtL SAFs requires green hydrogen as a feedstock, the requirement for hydrogen increases to ~50 Mt by 2050. Starting with today’s base production of approximately zero for both fuel types, this represents a massive increase in PtL SAF production, green hydrogen production, and zero carbon energy generation. The availability of zero carbon energy will also be a key challenge to the availability of green hydrogen and PtL SAFs, with ~3–5 PWh required to provide sufficient fuel volumes in the extreme ‘Approaching Climate Neutral Scenario’. Furthermore, the ramp-up of all the required infrastructure to reach scale production for SAFs and hydrogen will be crucial for costs to reduce for operators, and improve the business case for 2030+ EIS aircraft. Finally, non-CO₂ benefits of SAFs are also recognised (e.g., reduced NOₓ and contrail emissions) — but may also be achievable before SAFs ramp-up through low aromatics conventional fuels. Thus, Europe should:

- Develop necessary production capacity for SAFs and liquid hydrogen
- Ensure availability of key feedstocks, and in particular of renewable/zero carbon energy, for fuel production
• In the meantime, introduce fuels with low aromatic content to mitigate non-CO₂ effects (also as an enabler of Recommendation 6)

5. Enable the adoption of new network strategies that can fully take advantage of the capabilities of novel aircraft types

New network strategies will be key to unlocking the full potential of regional aircraft with novel propulsion systems, such as hydrogen (fuel cell) and battery electric. These aircraft, despite their (expected) short range, could represent a major share of decarbonisation with new network strategies, such as distributed aviation, increased point-to-point, de-hubbing, and consolidation of flights. At the same time, even at the larger narrowbody scale, the adoption of novel aircraft types (especially hydrogen) will require airlines to adopt split fleet models during the transition period from the current to the future fleet. Thus, Europe should:
• Unlock the potential of alternative network strategies as an accelerator of 2030+ EIS aircraft adoption
• Enable airlines to adopt split fleets, potentially with dedicated networks, more range-tailored aircraft usage and new business models

6. Develop and implement effective mitigation strategies for non-CO₂ effects pursuing practical solutions on NOₓ, particulates and contrail mitigation that are backed up by science

Finally, it is clear that non-CO₂ effects exist and that the total climate impact of aviation may be 2–4× as much as the impact of CO₂ alone (depending on the metric employed to compute carbon equivalence, as laid out in Appendix C.3). Indeed, the adoption of SAFs and hydrogen-powered aircraft, though hugely impactful in reducing net CO₂, may be much less effective in reducing total climate forcing (e.g., as measured in Global Warming Potential terms). It is paramount that whatever technological and operational improvements are undertaken account for non-CO₂ effects, ensuring they do not worsen with the adoption of new technologies, and ideally that they reduce in-line with the target to approach climate neutrality. Thus, Europe should:
• Improve research into non-CO₂ effects due to current aircraft
• Accelerate analysis of non-CO₂ effects from 2030+ EIS aircraft, especially hydrogen aircraft
• Develop and demonstrate practical mitigation strategies, especially regarding contrail and aviation induced cloudiness mitigation

Paving the way to global climate neutrality

If Europe is successful in implementing the full suite of recommendations set out here, it will be on the path to climate neutrality in aviation by 2050 as the share of hydrogen aircraft in the fleet can be expected to continue to increase beyond 2050, and as technologies are developed to produce SAFs in a truly zero carbon way and remove all lifecycle emissions.

While this suite of policies may set Europe apart in a global aviation ecosystem, if Europe can prove the effectiveness of this pathway, we believe that other regions will follow.

Indeed, if it succeeds, Europe will have paved the way to climate neutrality for global aviation.
Appendices
A. Chapter 1 supporting appendices

This appendix provides further details of the analytical methods used to calculate the socioeconomic impact of the aviation sector and the CS2 R&D programme. The structure of this appendix follows the main body of the report, with a sub-appendix for each sub-section of the main report.

A.1 Estimating and forecasting the economic footprint of the European and global aviation sectors

Our estimates of the core of the global aviation sector are based on the following industry definitions:

**Airlines**
We used the standard industrial classification for air transport (sector 51 in Eurostat’s “NACE” structure), which includes both passenger and freight transport by air.

**Airports**
We applied the definition of airports used in ATAG’s “Benefits Beyond Borders” reports. This includes airport operators and air navigation service providers, on-site airport activity including consumer-facing businesses such as retail outlets, restaurants and hotels, as well as operations-related businesses such as ground handlers.

**Aerospace manufacturing**
We used the standard industrial classification “Manufacture of air and spacecraft and related machinery” (sector 30.3 in Eurostat's NACE structure). This includes the manufacturing of all types of aircraft and components thereof, as well as the overhaul and conversion of aircraft and engines. However, from this overall sub-sector we made a series of adjustments to remove manufacturing associated with military aviation and with space. Our estimates therefore relate solely to civil aviation.

A.1.1 Base year direct impact estimates

Our base year (2019) estimates of the direct impact of the aviation sector were calculated from the following data sources.

**Airlines**
For Europe and the US, GVA and employment data were collected from official sources, such as the Eurostat national accounts by industry and US Bureau of Economic Analysis industry economic accounts.

For China, employment data was collected from the national statistics agency and GVA was estimated based on imputed productivity.

For the rest of the world, GVA data were collected from secondary data sources such as the OECD statistics database and OE’s existing global industry databank, and employment was either collected from the same or imputed.

**Airports**
For all regions, employment was estimated for 2018 based on ATAG’s 2020 “Benefits Beyond Borders” report, grown to 2019 based on changes in air traffic. GVA for all regions was imputed based on estimated levels of productivity per worker in each region.

**Aerospace manufacturing**
For Europe and the US, GVA and employment data were sourced from national statistics, as with airports above, and adjusted based on expert consultation to remove space activities and military aerospace.

For the rest of the world, GVA data were used from OE’s global industry database, and employment was estimated by applying estimates of productivity levels to the GVA figures.
A.1.2 Indirect and induced impact estimates

Our approach for assessing the aviation sector’s economic footprint across the world is based on Oxford Economics’ global economic impact modelling framework. This framework leverages the knowledge and techniques we have developed in mapping economic relationships between countries and industries across the world. The model includes information about global supply chains that are typically excluded from standard economic impact assessments, enabling comprehensive measurement of economic footprints.

The ability to trace how global supply chains stimulate activity in different economies is essential for developing a comprehensive measure of the aviation sector’s footprint in any given geography. For example, it enables us to trace how the spending that European aerospace manufacturers make with suppliers can stimulate supply chains that pass in and out of the United States further up the value chain. Consequently, the GSM provides a comprehensive measure of a sector’s total impact on a given economy.

To estimate the indirect and induced impacts of global aviation, we first estimated supply chain spending and worker compensation in each sub-sector of the aviation industry. This was done based on the relationship between output and procurement by product in each sub-sector, as well as the relationship between output and compensation of employees, taken from macroeconomic statistics. These estimates were then inputted into the global economic impact model described previously.

A.1.3 Forecasting out to 2050

We used Technology Evaluator (TE) projections to drive our forecasts out to 2050 based on the following driver variables:

**Airlines**
GVA grown in line with TE terminal revenue passenger kilometres projections.

**Airports**
GVA grown in line with TE terminal passengers projections.

**Aerospace manufacturing**
GVA grown over the short-term in line with OE industry forecasts (based on aerospace industry order books) and in the long-term by TE terminal passenger projections.

A.1.4 Tourism catalytic impact

We based our estimates of the catalytic tourism impact of the aviation industry on the approach taken in ATAG’s aviation footprint assessment reports. This involves using Oxford Economics’ existing estimates of GDP and employment supported by tourism in each country of the world. This incorporates direct, indirect and induced impacts as described in the core impact section (A.1.1 and A.1.2). For the tourism catalytic impacts, these channels refer to the following activities:

- **Direct impact**: activities of tourist-facing businesses and industries, e.g., hotels, restaurants and entertainment
- **Indirect impact**: produced through the supply chains associated with the above
- **Induced impact**: produced through the wage spending of workers in tourism industries and their supply chains

From these 2019 estimates we used the TE projections to forecast the total number of visitors to each country. We combined projected visitor numbers with OE’s forecasts of estimated average spend per visitor to obtain a forecast of total visitor spending in each country. We then used the growth rate of total visitor spending to grow forwards tourism GDP in each country.
A.2 Measuring the catalytic connectivity impact of the European aviation sector

Our approach to measuring the connectivity using an Air Connectivity Index is based on a previous World Bank study. This is, in turn, grounded in network analysis methods and a gravity-like model commonly used in international trade studies.

The advantage of this approach is that it accounts for the hub-and-spoke nature of global air transport in a way that aggregating flights or seats data would not. Our measure of connectivity is global and aims to capture relationships between all network nodes even when there is no direct flight connection between them.

The main limitation of the air connectivity index produced by the World Bank methodology is that it is based on weekly data from June, a month where tourism flows in the early summer period in the northern hemisphere might bias the connectivity scores. We have updated the analysis by using annual data for the five-year period from 2015 to 2019. Using annual data allows us to avoid biases due to seasonality as well as any one-off events that may increase or decrease connectivity for a limited time period (such as special sporting events). Further, using GDP as one of the factors in the model allows us to account for changes in connectivity due to changes in the economic strength of the origin/destination.

We followed a two-step approach to creating our Air Connectivity Index:

**Step 1: Estimating the connectivity value of each origin-destination pair**

We used econometric analysis to determine the connectivity value of each country as an origin and as a destination, against each of the other countries. Each origin-destination pair’s connectivity value is a function of its economic size, the distance between the countries, and any special characteristics (e.g., historic links between commonwealth countries). This approach isolates any non-systematic factors that may have caused an increase in flights in some years (e.g., the Olympics).

The econometric model uses data between 191 origin and destination countries over a five-year period from 2015 to 2019.

**Step 2: Combining the connectivity values for each origin-destination pair into an Air Connectivity Index value for each country**

We then combined the estimated connectivity values from the previous step into an Air Connectivity Index for each country, to account for its connections to all other countries. This index value was calculated as the sum of the connectivity values for each origin-destination pair that included that country. Our calculations to estimate the Air Connectivity Index are identical to those in the World Bank study.

Once the scores were normalised across years, we used several econometric approaches to estimate the impact of air connectivity on productivity: pooled OLS, Random Effect (RE), Fixed Effect (FE) and System/Difference Generalized Method of Moment (GMM).

The findings from this modelling were then applied to the Technology Evaluator forecasts and a baseline counterfactual to estimate the potential impact of continued growth in European aviation connectivity on the region's economy.

A.3 Assessing the competitiveness and innovativeness of the European aerospace manufacturing sector

One of the most recent and comprehensive studies on defining and measuring competitiveness is by the Centre for European Economic Research (ZEW) and the Austrian Institute of Economic Research (WIFO) commissioned by the European Commission. The authors of the study recognised the multi-dimensional nature of competitiveness and developed a framework which categorises indicators into a number of groups.
We used this study as the foundation of our analysis, particularly for assessing competitiveness. However, given the priorities of the CS2 programme, we adapted the existing framework to give a greater focus to innovation. This was done by drawing from insights published by the World Intellectual Patent Office (WIPO) in collaboration with Cornell University and INSEAD, who have produced an annual Global Innovation Index since 2007 to assess and rank countries on their innovation ecosystem.

We also drew from the European Innovation Scoreboard, which provides a comparative analysis of innovation performance, enabling countries to identify their relative strengths and weaknesses. The scoreboard distinguishes between four main types of activity with three innovation dimensions sitting underneath each activity.

From the frameworks underpinning our hybrid approach, we drew up a long list of potential indicators to include in our assessment. These were then refined into the short list seen in this report by assessing and excluding indicators based on:

- Relevance to aerospace sector
- Granularity of data sector, i.e., does it provide coverage of the aerospace manufacturing sector
- Data availability for all three geographies
- Recency of available data
- Ensuring a balance of indicators between different sections of the framework

A.4 The immediate economic contribution of CS2 R&D project operations

We estimated the economic impact of private and public R&D funding contributions to the Clean Sky 2 programme for 2014 to 2024.

Public grants received by organisations participating in CS2 as well as private sector in-kind contributions were treated as the equivalent of “gross output” in economic impact modelling terms, representing a measure of an industry's sales or revenues.

From gross output we derived estimates of direct GVA and employment from existing, published economic statistics using ratios from published data such as Eurostat's Structural Business Statistics.

We used other sources such as the OECD’s Inter-Country Input-Output tables to derive supply chain spending and worker compensation from gross output, which were then run through Oxford Economics' Global Economic Impact Model to estimate indirect and induced impacts on Europe.

A.5 Private sector R&D crowded in by CS2 public funding

Our approach for measuring the extent of private R&D crowded in by public R&D spending was based on Oxford Economics’ previous research for the UK government. That earlier study identified a causal link to establish the extent to which public R&D leads to greater private R&D, as opposed to merely looking at the correlation between public and private R&D (the latter approach would not have enabled us to establish how changes to public R&D affect private R&D).

A range of observable and unobservable factors influence private sector R&D decisions, so isolating the influence of public R&D expenditures on private R&D is challenging and requires large datasets. Using OECD data on public and private R&D investments for around 30 countries over a 20-year period, we developed a set of robust econometric models to estimate the extent of crowding-in.

From our models, we found that a 1% change in private gross expenditure on R&D (GERD) last year is, all else equal, associated with a 0.72–0.79% change in private GERD this year. Therefore, a 0.31–0.37% increase in private GERD today (due to a 1% increase in public GERD) leads to 0.22–0.29% increase in private GERD in the following period. This momentum continues into the future, albeit by smaller amounts in each year.

Applying these coefficients to estimates of Clean Sky 2 projections for public R&D spending suggests, each EUR 1 of public R&D expenditure stimulates EUR 0.42 of private R&D expenditure in the short run.
(within the same year). The long-run impact of public R&D on private R&D is around three times the short-run impact: we estimate that EUR 1 of public R&D investment stimulates approximately EUR 1.34 of private R&D in the long run.

A.6 The long-term economic impact of the CS2 R&D programme

A.6.1 Contribution to the European aerospace sector and to the wider economy through spillover benefits

This element of the analysis investigated how the research that Clean Sky 2 funds in Europe benefits not only the entities conducting the research, but also the economy more widely. This occurs as the knowledge gained via research spills over into the wider economy, for example as know-how is shared with suppliers, customers benefit from new and improved products, and knowledge is disseminated as staff move between employers.

In previous research, Oxford Economics developed an econometric model to explain how R&D expenditure in different sectors contributes to productivity growth. The boost to productivity comes from both innovation and increasing the skills of the labour force. The model includes two channels of benefits supported by this investment:

- Those which accrue directly to the sector undertaking the research; and
- Spillover benefits generated as firms in other sectors of the economy apply the knowledge and innovations to help to develop new products and improve operational efficiency

Our modelling approach was adapted from a study by Badinger and Egger who used a spatial econometric approach to estimate intra-industry and inter-industry productivity spillovers in total factor productivity (TFP) transmitted through input-output relations in a sample of 13 OECD countries and 15 manufacturing industries. Our model follows a similar approach with a larger dataset with more countries and more recent data.

The basis for the OE model is a panel dataset underpinned by a time series of R&D expenditure by sector across a range of countries. The data were sourced from the OECD and EU KLEMS. From this, a dynamic panel data econometric model was developed, using a number of statistical tests to identify potential statistical issues that could impinge on the model coefficients. The preferred model specification was developed iteratively to ensure that the results were statistically significant and passed the various statistical diagnostic tests.

For this study, the results from that model were combined with CS2 funding data to obtain the results presented.

A.6.2 Contribution to the long-term competitiveness of European aerospace through increased local capital investment

Previous research by Oxford Economics has investigated how R&D spending influences the locational decisions of multi-national corporations (MNCs) with associated effects on foreign direct investment (FDI). We analysed this through a microeconometric framework which investigated the determinants of firm-level decisions regarding manufacturing projects across a variety of industries. Our research followed the methodology in a previous paper by Defever.

The model specification was informed by a detailed literature review. This review identified a wide range of influences on manufacturing location decisions, including proximity to new infrastructure, the presence of agglomerations, and access to funding. These factors represent the co-location of industries, labs and high-tech manufacturing plants. Another determining factor for firms’ decisions to allocate their manufacturing capacity to a country is the presence of competitors.

For this analysis, multiple datasets from sources such as the OECD and World Bank were explored to obtain a wide range of explanatory variables. We then used a
general-to-specific modelling approach to identify the most appropriate control variables. This approach involved testing first for a wide range of variables in the model before narrowing down to a more tightly defined model. Through a rigorous testing process, we developed a baseline model to quantify the relationship between increases in R&D and the probability of being selected as a manufacturing location.

For this study, we used the coefficients from that model with CS2 funding data to develop the results presenting this report.

**A.6.3 Broader net contribution of CS2 R&D through supply chain impacts**

The effects described in the previous sections are “partial”: they consider each of the effects in isolation, but do not capture knock-on effects elsewhere in the economy as a result of increased procurement expenditures and workers’ spending.

The full extent of these indirect and induced impacts cannot be attributed to the CS2 R&D however, since greater economic activity in aviation and other sectors benefitting from the R&D investment may result in capital and labour being diverted away from other activities.

The final step in our analysis was therefore to use a “computable general equilibrium” model to simultaneously estimate the various impacts of CS2 and wider effects right across the economy. This enabled us to estimate the “net” economic impact of CS2, i.e., the overall extent to which European GDP could increase as a result of the programme.

A CGE model is a “bottom-up” macroeconomic model which numerically simulates the economic behaviours of agents (individuals, producers, government, investors, importers, exporters) in the economy. The reactions of these agents following a particular “shock” (such as R&D investment) are modelled within the CGE model as resources such as capital and labour are redistributed around the economy. These are then aggregated to impute the economic effects at a macroeconomic level.

CGE models are computationally intensive requiring an immense amount of data and building one for the 28 countries involved is beyond the scope of this project. We used Oxford Economics’ CGE model for the UK to simulate the effects of higher productivity in the aerospace sector on other sectors in the economy.

We also simulated the effects of higher productivity in other sectors that may be most likely to benefit from spillovers from R&D in aerospace, notably the manufacturing of automobiles, plastics, machinery and electrical equipment as well as the scientific research sector.76

The results of the simulations were then scaled to assess the effect of the productivity shocks on the EU-27 and UK aggregate economy. The scaling is undertaken to reflect the difference in structure of the UK economy and the aggregate 28 economies (EU-27 and UK). In particular, we accounted for differences in consumption patterns across sectors to accurately measure the induced income effect. Similarly, we accounted for the differences in the structure of backward and forward linkages of the aerospace sector to accurately capture the indirect effects of the productivity shocks.

**A.7 Assessing the environmental benefits contributed to by CS2 R&D**

**A.7.1 The impact of CO₂ reductions**

We reviewed the economic literature to identify a consensus set of values to estimate the benefits of CO₂ reductions in aerospace. This revealed two schools of thought for valuing CO₂ emissions:

- Estimating the social cost of carbon (SCC), which is the marginal cost of the impacts caused by emitting one extra tonne of CO₂ in a given year, including impacts on the environment and on human health
- Estimating the shadow price of carbon (SPC), which is the marginal cost to implement policies to reduce CO₂ emissions to target levels
To capture the uncertainty in this type of valuation, we used estimates from a range of prominent studies across both schools of thought to provide a range for the benefits of aviation CO₂ emission reductions. The estimates taken, and the rationale for each, are given below.

- **US Inter-agency Working Group:** this group’s analysis, which is the current guidance from the US government, provides four sets of estimates for the SCC. These are a low scenario, a central scenario, a high scenario and a “highest” scenario. We took the “highest” scenario as the original study is now some years old, and the latest IWG discussion suggests that their estimates would be significantly revised upward if updated.

- **Professor Nordhaus, Yale:** creator of one of the most prominent models of the SCC, Nordhaus provides estimates of the SCC under several sets of assumptions. Based on much of the reviewed literature, using lower discount rates in these types of analysis appears to be the preferred option. As such, we took the scenarios based on a 2.5% discount rate as well as a discount rate with a zero time preference rate, meaning future generations should be treated consistently with the present generation.

- **European Investment Bank (SCC):** this paper provides a “central” estimate and a “high” estimate for the SCC. Since this assessment was undertaken, the prevailing consensus appears to be towards higher valuations of carbon than previously and as such, we used the high estimate.

- **European Commission:** this appraisal guidance document provides a low, central and high estimate for the SPC: we used the central estimate.

- **Intergovernmental Panel on Climate Change:** the IPCC’s 2019 Special Report provided estimates of the SPC under different global temperature scenarios. We used the scenario where global temperatures slightly overshoot the +1.5°C mark that is the target of the Paris Agreements.

- **UK government:** the UK government provides a low, central and high estimate for the SPC: we used the central estimate.

- **Norwegian government:** one set of estimates of the SPC is provided: we use this.

- **French government:** the French government provides a low, central and high estimate for the SPC: we used the central estimate.

- **European Investment Bank (SPC):** this analysis provides a median estimate for SPCs: we use this.

Each of these papers provides estimates of the value of CO₂ emissions at different points in time out to 2050. Where estimates are not provided for every year, we interpolate between provided years.

We then apply these CO₂ emission valuations to the reductions estimated by the Technology Evaluator each year between 2035 and 2050. These reductions are based on a global fleet starting to incorporate CS2 technologies compared to a global fleet where technologies improve no further than 2014 levels. As such, this counterfactual does not represent a world in which CS2 did not exist, as further R&D would likely have taken place. This means these benefit estimates cannot be wholly attributed to the CS2 programme, but instead represent the benefits of ongoing aviation R&D more broadly.

### A.7.2 The impact of NOₓ reductions

Assessing the benefits from CO₂ reductions alone may be considered conservative since further benefits are also expected to accrue through a reduction in emissions of NOₓ. However, there is no existing straightforward method to directly assessing the value of NOₓ reductions, so instead we sought to convert NOₓ into CO₂ equivalency using the approach set out in Appendix C.3.

Once NOₓ emission reductions are converted into CO₂ equivalent terms, we then applied the same approach taken for CO₂. That is, we used a range of estimates of the value of CO₂ emissions and multiplied these by the amount of NOₓ emissions projected by the Technology Evaluator in each year from 2035 to 2050.
B. Chapter 2 supporting appendices

B.1 Methodology

In order to develop a reliable assessment of the impact of COVID-19 on the aerospace and aviation ecosystem, in recognition of the complexities and nuances of every modelling approach, Roland Berger developed several counterfactuals in addition to COVID-19 recovery trajectories. This allowed us to isolate the impact of COVID-19 in particular, or more accurately the effect of COVID-19 as well as megatrends (in particular, the megatrend of sustainability) which was accelerated over the COVID-19 period.

For each forecast, we then considered three steps in the methodology:

**Step 1: COVID-19 evolution analysis**

There are several drivers that determine the COVID-19 pandemic evolution, including COVID-19 variant evolution, vaccine efficacy and roll-out, as well as natural immunity development. Three recovery trajectories were considered:

- **Baseline trajectory**: continuation of the recovery trajectory the world is currently on. The emergence of new COVID-19 variants after Omicron is expected to continue for several years, in terms of severity those variants are expected to be similar or less of a concern. Nevertheless, there will be short periods of restrictions following the variant emergence, especially on international travel, as an act of precaution while the variant-severity is evaluated. Vaccine roll-out is continuous, but patchy/uneven with wealthier countries able to achieve a high rate of vaccine deliveries, while

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**Counterfactuals to be considered for modelling**

- **PRE-COVID-19, NO SUSTAINABILITY CONSIDERATIONS**: The "counterfactual" based on pre-COVID-19 growth rates
- **PRE-COVID-19, INCLUDING SUSTAINABILITY CONSIDERATIONS**: The "counterfactual" considering how sustainability factors would have impacted before COVID-19
- **POST-COVID-19, INCLUDING SUSTAINABILITY**: A set of three trajectories considering how aviation will develop post-COVID-19, also taking the megatrend of sustainability into account — the only considerations known so far

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Source: Roland Berger
### Assumptions for RB trajectories of global demand recovery

<table>
<thead>
<tr>
<th>Year of RPK recovery to 2019</th>
<th>RB trajectory “RAPID”</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2023</td>
<td>2024</td>
<td>2026</td>
</tr>
<tr>
<td>High level of vaccine roll-out reached</td>
<td>2023</td>
<td>2024</td>
<td>2026</td>
</tr>
<tr>
<td>Travel demand loss</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business (permanent) — videoconferencing</td>
<td>-10%</td>
<td>-20%</td>
<td>-30%</td>
</tr>
</tbody>
</table>

### CAGR for RPK

<table>
<thead>
<tr>
<th></th>
<th>RB trajectory “RAPID”</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAGR for RPK over 2019–50</td>
<td>3.1%</td>
<td>2.8%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Indicative likelihood of occurring</td>
<td>Less likely</td>
<td>Most likely</td>
<td>Less likely</td>
</tr>
<tr>
<td>GDP scenario (Oxford Economics)</td>
<td>Consumer boom</td>
<td>OE baseline</td>
<td>Return of inflation</td>
</tr>
<tr>
<td>CAGR 2021–26</td>
<td>3.4%</td>
<td>3.3%</td>
<td>2.6%</td>
</tr>
<tr>
<td>CAGR 2026–50</td>
<td>Reducing from 2.7% in 2026 to 1.8% in 2050 (as in OE baseline)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Lifting of travel restrictions

<table>
<thead>
<tr>
<th>Region</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe &amp; North America</td>
<td>2022</td>
<td>2023</td>
</tr>
<tr>
<td>China</td>
<td>2023</td>
<td>2024</td>
</tr>
<tr>
<td>RoW</td>
<td>2023 (but fastest decline)</td>
<td>2025 (but fastest decline)</td>
</tr>
</tbody>
</table>

### Behavioural trends (business and private)

<table>
<thead>
<tr>
<th>Aspect</th>
<th>RB trajectory “RAPID”</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent loss of travel due to environmental concerns</td>
<td>0%</td>
<td>-5% (except RoW, China)</td>
<td>-10% (except RoW, China)</td>
</tr>
<tr>
<td>Temporary loss of travel due to health concerns</td>
<td>-30%</td>
<td>-30%</td>
<td>-30%</td>
</tr>
</tbody>
</table>

### Digital adoption CAGR

<table>
<thead>
<tr>
<th>Region</th>
<th>RB trajectory “RAPID”</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>0.7% (Europe)</td>
<td>1.5% (RoW)</td>
<td>Same as in RB Baseline</td>
</tr>
<tr>
<td>RoW</td>
<td>Same as in RB Baseline</td>
<td>Same as in RB Baseline</td>
<td>Same as in RB Baseline</td>
</tr>
</tbody>
</table>

### KOF index of globalisation CAGR

<table>
<thead>
<tr>
<th>Region</th>
<th>RB trajectory “RAPID”</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same as in RB Baseline</td>
<td>+1% pp. in 2022⁷</td>
<td>0.1% until 2025, 0.3% thereafter</td>
<td>-2.4% pp. in 2022⁷</td>
</tr>
</tbody>
</table>

### E-Commerce spending index CAGR

<table>
<thead>
<tr>
<th>Region</th>
<th>RB trajectory “RAPID”</th>
<th>RB trajectory “BASELINE”</th>
<th>RB trajectory “SETBACK”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same as in RB Baseline</td>
<td>3–13% until 2030, 2–4% thereafter</td>
<td>Same as in RB Baseline</td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1 Loss mainly in internal company meetings, trainings, and customer support; 2 Pre-COVID-19 commercial aircraft OEM forecast was ~4.2% p.a.; 3 Oxford Economics only publishes a GDP forecast of the OE baseline scenario post-2026; we assume the long-term growth rate to be the same for all trajectories; 4 Certain countries, such as Australia/New Zealand assumed to be more restrictive, but only small share of RoW market; 5 Permanent = lasting effect until 2050, temporary = effect until year when restrictions are lifted with gradual recovery; 6 Based on the World Bank Digital Adoption Index measuring countries’ digital adoption across three dimensions of the economy: people, government, and business; 7 In line with respective OE GDP scenarios

Source: Primary and secondary research, Roland Berger Aircraft Production Model
poorer countries take longer to get to high vaccination rates. Vaccinations are expected to reach high levels globally by 2024, allowing travel restrictions to finally relax in 2023 for Europe and North America and 2024 for China and Rest of World (RoW) accordingly. This allows for the recovery to pre-COVID-19 levels of RPKs by 2024.

Rapid trajectory: assuming that new COVID-19 variants following Omicron are less severe compared Omicron and do not trigger renewed travel restrictions. Additionally, we are assuming an accelerated vaccine roll-out, allowing most countries globally to achieve a high rate of vaccination in 2023. This in turn enables governments to continue ramping down travel restrictions rapidly thereafter, which is 2022 for Europe and North America and 2023 for China and RoW. As a result, the recovery to pre-COVID-19 levels of RPKs is expected to occur by 2023.

Setback trajectory: assuming that new COVID-19 variants of concern keep emerging for which available vaccines are substantially less effective or for which the severity is significantly higher compared to Omicron. This triggers a new wave of travel restrictions setting back the world’s recovery process and effective vaccine deployment. Eventually, a new/modified vaccine is expected be developed to counteract these effects, but with a marked delay for the global vaccination campaign and an uneven uptake of vaccines until that point (with wealthier countries again leading the way as has been seen to date). The recovery of RPKs to pre-COVID-19 levels in this scenario will be reached in 2026.

These served as inputs for both the demand- and supply-side considerations in Steps 2 & 3, with assumptions summarised in the previous Figure. → DD

**Step 2: Aviation demand-side analysis**

A demand-side analysis was then conducted, as showcased in Figure EE, considering a holistic set of demand drivers, and estimating demand (in RPKs) broken into defined cuts in the model of flow type (inter-regional, intra-regional), region (Europe, China, North America and RoW) and demand type (business vs. leisure). All inputs for this modelling activity was based on Roland Berger datasets and a holistic expert interview programme. → EE

**Step 3: Aviation supply-side analysis**

We then conducted a supply-side analysis to complement the demand-side analysis, where required capacity (in ASKs/ATKs) were matched to a composite set of drivers defining how demand is met (considering expected network, airline fleet strategy, operator business model, industry structure and biosafety requirements). All inputs for these model drivers were based on Roland Berger datasets and a holistic expert interview programme. → FF

With the interplay of demand and supply determined across the key domains described in Steps 1–3, Roland Berger modelled the equilibrium air traffic, capturing all relevant feedback loops, by performing a series of iterations between the two models. The overall output of this exercise was a series of COVID-19 air traffic recovery trajectories of global air traffic (RPKs and ASKs) at 5-year intervals from 2020 to 2050 broken down by relevant segmentation variables.
EE Driver tree of model — demand-side

Fuel cost increase (SAFs, carbon prices) → Evolutionary Cost improvements → Cost change¹ [%] → Revenue passenger kilometres [km]

Aircraft cost increase → Sustainability-induced cost change [%] → Price Elasticity → Flow type

Other → Non-sustainability induced yield increase/decrease → Inter-regional

COVID-19 evolution → Regulatory Restrictions International travel stringency index

Variant evolution → Behavioural Trends Consumer propensity to travel, ESG policies, etc.

Vaccine evolution → Technological Development Digital Adoption Factor

Nat. immunity evolution → Globalisation KOF Index of Globalisation, Global trade flows

Macro-economic Growth GDP growth by region [%] → Baseline Demand RPK

Macro-economic Growth GDP growth by region [%] → Consumer Buying Trends E-Commerce Spending Growth

Notes: ¹ We assume a constant profit margin, implying cost changes and price changes are equivalent

Source: Roland Berger
Driver tree of model — supply-side

**DEMAND**
- Revenue passenger kilometre [km]
- Operator industry structure
  - Biosafety requirements
  - Operator business model
  - Airline fleet strategy
  - Expected network
- Available seat/tonne kilometre [km]
  - Passenger load factor [%]

**SUPPLY**
- Fleet usage per ASK/ATK
  - Aircraft type
    - Wide-body
    - Narrow-body
    - Regional
  - Engine Type
    - CEO
    - NEO
    - Next Generation
  - Airline type
    - Low-cost
    - Full-service

**INDUSTRY**
- Aircraft delivery
- Aircraft grounding
- Aircraft Retirement

Source: Roland Berger
B.2 Fleet assumptions

To detail the evolution of the supply-side, we have made a set of assumptions which we believe set out a realistic baseline for potential new aircraft launches, based on our survey of industry participants (including CTOs and strategy teams at airlines, aerospace companies, and fuel producers) and interviews, the Chapter 3 literature review and Roland Berger’s project experience. → GG

Assuming historical rates of retirement globally, and somewhat varying replacement rates by region (in-line with expected market and regulatory change), these EIS assumptions led to the fleet evolution laid out in the Baseline trajectory charts overleaf. → HH

B.3 COVID-19 impact on CS2 — Further details

Roland Berger and Oxford Economics assessed the extent to which COVID-19 affected the impact of the CS2 programme. In particular, the COVID-19 pandemic affected working conditions for a limited period of time, and thus may have:

- Delayed specific projects in either delivery of milestones or receipt of funding
- Caused cancellations of specific projects
- Accelerated the delivery of specific projects, e.g., if operational resources were allocated to R&D work through the pandemic to prevent layoffs/furloughs
- Caused no effect at all on specific projects

Thus, to evaluate the effect of COVID-19, the first step was to gather data on the above breakdown under CS2’s umbrella, before then deriving the impact of COVID-19 on the socioeconomic impact of the CS2.

Figure II lays out the summary of how total CS2 funding was then broken down. → II

A series of discussions were conducted with CS2 management to check on the specifics of individual projects to check whether any highly substantive

---

GG Roland Berger Baseline trajectory — EIS assumptions

<table>
<thead>
<tr>
<th>Category</th>
<th>Regional (50–100 pax)</th>
<th>Narrowbody</th>
<th>Widebody</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyper efficient conventional aircraft (HECA)</td>
<td>n/a</td>
<td>2035</td>
<td>2035</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(new aircraft)</td>
<td>(re-engining)</td>
</tr>
<tr>
<td>Hybrid</td>
<td>2035</td>
<td>n/a</td>
<td>2045</td>
</tr>
<tr>
<td>Battery electric</td>
<td>2040</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2035 (either combustion or Fuel Cell)</td>
<td>2040 (combustion)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Source: Roland Berger
**Roland Berger Baseline trajectory**

Fleet evolution by aircraft category [% share of total fleet]

### REGIONAL

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy</td>
<td>100%</td>
<td>80%</td>
<td>60%</td>
<td>40%</td>
<td>20%</td>
<td>10%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### NARROWBODY

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy</td>
<td>100%</td>
<td>80%</td>
<td>60%</td>
<td>40%</td>
<td>20%</td>
<td>10%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### WIDEBODY

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy</td>
<td>100%</td>
<td>80%</td>
<td>60%</td>
<td>40%</td>
<td>20%</td>
<td>10%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: Roland Berger
### II  Estimated impact of COVID-19 on CS2 projects and funding, split by grant funding

Across both grants for CS2 partners, or GAP, and grants for CS2 members, or GAM, as well as private sector IKAA and IKOP contributions

<table>
<thead>
<tr>
<th></th>
<th>Number of GAP projects [#]</th>
<th>GAP [EUR m]</th>
<th>GAM [EUR m]</th>
<th>IKOP [EUR m]</th>
<th>IKAA [EUR m]</th>
<th>Sum [EUR m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A EUR budget of projects that were completed before the pandemic</td>
<td>153</td>
<td>108</td>
<td>704</td>
<td>581</td>
<td>944</td>
<td>2,338</td>
</tr>
<tr>
<td>B EUR budget of projects that are running and not impacted by COVID-19</td>
<td>210</td>
<td>244</td>
<td>265(^1)</td>
<td>222(^1)</td>
<td>180(^1)</td>
<td>911</td>
</tr>
<tr>
<td>C EUR budget of projects that were exposed to COVID-19 -delays …</td>
<td>180</td>
<td>185</td>
<td>200(^1)</td>
<td>167(^1)</td>
<td>136(^1)</td>
<td>688</td>
</tr>
<tr>
<td>… of which actually delayed</td>
<td>n/a</td>
<td>12</td>
<td>51</td>
<td>42(^2)</td>
<td>34(^2)</td>
<td>139</td>
</tr>
<tr>
<td>D EUR budget of projects that have been cancelled due to COVID-19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E EUR budget of projects that have been accelerated due to COVID-19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sum</td>
<td>543</td>
<td>537</td>
<td>1,169</td>
<td>970(^3)</td>
<td>1,260(^4)</td>
<td>3,937</td>
</tr>
</tbody>
</table>

#### IMPACT OF COVID-19 ON CS2

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. GAM/GAP projects affected by delays [#]</td>
<td>189(^5)</td>
<td>Budget actually delayed [EUR m]</td>
<td>139</td>
<td>Average delay of affected projects [months]</td>
<td>11(^6)</td>
<td>Total delays [months]</td>
</tr>
<tr>
<td>Sum of budget affected by delays [EUR m]</td>
<td>688</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1 Extrapolated based on GAP split; 2 Extrapolated based on GAM split; 3 Assuming no change in 83% share of IKOP vs. GAM; 4 Assuming a EUR 100 m expected IKAA funding for 2022 & 2023; 5 Consisting of 180 GAP, 9 GAM; 6 Total delays divided by no. of projects (rounded)

Source: Clean Sky 2, Roland Berger
projects experienced delays with material implications for the results of the CS2 project. This was found to not be the case, with no implications for long-term value/result of the projects conducted. Furthermore, the structure of delays was also checked to ascertain whether there were any individual projects that experienced very significant delays, or if there was a multi-modal distribution in the delays — this was also not found to be the case, with ~11 months being a genuinely useful average to consider with respect to delays (when considering funding allocation).

C. Chapter 3 supporting appendices

C.1 Methodology

In order to develop an outlook for the aviation sector’s environmental impact, risk-assess the strategy of the Clean Aviation Joint Undertaking, and provide recommendations for the European ecosystem to achieve climate neutrality, Roland Berger assessed the performance of different potential technology investment strategies across a range of scenarios. To do this, we followed a five-step process:

1. Determined a longlist of variables that will govern the evolution of the aviation ecosystem through to 2050. We developed a longlist of 33 aerospace, aviation, technology, socio-economic, macro-economic, political, and environmental variables, through a detailed literature review and a series of ~50 interviews with a range of stakeholders from across the aviation ecosystem (including airlines, aerospace OEMs, start-ups, academics, public bodies, NGOs and fuel producers).

2. Prioritised the longlist of variables on the basis of impact and uncertainty to understand what the most important factors and make sure the scenarios we assessed represented the full range of futures for the ecosystem. This was conducted through a workshop with a range of industry participants.

3. Defined and detailed a set of scenarios for the evolution of the aviation ecosystem through to 2050 based on the prioritised list of variables, leveraging insights from a workshop with a range of industry participants.

4. Modelled each scenario in detail, then debated results and implications in a workshop discussion with CAJU, academic/public body participants, and deduced optimal investment areas for each scenario.

5. Assessed the performance of the SRIA and the aviation ecosystem across the baseline trajectory and each scenario, to understand the performance of the CAJU and potential areas for improvement.

- **Impact**: the extent to which the range of probable outcomes of a particular variable will impact development through to 2050 of the aviation and aerospace sectors
- **Uncertainty**: the degree to which the outcome of a particular variable is unclear

In addition to the specific targets set out in CAJU’s mission, we have assessed the extent to which European aviation can approach climate neutrality, with net zero as a first step. In this report, we interpret this target of approaching climate neutrality as aiming for 90%+ reduction in net CO₂ vs. 2019 levels (noting that 90% reduction vs. 1990 levels would imply c. 97%
reduction vs. 2019). We further recognise non-CO₂ effects are crucial and mitigation strategies must be factored in.

However, we recognise that there are a number of important targets as set out within relevant policies within Europe, as summarised in Figure JJ. Some of these targets, as in the CAJU mission, the Single Basic Act, and Destination 2050 are highly specific to aviation, whilst those found in the European Green Deal and Fit for 55 are EU-wide or targeted at the transportation sector (and do not specify decarbonisation trajectories for specific transportation modes). → JJ

### Overview of targets from key documents

<table>
<thead>
<tr>
<th>2030</th>
<th>net CO₂</th>
<th>CO₂e/GHG</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAJU mission</td>
<td>n/a</td>
<td>-30% vs. 2020 state-of-the-art (demo by 2030; EIS by 2035)</td>
<td>n/a</td>
</tr>
<tr>
<td>Single Basic Act</td>
<td>n/a</td>
<td>-30% vs. 2020 state-of-the-art; -55% vs. 1990</td>
<td>n/a</td>
</tr>
<tr>
<td>European Green Deal</td>
<td>n/a</td>
<td>-55% vs. 1990</td>
<td>n/a</td>
</tr>
<tr>
<td>Fit for 55</td>
<td>n/a</td>
<td>-55% vs. 1990</td>
<td>5% SAF blend (4.3% bio., 0.7% PtL)</td>
</tr>
<tr>
<td>Destination 2050</td>
<td>-45% vs. fleet standstill; -55% vs. 1990</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2050</th>
<th>net CO₂</th>
<th>CO₂e/GHG</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAJU mission</td>
<td>-90% vs. 2019 at aircraft level</td>
<td>n/a</td>
<td>75% global fleet replacement</td>
</tr>
<tr>
<td>Single Basic Act</td>
<td>n/a</td>
<td>-100%</td>
<td>75% global fleet replacement</td>
</tr>
<tr>
<td>European Green Deal</td>
<td>n/a</td>
<td>-90% vs. 1990; -100%</td>
<td>n/a</td>
</tr>
<tr>
<td>Fit for 55</td>
<td>n/a</td>
<td>n/a</td>
<td>63% SAF blend (35% bio., 28% PtL)</td>
</tr>
<tr>
<td>Destination 2050</td>
<td>-100%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

- Aviation specific targets
- Transportation targets
- EU-wide targets

Notes: 1 Accounting for effects of SAFs and Hydrogen as a fuel; 2 Pace of decarbonisation not specified by mode of transport; 3 ITRE proposals recommend increasing this to 100%; 4 At an aircraft level, demonstrated by 2030 for aircraft entering service by 2035

Source: Single Basic Act, Eurocontrol, European Commission, Destination 2050, Roland Berger
C.3 Emissions

As part of this report, it has been important to consider the full impact of aviation’s emissions, including CO₂, NOₓ, sulfates, water vapour, soot and contrails and contrail cirrus. In order to do this consistently, it is important to select a specific metric that enables direct comparison of different effects on a CO₂-equivalent (CO₂e) basis.

There are a wide range of potential commonly used metrics to consider for emissions, with different meaning and weighting of different effects.

- CO₂ emissions, measures the annual direct tailpipe CO₂ emissions of aviation. However, this does not reflect the climate impact of non-CO₂ effects, thus understating the total impact of aviation significantly.
- Effective radiative forcing (ERF), representing the imbalance of energy into and out of the atmosphere (in mW m⁻²) resulting from all radiative forcing contributions, adjusted to account for the efficacy of short-term forcers (e.g., adjustments in cloud cover). This accurately accounts for immediate impact of the various forcers, however, it struggles to account for the lifetime of different species.
- Global warming potential (GWP), representing the total integrated radiative forcing impact of emissions over a set time horizon (typically 20/50/100 years), yielding net energy contribution to the atmosphere resulting from a given emission/effect relative to CO₂ emissions. Thus, GWP accounts both for the ERF and lifetime of forcers and has been used in various legislative contexts (e.g., Kyoto protocol). Whilst GWP does not directly translate to a warming impact, it is useful to understand the total climate impact of different emissions and effects.

Global warming potential of different emissions and effects across different time horizons

<table>
<thead>
<tr>
<th></th>
<th>GWP20</th>
<th>GWP50</th>
<th>GWP100</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO₂e/CO₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>4.0x</td>
<td>2.3x</td>
<td>1.7x</td>
</tr>
<tr>
<td>Net NOₓ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water vapour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contrail cirrus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total impact</td>
<td>1.0</td>
<td>1.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

CO₂ emissions | Non-CO₂ emissions and effects

**Emissions impact of different aircraft (GWP50)**

Indexed¹ ("NEO" generation aircraft using 100% kerosene fuel = 100%) [CO₂e]

<table>
<thead>
<tr>
<th>Technology</th>
<th>EIS</th>
<th>Normalised fuel burn² from engine</th>
<th>Normalised fuel burn² from airframe</th>
<th>Impact of fuel</th>
<th>Net impact¹ [CO₂e (GWP50)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;NEO&quot; generation Kerosene</td>
<td>AIS</td>
<td>100%</td>
<td>100%</td>
<td>○ ○ ○ ○</td>
<td>100%</td>
</tr>
<tr>
<td>&quot;NEO&quot; generation 35%² SAF blend</td>
<td>AIS</td>
<td>100%</td>
<td>100%</td>
<td>● ○ ○ ●</td>
<td>75–85%</td>
</tr>
<tr>
<td>HECA 35%³ SAF blend</td>
<td>2035</td>
<td>80–85%</td>
<td>85–95%</td>
<td>● ■ ○ ●</td>
<td>45–65%</td>
</tr>
<tr>
<td>Hybrid 35%³ SAF blend</td>
<td>2035</td>
<td>75–85%</td>
<td>75–85%</td>
<td>● ■ ○ ●</td>
<td>35–55%</td>
</tr>
<tr>
<td>Hydrogen Combustion Liquid H₂</td>
<td>2035</td>
<td>80–85%</td>
<td>90–95%</td>
<td>● ■ ● ●</td>
<td>20–60%</td>
</tr>
<tr>
<td>Hydrogen Fuel Cell Liquid H₂</td>
<td>2035</td>
<td>65–75%</td>
<td>90–95%</td>
<td>● ● ● ●</td>
<td>10–30%</td>
</tr>
<tr>
<td>Battery electric Electric</td>
<td>2040</td>
<td>40–50%</td>
<td>75–115%</td>
<td>● ● ● ●</td>
<td>0–5%</td>
</tr>
</tbody>
</table>

**SIGNIFICANT UNCERTAINTIES PERSIST IN SCIENTIFIC UNDERSTANDING AND DEVELOPMENT PATHWAYS OF DIFFERENT TECHNOLOGIES, THAT WILL DETERMINE FUTURE IMPACT OF DIFFERENT EMISSIONS/EFFECTS**

● Full reduction  ○ Significant reduction  ■ Minor reduction  ○ No change  ● Increase  ● Significant net reduction

Notes: 1 Relative to “NEO” generation aircraft flying equivalent mission; 2 On a per kWh thrust basis; 3 Assuming 35% SAF blend (of which 50% bio-based and 50% PtL) for kerosene, reflecting our Baseline global assumptions

Source: D.S. Lee, Interviews with market participants, Secondary research, Roland Berger
• Global temperature change potential (GTP), representing the change in global temperature induced by a climate forcer as a result of its residual ERF at a set time horizon (typically 20/50/100 years), based relative to that of CO₂. GTP can be directly interpreted in terms of temperature outcomes and accounts for climate conditions at the time horizon, however only accounts poorly for short-term/intermediate effects relative to the time horizon.

We have chosen GWP50 (i.e., global warming potential over a 50-year time horizon) as the appropriate metric for looking at the total climate impact of aviation for the purposes of this project. This is because GWP accounts for both the immediate effective radiative forcing and the lifetime of the different emissions and is an established metric within legislative contexts (e.g., the Kyoto protocol). Considering the 2100 target set by the Paris Agreement (which led to the European Green Deal and Clean Aviation’s existence), we believe that a 50-year time horizon is appropriate for the project for consistency with the timeframes of Clean horizon, given the 2050 fleet replacement horizon. Furthermore, we believe that this 50-year time horizon provides a good balance between the short- and long-term climate impacts of aviation (e.g., contrail cirrus and CO₂, respectively).

To compare the impact of emissions from current aircraft to the likely emissions of new aircraft types (whether kerosene-propelled or using new fuels), we conducted a detailed literature review of existing studies to understand the changes in climate effects they are expected to cause (accounting for both radiative forcing and atmospheric lifetimes). Additionally, we spoke with many academic experts and industry participants to more fully understand expected emissions impact of different fuels and technologies, as well as the likely efficiency impacts of technological developments (in terms of engine fuel burn and airframe efficiency) that could affect aircraft entering service around 2035.

Whilst it is clear that non-CO₂ effects are a significant contributor to climate change, there is significant uncertainty as to their exact impact due to ongoing scientific uncertainty (both in terms of agreement and evidence) as to the precise radiative forcing impacts of the different effects. These uncertainties are particularly large for contrails and contrail cirrus, which is thought to be the most impactful non-CO₂ effect under current operations. This is exacerbated for the future evolution of emissions due to uncertainties over the development of different technology pathways and mitigation strategies. For the purposes of total GHG trajectories, we have used central estimates.

C.4 Fuel requirements

All the sensitivities that reach 90% net CO₂ reductions require significant volumes of both SAFs and hydrogen fuels: to achieve 90% reduction in net CO₂, 100% SAF and at least 40% fleet share of hydrogen aircraft, is required, necessitating 7–20 Mt of hydrogen and 45–75 Mt of SAF production for Europe alone.
**MM** Required SAF and Hydrogen fuel volumes by sensitivity [Mt]

### Hydrogen aircraft uptake

[2050 fleet share]

- **Rapid uptake (-80%)**
  - Baseline: 5–10
  - High uptake: -10
  - No hydrogen: 15–20

- **Baseline (-40%)**
  - Baseline: 10–15
  - High uptake: 0
  - No hydrogen: 15–20

- **No hydrogen aircraft**
  - Baseline: 0
  - High uptake: 0

Outcomes that approach climate neutrality:

- **Baseline**
  - SAF: 70–75
  - PtL: 7

- **ITRE**
  - SAF: 95–100
  - PtL: 7

### SAF uptake by 2050 [% of total jet fuel demand]

- **Downside — 20% SAF (10% Bio, 10% PtL)**
- **Baseline — 50% SAF (25% Bio, 25% PtL)**
- **ReFuel EU — 63% SAF (35% Bio, 28% PtL)**
- **ITRE — 100% SAF (35% Bio, 65% PtL)**
- **100% PtL**

**Notes:**
1. Excluding hydrogen for use as a feedstock for PtL SAFs; 2 Regional (50-100 PAX), Narrowbody, and Widebody aircraft

**Source:** Expert interviews, Industry surveys, Roland Berger
1. 2020 Technology Evaluator First Global Assessment.
2. The effect of the ongoing Ukraine crisis, though extremely important, is not considered quantitatively in this report, with its conclusion and long-term effect highly uncertain at the point of writing (May 2022). A qualitative evaluation of the currently known effects of the Ukraine crisis is provided in Section 2.4.
3. Measured in terms of passenger-kilometres, which is the total number of passengers to, from and within the region multiplied by the distance each one travelled. ICAO, The World of Air Transport, 2019.
5. In Oxford Economics’ modelling we consider all rounds of supply chain spending, i.e., not just the aviation industry’s purchases from its suppliers, but also suppliers’ purchases from their suppliers, and so on right down the supply chain. Our model enables linkages between all sectors and countries to be mapped, enabling us to capture the full contribution of the aviation industry across globalised supply chains.
6. Note that this type of analysis generates results on a “gross” basis. It enables us to understand the contribution of aviation to the economy in a given year, but it does not make any assessment of what the resources used in aviation would have produced in their next most productive use. In other words, this type of analysis is helpful to understand the “economic footprint” of aviation, but does not tell us the degree to which the overall size of the European economy is larger as a result of aviation.
10. Our analysis is based on TE projections that were updated using post-COVID-19 Oxford Economics GDP and employment forecasts. We use the “constrained” version of these projections, meaning that growth at airports that are already heavily congested is constrained by capacity and is not able to grow by as much as demand would suggest.
11. Further details of how we apply the TE forecasts to our base year numbers to generate our economic forecasts are given in the Appendix.
12. At constant 2019 prices and exchange rates.
14. Ibid.
15. The name “gravity” comes from the fact that in its nonlinear form, the model resembles Newton’s law of gravity. The gravity model of trade considers exports to be directly proportional to the exporting and importing countries’ economic “mass” (GDP), and inversely proportional to the distance between them. The gravity model predicts that larger country pairs would tend to trade more, and countries that are further apart would tend to trade less, perhaps because transport costs between them are higher.
17. This is a simplifying assumption. In reality it is possible to hypothesis how COVID-19 may have more lasting effects on behaviour which mean that previous relationships no longer hold. However, it is too soon to evaluate whether such effects may arise, and our modelling relies on data from the pre-pandemic period.
18. We investigated the feasibility of assessing the contribution of CS2 research to European air connectivity during the early phases of our study, but consultations with stakeholders indicated that the uncertainties were too great to enable a meaningful analysis.
20. A low share of imported inputs may also be a sign of insufficient integration into world markets, for example, state-owned companies may be forced to source from domestic suppliers, or the country may protect its industries with import tariffs. This situation may well have detrimental impacts on competitiveness and innovation picked up implicitly in the other indicators included here.
21. Gross value added is an industry’s contribution to a country’s gross domestic product (GDP).
22. As in the aviation footprint assessment, these estimates are presented on a “gross” basis, i.e., we estimate the “economic footprint” of CS2 activity, but not the extent to which the European economy is larger as a result of CS2 spending.
24. OECD, R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries, 2001. Productivity is measured by multifactor productivity (MFP), which is the residual once the contributions of labour and capital are subtracted from GDP growth.
26. Figures from CS2.JU 2020 Consolidated Annual Activity Report referencing a total of 1,887 participations in CS2.
29. In our previous research we investigated the feasibility of obtaining industry-specific coefficients, but it was not possible to obtain statistically robust results at this greater level of granularity.
31. A CGE model is a “bottom-up” macroeconomic model which simulates the economic behaviours of agents (individuals, producers, government, investors, importers, exporters) in the economy. The reactions of these agents following a particular “shock” (such as R&D investment) are modelled within the CGE model as resources such as capital and labour are redistributed around the economy. These effects are aggregated to impute the economic effects at a macroeconomic level. The CGE model takes into account that the extra resources allocated to aerospace and related sectors will, to some degree, displace activity from other uses within the European economy.
32. While some of the benefits estimated will result much less directly from the CS2 projects, we believe the 20-year period should provide a reasonable indication of the period during which a large share of the overall benefits is likely to accrue.
34. We include both public and private funding within the benefit to cost ratio in line with government investment appraisal guidance, including the European Commission’s Guide to Cost-Benefit Analysis of Investment Projects (section 2.7.5) and the UK Treasury’s Appraisal and Evaluation in Central Government (section 5.7). An alternative approach would be to include only the CS2 grants on the cost side of the equation to estimate the total benefits leveraged from public funding. However, since private participants must allocate some of their own resources to realise the full value of benefits it is more appropriate for this type of analysis to include the full range of both public and private costs and benefits.
35. A larger share of IKAA funding occurs earlier in the programme than IKOP and grant funding, meaning a larger share of the benefits happen earlier and as such are discounted to a lesser extent.
36. The counterfactual assumes the latest technologies available in 2014 are gradually incorporated into the global fleet between 2020 and 2050 as older aircraft are replaced. But no allowance is made for technologies developed after 2014.
39. As with the CO₂ analysis, the counterfactual is a global fleet with technology no newer than 2014, and so the results are illustrative of a broad range of innovation in aerospace but may not be attributed to CS2 alone.
41. European Environment Agency, NO₂ emissions.
45. “Annoyance” can be conceptualised and measured in a number of ways, with more detail given in the Appendix.
48. This analysis enables comparison of a situation with and without CS2 technologies for a given level of air traffic. However, it does not provide a pure counterfactual since some degree of technological advancement would be expected if the CS2 programme did not exist.
49. The underlying assumption for this is that the longer the pandemic and travel restrictions last, the more the economy will suffer, and the more travellers are assumed to become used to travelling less — e.g., for business, travellers are assumed to become more and more used to alternative modes of communication such as video conferencing.
50. Defined as all regions excluding Europe, China and North America.
51. The effect of the ongoing Ukraine crisis could also drive supply chain localisation, and possibly be more impactful in the long-term than COVID-19 driven supply chain structural changes. However, the Ukraine crisis is not considered quantitatively in this report, with its conclusion and long-term effect highly uncertain at the point of writing (May 2022). A qualitative evaluation of the currently known effects of the Ukraine crisis is provided in Section 2.4.
52. Completed either by final project milestones having been delivered (grant funding) or funding having been validated (in-kind contribution).
53. This is based on delayed spending of EUR 12 m for GAP projects, EUR 51 m for GAM projects, and EUR 42 m for IKOP and EUR 34 m for IKAA, again extrapolated based on grant funding. According to CS2JU, a proportional delay of in-kind contribution funding in line with grant funding is the most accurate estimation for these values due to limited data availability. In particular, IKOP funding can be assumed to be proportional to GAM funding (at ~83%), therefore the share of delayed funding of total outstanding project budget in Grants for Members is used for IKOP, but also for IKAA estimates (resulting in EUR 138 m in total). Due to limited data availability on the overall budget of affected GAM projects, the GAP share is used for estimating the impact on affected (not delayed) budget (EUR 688 m in total).
Europe is defined as EU-27, Switzerland, Norway, Balkan states, Turkey and UK, accounting for both intra-regional flights, and departing flights.


Given the range of operations undertaken at airports, it is difficult to fully capture the economic impact of airports by using standard industrial classifications alone.


The name “gravity” comes from the fact that in its nonlinear form, the model resembles Newton's law of gravity. The gravity model of trade considers exports to be directly proportional to the exporting and importing countries' economic “mass” (GDP), and inversely proportional to the distance between them. The gravity model predicts that larger country pairs would tend to trade more, and countries that are further apart would tend to trade less, perhaps because transport costs between them are higher.

Ibid.


Eurostat, Structural Business Statistics database.


Krenz, Astrid. "What drives the location choice of new manufacturing plants in Germany?" Available at SSRN 3436786 (2019).


The choice of these sectors, and the extent to which spillover benefits accrue to each, is taken from prior research by the Aerospace Technology Institute (Spillovers: Revealing the broader economic benefits of aerospace R&D, 2021). That research is carried out for the UK: we make the simplifying assumption that the same trends hold true for the EU-27 and UK as a whole.


Intergovernmental Panel on Climate Change, Global Warming of 1.5°C, 2019.


