Department for Transport

Jet Zero: further technical consultation

March 2022

Department for Transport
Great Minster House
33 Horseferry Road
London
SW1P 4DR

This publication is also available on our website at www.gov.uk/government/organisations/department-for-transport

Any enquiries regarding this publication should be sent to us at www.gov.uk/government/organisations/department-for-transport

Contents

Executive summary

Introduction

1.1 The Jet Zero Consultation published in July 2021 set out our vision and strategic framework for achieving net zero aviation by 2050 and included a range of existing policy commitments and new policy proposals to put us on a path to reach this goal.

1.2 Alongside the Jet Zero Consultation, we published a supporting analytical document 'Jet Zero Consultation: Evidence and Analysis' which summarised the latest evidence available from the Climate Change Committee (CCC), industry, academics, and others, on the potential emissions reductions, uptake and cost of abatement measures in aviation. We used that evidence to model four different scenarios with a different mix of technologies to illustrate different pathways for reaching net zero aviation by 2050.

1.3 Since the consultation was published, there have been a number of developments which have allowed us to further develop our analysis and re-visit the four scenarios. These developments include a new version of the department's aviation model[1], new model input assumptions, more up-to-date evidence regarding the development and uptake of new technologies, and further internal policy work on SAF.

1.4 The use of the new model and assumptions has the potential to change the scenarios used in the Jet Zero Strategy, and therefore, **we are undertaking this further technical consultation to provide the opportunity for comment on the updated evidence and how, if at all, it affects responses to the questions set out in the Jet Zero Consultation.[2]**

---

[1] Further detail on the changes to the aviation model can be found in the separately published document *Jet Zero: modelling framework*[ii]

[2] The Department keeps its aviation model and the evidential base under review. We may carry out further model runs before and after publication of the Jet Zero Strategy, to take into account changes to the model or the evidential base, which can arise from a wide range of factors. We do not currently anticipate that there will be changes prior to publication of the Jet Zero Strategy which would significantly impact on the range of illustrative scenarios set out in this document. It is also not considered necessary or practicable to consult on every such change.

1.5 All responses to this further technical consultation will be considered alongside responses to the initial consultation, therefore **no responses need to be resubmitted.** Responses to this consultation only need to be submitted if you have views on the questions below, or your previous response to the questions below, or your views on any of the proposals set out in the initial consultation, have changed considering the updated illustrative scenarios and additional evidence.

1.6 Through this consultation, we are inviting views on the following questions:

1. Do you agree or disagree with the range of illustrative scenarios that we have set out as possible trajectories to net zero in 2050? Are there any alternative evidence-based scenarios we should be considering? (question 2 of the initial consultation)

2. Do you agree or disagree with the possible trajectories we set out, which have in-sector CO_2e[3] emissions of 36Mt in 2030, 28Mt in 2040 and 15Mt in 2050, or net CO_2e emissions of 24-29Mt in 2030, 12-17Mt in 2040 and 0Mt in 2050? (question 3b of the initial consultation - values updated in line with the new analysis)

3. Do you have any other comments in relation to the updated illustrative scenarios?

Please note, only responses relating specifically to the updated analysis and evidence described in this document will be taken into consideration.

1.7 The following chapters set out the updates to the evidence and analysis in more detail and show the impacts these updates have had on the four illustrative scenarios published in the Jet Zero Consultation. In summary:

- Chapter 2 sets out the updated evidence on abatement potential and costs of the four policy measures included in the Jet Zero Consultation modelling. These are: system efficiencies; sustainable aviation fuel; zero emission flight; and markets and removals. The updated evidence includes both the latest external and internal developments from industry and the Government.

- Chapter 3 sets out how the updated evidence described in Chapter 2 has been reflected in updated model input assumptions and how the use of the new version of the Department's aviation model has impacted on the four illustrative scenarios. In this section, the key challenges associated with the updated scenarios, results of the new modelling, and differences from the initial modelling are described.

- Chapter 4 summarises the outcomes and the overall impact of the new analysis on our strategy for achieving Jet Zero.

[3] CO_2e emissions are defined 'CO_2 equivalent emissions. See paragraph 3.3 for more detail on this.

How to respond

The consultation period began on 21 March 2022 and will run until 23:45 on 25 April 2022. Please ensure that your response reaches us before the closing date. If you would like further copies of this consultation document, it can be found at https://www.gov.uk/dft#consultations or you can contact NZaviationconsultation@dft.gov.uk if you need alternative formats (Braille, audio CD, etc.).

We strongly encourage responses by email to NZaviationconsultation@dft.gov.uk. If you are unable to respond by email, we would invite you to ask someone to email on your behalf. If none of the above is possible, then we invite you to provide responses to:

Aviation Decarbonisation Division
Great Minster House
33 Horseferry Road
London
SW1P 4DR

When responding, please state whether you are responding as an individual or representing the views of an organisation. If responding on behalf of a larger organisation, please make it clear who the organisation represents and, where applicable, how the views of members were assembled.

There will be a consultation engagement event held on 24 March 2022. If you would be interested in attending this event, please contact NZAviationconsultation@dft.gov.uk

If you have any suggestions of others who may wish to be involved in this process please contact us.

Freedom of Information

Information provided in response to this consultation, including personal information, may be subject to publication or disclosure in accordance with the Freedom of Information Act 2000 (FOIA) or the Environmental Information Regulations 2004.

If you want information that you provide to be treated as confidential, please be aware that, under the FOIA, there is a statutory Code of Practice with which public authorities must comply and which deals, amongst other things, with obligations of confidence.

In view of this it would be helpful if you could explain to us why you regard the information you have provided as confidential. If we receive a request for disclosure of the information, we will take full account of your explanation, but we cannot give an assurance that confidentiality can be maintained in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not, of itself, be regarded as binding on the Department.

The Department will process your personal data in accordance with the Data Protection Act (DPA) and in the majority of circumstances this will mean that your personal data will not be disclosed to third parties.

Confidentiality and data protection

The Department for Transport (DfT) is carrying out this consultation to gather further evidence on our approach to meet our target of net zero aviation by 2050. This consultation and the processing of personal data that it entails is necessary for the exercise of our functions as a government department. If your answers contain any information that allows you to be identified, DfT will, under data protection law, be the Controller for this information.

As part of this consultation, we are asking for responses via email, which may include your name and will provide us with your email address. We will use this information only for the purposes of asking follow-up questions or notifying you if there is information relating to the consultation which it may be useful for you to be aware of.

DfT's privacy policy has more information about your rights in relation to your personal data, how to complain and how to contact the Data Protection Officer. You can view it at www.gov.uk/government/organisations/ department-for-transport/about/personalinformation-charter.

To receive this information by telephone or post, contact us on 0300 330 3000 or write to Data Protection Officer, Department for Transport, Ashdown House, Sedlescombe Road North, St Leonards-on-Sea, TN37 7GA.

Your information will be kept securely on the IT system within DfT and destroyed within 12 months after the consultation has been completed.

2. Measures to deliver net zero aviation

2.1 This section summarises updates to the evidence on abatement potential and costs of the policy measures highlighted in the initial Jet Zero Consultation.

System Efficiency[4]

2.2 For the purposes of this analysis, the term ‘system efficiency’ is used to encompass both improvements in existing engine and airframe design (such as more efficient engines and lighter materials), and also operational improvements (such as air traffic control improvements and efficiencies at airports).

2.3 The Jet Zero Consultation made use of research by Air Transportation Analytics (ATA), commissioned by the Government jointly with the CCC in 2018.[i] This suggested that efficiency improvements reduce the fuel burn of aircraft coming into service in the mid-2040s by 40-50% compared to types entering service in the early 2000s. This research has been reviewed since the initial consultation and is still considered to be appropriate for use in this updated analysis.

2.4 The ATA assumptions on aircraft technology are applied to next generation aircraft types in our aviation model. As part of the wider updates to the aviation modelling suite, there have been updates to the fleet modelling which have an impact on the way these assumptions are included in the analysis, most notably on when these efficiency improvements are assumed to come into effect. This had led to some changes in the average annual efficiency improvements in specific years. More detail on the updates to the fleet mix modelling can be found in Chapter 4 of the accompanying *Jet Zero: modelling framework* document[ii]. However, overall, between the period of 2017 – 2050, this still translates to average annual fuel efficiency improvements from aircraft and operational measures of 1.5% in the ‘likely’ ATA scenario and 2% in the ‘optimistic’ ATA scenario. Further detail on the specific aircraft and operational measures assumed in these scenarios can be found in the ATA research. Based on the ATA analysis, it is estimated that in the ‘optimistic’ scenario, on average, approximately 60% of the efficiency improvements come from aircraft technologies, and the remaining 40% come from operational and air traffic

[4] Previously discussed in paragraphs 2.2 - 2.4 of the Jet Zero Consultation: Evidence and Analysis document

management measures. In the 'likely' scenario, approximately 75% of the efficiency improvements come from aircraft technologies.

Sustainable Aviation Fuels (SAF)[5]

2.5 There have been some significant policy and industry developments on SAF since the Jet Zero Consultation was published. The DfT published a specific consultation on a SAF mandate, '*Mandating the use of sustainable aviation fuels in the UK'* in the Summer which contained several potential SAF uptake scenarios.[iii] Following a review of the responses and evidence submitted to this consultation, in October 2021, the Government published the '*Net Zero Strategy'* which confirmed the UK's ambition to have 10% SAF in the UK fuel mix by 2030 and announced further government support for UK SAF production.[iv] A summary of the responses to this consultation was published in March 2022.[v]

2.6 There have also been developments and announcements globally on SAF ambition. Notably, the European Commission unveiled proposals under the 'Fit for 55' package, which include blending obligations for fuel suppliers of 5% SAF in 2030 and 63% SAF in 2050.[vi] The United States also published their plans for aviation decarbonisation in their Aviation Climate Action Plan, where they highlighted their emission reduction trajectory.[vii] This includes a SAF uptake scenario which would provide a 50 – 100% emission reduction by 2050. In addition, the World Economic Forum's Clean Skies for Tomorrow coalition, which includes 60 companies covering airlines, airports, fuel suppliers and other aviation innovators, announced an ambition statement in September 2021 for the supply and use of SAF technologies to reach 10% of global jet aviation fuel supply by 2030.[viii]

Zero Emission Flight[6]

2.7 As part of the Aerospace Technology Institute (ATI) programme the Government funded the FlyZero project which brought together experts to understand the challenges and opportunities designing zero emission commercial aircraft. This included consideration of design challenges, manufacturing demands, operational requirements, and market opportunity. Since the Jet Zero Consultation was published, the project has unveiled three design concepts which includes regional, narrow-body and mid-size aircraft. The mid-size concept, powered by liquid hydrogen, demonstrates a zero emission aircraft capable of carrying 279 passengers with a range of 5,250 nautical miles.[ix] There are still significant uncertainties around the potential future costs of a zero emission aircraft, both in terms of upfront capital costs and operating costs. Final outputs of the FlyZero project will be published in March 2022.

---

[5] Previously discussed in paragraphs 2.5-2.8 of the Jet Zero: Evidence and Analysis document
[6] Previously discussed in paragraphs 2.9-2.11 of the Jet Zero Consultation: Evidence and Analysis document

Markets and Removals[7]

Markets

2.8 In September 2021, the Department for Business, Energy and Industrial Strategy (BEIS) published revised guidance on valuing greenhouse gas emissions in policy appraisal, which included a new set of carbon values to 2050[x]. Carbon values are an important input to the demand module of our aviation modelling suite. The carbon values in the model are intended to reflect the costs airline operators face via carbon pricing mechanisms and the model uses these values to calculate the knock-on impact on future air fares and passenger demand.

2.9 In the past, traded-sector carbon values published as part of the Government's published guidance for valuing greenhouse gas emissions in appraisal have been used in the aviation model.[xi] These values were calculated by BEIS using a hybrid approach, which started at current observed EU allowance prices and increased linearly up to a target-based carbon appraisal value in 2050. It was assumed that these values provided a reasonable indication of possible future carbon prices faced by airline operators.

2.10 The new carbon appraisal values, published by BEIS in September 2021, use a different methodology to those published previously. There is no longer a separate carbon value series for the traded sector. The single carbon value series does not reflect current allowance prices and is derived solely from a target-based carbon value.[8] As a result, the series is considerably higher, particularly in the short term, and no longer reflects the carbon prices airline operators face (via the UK Emissions Trading Scheme and Carbon Offsetting and Reduction Scheme for International Aviation) in the short-medium term. Use of these values would risk overstating the emissions reductions that could be achieved through carbon pricing measures. For this reason, these new carbon values are not suitable for use in forecasting aviation demand.

2.11 We have now produced a new set of carbon price assumptions for use in our aviation model which are designed to illustrate the potential range of costs faced by airline operators via the UK ETS, EU ETS and CORSIA in the future. Given the market-based nature of these schemes, that future prices will be affected by future policy decisions[9] and the need to make assumptions about carbon prices to 2050, there is considerable uncertainty around these assumptions. To reflect this uncertainty, we have produced illustrative low, mid and high series which cover a wide range of

---

[7] Previously discussed in paragraphs 2.12-2.20 in the Jet Zero Consultation: Evidence and Analysis document

[8] More detail on the methodology underpinning the new BEIS appraisal values can be found at: https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

[9] For example, the wider policy set out in the Governments "*Net Zero Strategy*" will mean the UK ETS prices associated with reaching net zero will be lower.

possible future scenarios.[10] More information on these new assumptions can be found in Annex B.

2.12 The Government will soon be consulting on the future development of the UK ETS, including to align it with a net zero 2050-consistent emission trajectory. The carbon price assumptions used in this Jet Zero consultation do not pre-empt the outcome of that consultation or any other future policy.

2.13 In previous versions of the aviation model, it was not possible to distinguish between different carbon pricing mechanisms on different routes, such that we were only able to apply a single set of carbon price assumptions across all routes. In practice, flights within the UK, from the UK to the European Economic Area (EEA) and between the UK and Gibraltar are in scope of the UK ETS, while international flights[11] are in scope of CORSIA.[12] The updated version of the aviation model allows us to apply different carbon price assumptions to different routes which means we can reflect the impacts of different carbon pricing mechanisms more accurately on demand and emissions.[13]

Removals

2.14 BEIS analysis conducted at the time of the Net Zero Strategy shows that, to achieve net zero across the UK economy, engineered Greenhouse Gas Removal (GGR) methods will be required to balance residual emissions from some of the most difficult to decarbonise sectors, such as agriculture and aviation. This confirms the assessment by independent institutions such as the CCC and the National Infrastructure Commission. BEIS modelling at the time of the Net Zero Strategy publication suggests that by 2050, between 75 and 81 MtCO2e/year of negative emissions from engineered removals will be required to offset residual emissions in hard-to-abate sectors. Recent analysis by Element Energy[xii], commissioned by BEIS, on GGR methods and their potential UK deployment suggests that engineered GGRs could provide over 100MtCO2/year of removals by 2050 but this does rely on availability of CO2 transport and storage and bioenergy supply.

2.15 The recent research by Element Energy finds the costs of Power BECCS[14] may be around £30-170/tCO2 gross in 2050 and for direct air carbon capture and storage (DACCS) £70-250/tCO2 gross in 2050.[xiii] This research shows costs could be slightly lower than those published in the Vivid Economics research referenced in the initial Jet Zero consultation and the GGR Call for Evidence.[xiv] This suggests that GGRs could be a relatively cheap and cost-effective removal measure in the future, to

---

[10] The three series each reflect a plausible trajectory for future carbon prices; the 'mid' scenario should not be interpreted as a 'central' or 'most likely' scenario.
[11] CORSIA applies to all international flights between participating states.
[12] The demand module of the aviation model also applies the carbon values on flights arriving in the UK. It is not able to apply a different series to these flights (e.g. those covered by the EU ETS) so the same carbon price (either UK ETS or CORSIA) is assumed on flights departing and arriving in the UK to/from a specific country/region. This is recognised as a minor limitation to the model. Carbon emissions are only modelled on departing flights.
[13] Flights from the UK to the EEA are in scope of both the UK ETS and CORSIA. For modelling purposes, the UK ETS carbon price series has been applied to these flights to reflect the higher carbon price airlines currently face on these routes. The Department is carefully considering the approach to CORSIA implementation and interaction with the UK ETS, and we will consult further in due course.
[14] Bioenergy with carbon capture and storage

compensate for residual emissions, however other factors such as the sustainability of feedstocks and energy requirements for GGRs must also be considered when determining the extent to which they can be deployed.

3. Pathways to net zero

3.1 We have used the updated version of the aviation modelling suite to re-run the modelling that we did for the four scenarios that were set out in the Jet Zero Consultation. More details on this updated version of the modelling suite can be found in the accompanying *Jet Zero: modelling framework document*[ii]. Some of the assumptions around the abatement potential from each measure used in the scenarios have been updated to reflect the developments and updates to the evidence base set out in Chapter 2. Details of the assumptions used in the updated modelling are set out below.

3.2 The scenarios presented here are not prescriptive and seek to illustrate different ways in which the UK aviation sector could reach net zero by 2050. The uncertainty surrounding the future costs of the measures mean that it is not possible to assess the relative cost effectiveness of the scenarios with confidence. The optimal mix of measures will become clearer over the coming decade as the relevant technologies mature and evidence of their relative costs improves. Achieving net zero will also rely heavily on a collaborative, international effort and these scenarios should be viewed in that context – the fruition of these scenarios will not be possible based on domestic action alone.

3.3 The results presented in this consultation are expressed as carbon dioxide equivalent (CO_2e). This is a change from the results presented in the initial Jet Zero Consultation which were expressed simply as carbon dioxide (CO_2). This approach has been adopted to ensure consistency with net zero publications from BEIS and to provide a more accurate representation of greenhouse gas emissions. The carbon dioxide equivalent measure also includes the emissions from other greenhouse gases including methane (CH_4) and nitrous oxide (N_2O). This change of units results in a very minor (less than 1%) change in emission levels because for aviation, carbon dioxide makes up the vast majority of greenhouse gas emissions.

3.4 The analysis does not currently take into account the effects of other non-CO_2 impacts such as contrails and Nitrogen oxides (NOx) emissions due to the uncertainties around their scale. As outlined in the initial consultation, we are improving our understanding of these impacts and will ensure that the latest scientific understanding of aviation non-CO_2 impacts is used to inform our policy.

3.5 The other noticeable change in results, which is reflected in all scenarios, is an increase in the level of abatement attributed to the demand impact of carbon pricing and a decrease in the abatement attributed to fuel efficiency improvements. The fuel efficiency assumptions flow through into the results via two different mechanisms. The first is simply that the efficiency improvements lead to lower fuel use and therefore lower emissions. The second mechanism is a fuel efficiency feedback loop which enables the cost savings assumed to be delivered by lower fuel use to be fed back into the aviation demand model.

3.6 In the latest modelling, it has been possible to better differentiate between the effects of this fuel efficiency feedback loop and the effects of carbon pricing. Previously, these effects were shown combined with each other under the ‘demand impact of carbon pricing’ wedge in the published charts for each scenario. The impact of applying the fuel efficiency feedback loop is lower fuel costs, lower fares and therefore higher demand. This increase in demand results in additional aircraft movements and therefore additional emissions. The impact of higher carbon pricing in the model is the opposite – carbon costs lead to higher fares and therefore lower demand and emissions. Combining these impacts in the original consultation analysis led to the carbon pricing impact on demand appearing to result in fewer emission savings. In the latest modelling, we have been able to isolate the impacts of the fuel efficiency feedback loop and assign those impacts to the ‘fuel efficiency improvements’ wedge. This means that the ‘demand impact of carbon pricing’ wedge now solely refers to the reduced demand from applying higher carbon values in the model. The ‘fuel efficiency improvements’ wedge now includes both the emission reductions resulting from improved fuel efficiency and the emission increases that result from fuel efficiency improvements driving lower fuel costs, which feeds through into greater aviation demand. These changes therefore lead to a larger carbon pricing wedge and a smaller fuel efficiency improvements wedge in the charts than was the case in the initial consultation. More detail on the fuel efficiency feedback loop can be found in the accompanying *Jet Zero: modelling framework*[ii] document.

3.7 In addition, the latest modelling also makes use of updated price elasticities in the Department for Transport’s demand model (NAPDM) which imply that passengers are now more sensitive to changes in fares than in the previous consultation analysis. This update further contributes to a larger carbon pricing impact on demand. The new carbon price assumptions we have produced, and the inclusion of a separate CORSIA series have also led to changes in the carbon pricing impact shown across the scenarios below.[15]

3.8 All scenarios are shown in the charts alongside an updated 'Policy-Off' baseline where there is no carbon price, no action on SAF or zero emission aircraft, and only minor annual efficiency improvements. In this case, total UK aviation emissions reach around 52 $MtCO_2e$ in 2050. This baseline has reduced by approximately 5 $MtCO_2e$ in 2050 since the initial consultation. The reasons for this reduction are due to the updates that have been made to the aviation modelling suite and more detail on these updates can be found in the *Jet Zero: modelling framework*[ii] document, published alongside this consultation.

3.9 Our scenarios are based on updated passenger demand scenarios but do not fully take account of the impact of COVID-19 on aviation demand. To address the short-

[15] More information on the new carbon values can be found in Annex B.

term fall in emissions, an uncertainty band has been added to the graphs covering 2020-2024 which is consistent with our approach on the initial consultation. There is also uncertainty about the impact of COVID-19 on passenger behaviour in the longer term. Adopting this approach to the impact of COVID-19 means our scenarios may be based on an overestimate of demand, and therefore lead to an overestimate of future emissions. However, this has the advantage that it allows us to robustly test our abatement options against a relatively high demand baseline. This feature of the analysis should be considered when interpreting the results. Further detail on the uncertainty related to COVID-19 can be found in the accompanying *Jet Zero: modelling framework*[ii] document.

3.10 There are also other important drivers of passenger demand which are inherently uncertain, including economic growth and oil prices. The analysis within this document is based on the official forecasts of these drivers, however the uncertainty around these should be considered when interpreting the results and future emissions may be higher or lower than those illustrated in this chapter if future GDP growth rates or oil prices are significantly different from the forecasts. Annex C shows how employing reasonable alternative assumptions about the main economic drivers of demand, relating to economic growth and oil prices, impacts on the emissions modelled for Scenario 2: High Ambition.

Scenario 1: Continuation of Current trends

3.11 This scenario represents a continuation of current trends in UK aviation. There is some, limited step-up in ambition on SAF and minor annual fuel efficiency improvements, but no introduction of zero-emission aircraft. This scenario does include carbon pricing, with the specific carbon price series varying depending on whether the flight is in scope of the UK ETS or CORSIA.

	Initial Jet Zero Consultation Assumptions	***Latest Assumptions***	***Rationale / Source***
Demand[16]	60% increase in terminal passengers by 2050	74% increase in UK terminal passengers by 2050.	Updated DfT demand forecasts
Carbon price series (2020 £ prices)[17]	BEIS central carbon price on all flights, reaching £231/tCO2 in 2050	DfT 'Mid' ETS price series (£150/t in 2030, £378/t in 2050) and 'Low' CORSIA price series (£6/t in 2030, £37/t in 2050).	New DfT carbon price assumptions for aviation modelling
Capacity	Jet Zero Consultation airport assumptions	Updated airport capacity assumptions	See separate *Jet Zero: modelling framework*[ii] document for more detail

16 The increase in terminal passengers is relative to the level of terminal passengers in 2018.
17 The carbon price assumed across these scenarios could be delivered through a number of measures including UK ETS, EU ETS, CORSIA or others. The carbon price assumptions do not reflect forecasts of future carbon prices.

Fuel efficiency[18] improvements	Central Efficiency 1.5% pa (2017-2050)	Central Efficiency 1.5% pa (2017-2050)	Based on 'likely, nominal' case from ATA research. This is within the range of average historic improvements and future expectations.
SAF uptake	5% by 2050	10% by 2050	Based on expert judgement and increased ambitions on SAF both in UK and internationally.
Zero emission tech uptake	None by 2050	None by 2050	Based on conservative assumptions about the trajectory for zero emission aircraft, whereby they do not enter the fleet at a significant level until 2050 at the earliest.

Figure 1. Assumptions in Scenario 1

Key Challenges

3.12 While this scenario should be relatively easy to achieve, there are still some uncertainties and deliverability challenges surrounding the assumptions. Firstly, this scenario assumes that beyond 2035 (the end of the period in which CORSIA currently applies) a carbon price continues to apply to international flights departing the UK outside the scope of UK ETS but remains at a similar level to that assumed in the period leading up to 2035. While this does not represent a very ambitious goal, it will be subject to international negotiation. Secondly, though in line with historic trends, our assumptions on fuel efficiency may not be met if airlines don't have significant funds to invest in new aircraft (e.g., due to the financial impact of COVID-19 on the aviation industry). Finally, for this scenario to be cost-effective and consistent with net zero, the costs of GGRs will need to be low relative to those of in-sector abatement measures, making it cost-effective to achieve the majority of emissions reductions required to reach net zero through out-of-sector mitigation.

[18] By fuel efficiency, we are referring to all the system efficiency improvement incorporated in the modelling outlined in Chapter 2

Results

3.13 In this scenario, passenger numbers reach 493 million in 2050. This scenario results in around 36 $MtCO_2e$ of residual emissions in 2050, which will need to be offset to reach net zero emissions. The residual emissions in the initial Jet Zero Consultation were also 36 $MtCO_2$ in the same scenario. While passenger numbers grow by around 74% on 2018 levels (from 283 million terminal passengers in 2018 to 493 million in 2050), emissions remain relatively constant over the time horizon due to the impact of continuous fuel efficiency improvements and the small uptake of sustainable fuels.

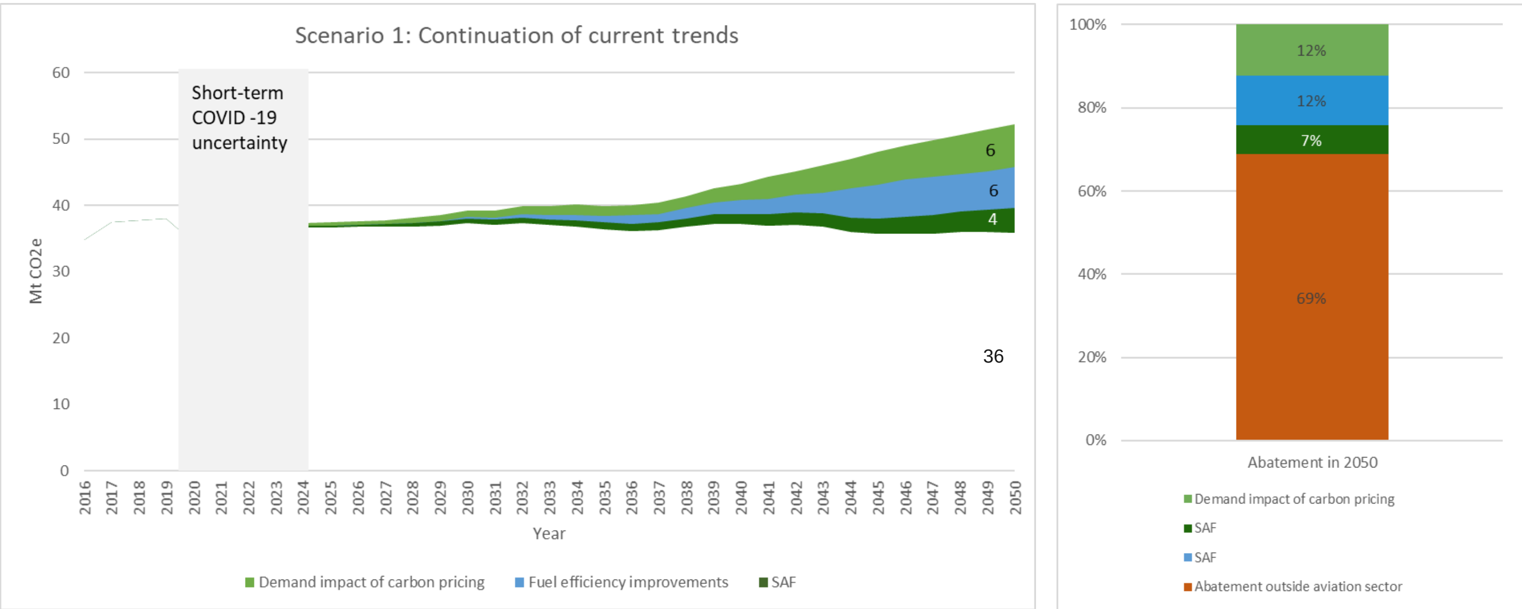


Figure 2. Scenario 1 – Continuation of Current Trends

Year		2030	2040	2050
Change on 2018 CO_2 emission levels	Initial Consultation analysis (MtCO2)	+6%	-2%	-5%
	Further consultation analysis ($MtCO_2e$)	-1%	-2%	-5%

Figure 3. Comparison of Scenario 1 to 2018 aviation emissions

Key changes from the initial consultation

3.14 In this scenario, we have assumed slightly higher levels of SAF uptake than in the initial consultation. We now assume 10% uptake of SAF in 2050, as compared to 5% SAF uptake in 2050 previously. This reflects the increased ambition announced by government and industry in recent months. This results in SAF contributing to emissions savings of 4 $MtCO_2e$ in 2050, compared to the 2 $MtCO_2$ emission saving in the Jet Zero Consultation.

3.15 In the initial consultation, the demand impact of carbon pricing using the old ‘central’ BEIS carbon values in this scenario led to 5 $MtCO_2$ savings in 2050. This updated analysis, using new DfT ‘mid’ ETS and ‘low’ CORSIA carbon price assumptions now leads to emissions savings of 6 $MtCO_2e$ in 2050. A proportion of this increase is due to the modelling updates outlined in paragraph 3.5. The DfT ‘mid’ ETS price series has been used in this scenario (and other scenarios) to illustrate a possible future in which the carbon price applied to routes in scope of the UK ETS increases significantly through time to reach the BEIS central carbon appraisal value by 2050.[19] The ‘low’ CORSIA carbon price series has been chosen to reflect a possible future in which carbon prices under CORSIA (or similar replacement scheme) remain relatively low to 2050.

3.16 All other changes to the results of this scenario are due to broader updates to the aviation model or input assumptions (e.g., economic growth assumptions) which are described in more detail throughout this document and in *Jet Zero: modelling framework*[ii] document.

Scenario 2: High Ambition

3.17 This scenario is more ambitious than Scenario 1. It includes the same assumptions on UK ETS carbon price and capacity but there is a step-up in ambition on fuel efficiency improvements, SAF uptake and the introduction of zero emission aircraft. Passenger demand is lower under this scenario than under Scenario 1 due to the higher CORSIA carbon price assumptions, which feed through into higher air fares.

	Initial Jet Zero Consultation assumptions	***Latest assumptions***	***Rationale / Source***
Demand[20]	60% increase in terminal passengers by 2050	70% increase in UK terminal passengers by 2050	Updated DfT demand forecasts
Carbon price series (2020 £ prices)	BEIS central carbon price on all flights, reaching £231/tCO2 in 2050	DfT Mid ETS price series (£150/t in 2030, £378/t in 2050) and Mid CORSIA price series (£6/t in 2030, £378/t in 2050).	New DfT carbon price assumptions for aviation modelling
Capacity	Jet Zero Consultation airport assumptions	Updated airport capacity assumptions	See *Jet Zero: modelling framework*[ii] document for more detail

[19] This should not be interpreted as the mid series as representing the DfT’s ‘most likely’ or ‘central’ view of future UK ETS prices.
[20] The increase in terminal passengers is relative to the level of terminal passengers in 2018.

Fuel efficiency improvements	2.0% pa (2017-2050)	2.0% pa (2017-2050)	Based on 'optimistic, nominal' scenario from ATA research
SAF uptake	30% by 2050	50% by 2050	Based on expert judgement, a review of the latest evidence and industry views, including increased ambitions on SAF in the UK and internationally.
Zero emission tech uptake	21% of ATMs[21] zero emission by 2050	27% ATMs zero emission by 2050	Entry into service for zero emission Class 1 & 2 planes (<150 seats) in 2035. Further 50% of retiring Class 3 aircraft (150-250 seats) replaced with zero emission aircraft from 2040, at current replacement rates. In line with industry ambitions and external evidence

Figure 4. Assumptions in Scenario 2

Key Challenges

3.18 There are several deliverability challenges associated with this scenario, which go beyond those identified for Scenario 1. Firstly, this scenario assumes that beyond 2035 (the end of the period to which CORSIA applies) the carbon price applying to international flights departing the UK outside the scope of UK ETS converges on the carbon price that is applied to flights that are in scope of the UK ETS. This will require international cooperation to achieve.

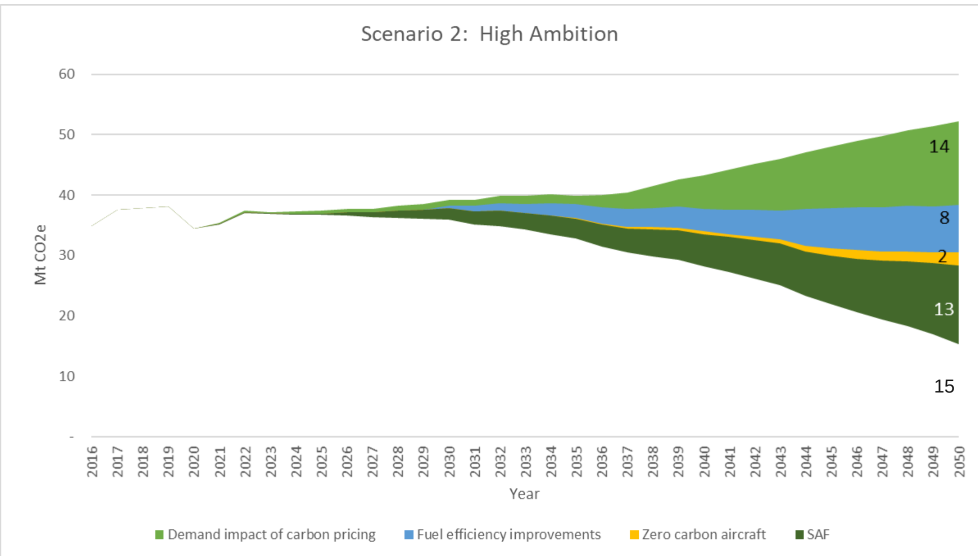
3.19 Secondly, to achieve 50% SAF uptake by 2050, a significant amount of feedstock would be required, and it is likely that aviation would need to be prioritised amongst other competing sectors. It is also likely that power-to-liquid SAF would need to be deployed at scale to meet this fuel demand. Furthermore, achieving a step up in fuel efficiency improvement relative to historical trends will also be challenging, and may not be met if airlines cannot afford to invest in modernising their fleets at sufficient speed, if the aerospace sector cannot afford to invest in creating the necessary aircraft advancements (made more likely by the huge financial impact of COVID-19 on the aviation industry), or if the aerospace sector chooses to focus more investment on zero emission aircraft technology. Finally, most crucial for realising the

[21] Air Transport Movements (ATMs) represent a take-off or a departure

introduction of zero emission aircraft by 2035, is the necessary progress in battery and hydrogen technology within this decade, as future aircraft availability by 2035 requires technology readiness by 2027-2030.

Results

3.20 In this scenario, terminal passenger numbers increase by 70% on 2018 levels reaching 482 million in 2050. More ambitious assumptions on efficiency and SAF uptake, higher carbon price assumptions, and the introduction of some zero emission aircraft result in less than half the residual emissions forecast in Scenario 1, 15 $MtCO_2e$ in 2050. This compares to residual emissions of 21 $MtCO_2$ in the initial Jet Zero Consultation in the same scenario. The introduction of zero emission aircraft in 2035 have a minimal impact on overall abatement, contributing to 4% of the total emissions reductions given they are mainly allocated within the model on domestic and short-haul routes.



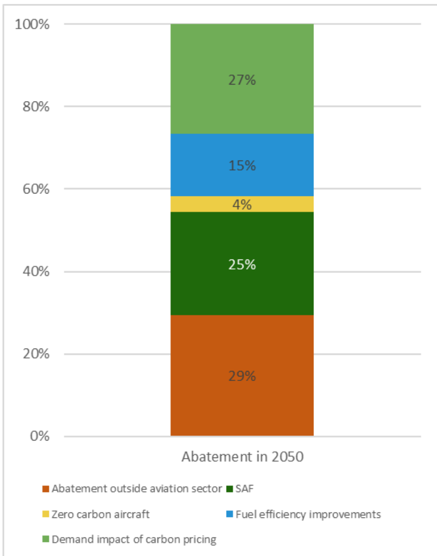


Figure 5. Scenario 2 – High Ambition

Year		**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	Initial Consultation analysis (MtCO2)	+3%	-19%	-45%
	Further consultation analysis ($MtCO_2e$)	-5%	-25%	-59%

Figure 6. Comparison of Scenario 2 to 2018 aviation emissions

Key changes from the initial consultation

3.21 One key change in terms of what we assume about abatement measures compared to the initial consultation is an increase in the uptake of SAF from 30% in 2050 previously, to 50% in this analysis. This reflects the increased ambition announced by governments and industry in recent months. This results in SAF contributing to emissions savings of 13 $MtCO_2e$ in 2050, compared to the 8 $MtCO_2$ in the High Ambition scenario in the Jet Zero Consultation.

3.22 In the initial consultation, the demand impact of carbon pricing using the old 'central' BEIS carbon values in this scenario led to 5 $MtCO_2$ savings in 2050. This updated analysis, using new DfT 'mid' carbon price assumptions now leads to emissions savings of 14 $MtCO_2e$ in 2050. A significant proportion of this increase is due to the modelling updates outlined in paragraph 3.5. Annex B shows how the carbon savings under this scenario vary under the new DfT 'low' and 'high' carbon price assumptions.

3.23 All other changes to the results of this scenario are due to broader updates to the aviation model or input assumptions (e.g., economic growth assumptions) which are described in more detail throughout this document and in *Jet Zero: modelling framework*[ii] document.

Scenario 3: High ambition with breakthrough on SAF

3.24 The third scenario is a speculative, extremely ambitious scenario. Fuel efficiency and carbon price assumptions are the same as in Scenario 2, but SAF emerges as a more cost-effective solution and ramps up at considerable scale enabling uptake of 100% of aviation fuel usage by 2050. Passenger demand in this scenario is the same as in Scenario 2, as it is assumed that reductions in the costs of SAF over time make it cost effective for airlines to use given the carbon prices assumed.

	Initial Jet Zero Consultation assumptions	*Updated assumptions*	*Rationale / Source*
***Demand*[22]**	58% increase in terminal passengers by 2050	70% increase in UK terminal passengers by 2050	Updated DfT demand forecasts
Carbon price series (2020 £ prices)	BEIS high carbon price on all flights, reaching £346/tCO2 in 2050	DfT Mid ETS price series (£150/t in 2030, £378/t in 2050) and Mid CORSIA price series (£6/t in 2030, £378/t in 2050).	New DfT carbon price assumptions for aviation modelling
Capacity	Jet Zero Consultation airport assumptions	Updated airport capacity assumptions	See *Jet Zero: modelling framework*[ii] document for more detail
Fuel efficiency improvements	2.0% pa (2017-2050)	2.0% pa (2017-2050)	Based on 'optimistic, nominal' scenario from ATA research
SAF uptake	75% by 2050	100% by 2050 (10% by 2030)	Based on expert judgement, a review of the latest evidence, industry views and increased ambitions on SAF in the UK and internationally
Zero emission tech uptake	21% of ATMs zero emission by 2050	27% of ATMs zero emission by 2050	Entry into service for zero emission Class 1 & 2 planes (<150 seats) in 2035. Further 50% of retiring Class 3 aircraft (150-250 seats) replaced with zero emission aircraft from 2040, at current replacement rates. In line with industry ambitions and external evidence

Figure 7. Assumptions used in Scenario 3

[22] The increase in terminal passengers is relative to the level of terminal passengers in 2018.

Key Challenges

3.25 This is an extremely ambitious scenario on SAF, and many challenges will need to be overcome for this to happen. Most crucially, the costs of SAF will need to fall significantly, and the cost of kerosene (inclusive of a carbon price) will need to increase significantly, as the relative cost of using SAF is currently one of the main barriers to uptake. Achieving such a high proportion of SAF would require significant development of advanced SAF production pathways (such as power-to-liquids), which are currently much more expensive than other SAF. Secondly, there will need to be a substantial ramp up of SAF production. There are currently a number of barriers to these two conditions, including the high capital costs of building first-of-a-kind plants and the high risk for investors due to technology risk. Moreover, there are stringent certification requirements for new fuel pathways that may emerge, and current fuel specifications prescribe certain blend limits (there are currently only eight certified SAF pathways which can only be blended up to 50% in volume). Other risks include the lack of secure and sustainable supply chains for feedstocks, competition for feedstocks with other sectors (such as biomass used in road fuels) and potential changes needed to aircraft engines and re-fuelling infrastructure to be compatible with SAF at blends higher than 50%. Only if all these challenges are overcome, in addition to those discussed in the previous scenarios, could such a scenario be plausible.

Results

3.26 This scenario results in the abatement of 100% of 2050 aviation emissions within-sector – the largest of the four scenarios. This compares to residual emissions of 9 $MtCO_2$ in the initial Jet Zero Consultation in the same scenario. SAF delivers the largest proportion of this abatement (54% in 2050). Passenger numbers are the same as in Scenario 2 at 482 million in 2050 and, as in Scenario 2, zero emission aircraft contribute 4% to the total emissions abated in 2050.

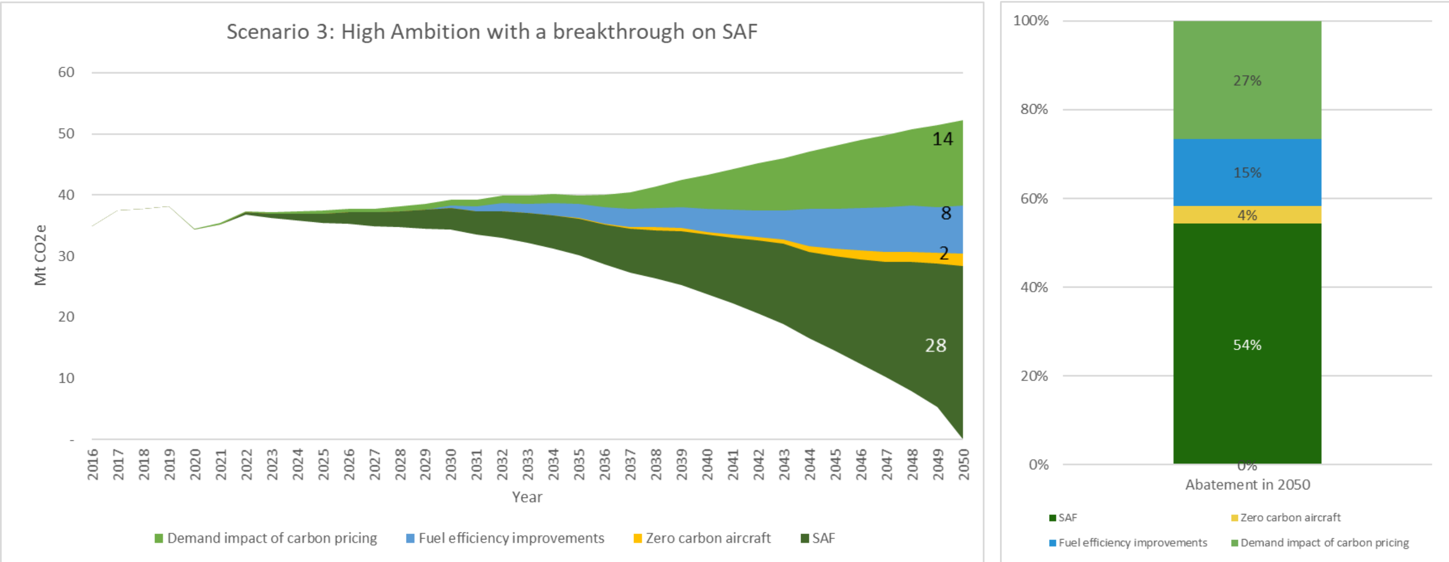


Figure 8. Scenario 3 – High ambition with a breakthrough on SAF

Year		**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	Initial Consultation analysis (MtCO2)	0%	-28%	-77%
	Further consultation analysis ($MtCO_2e$)	-9%	-37%	-100%

Figure 9. Comparison of Scenario 3 to 2018 aviation emissions

Key changes from the initial consultation

3.27 Compared to the initial consultation, in 2050 there is an assumed increase in the uptake of SAF from 75% previously, to 100% in this analysis. This scenario also includes 10% SAF uptake by 2030. This reflects the increased ambition announced by governments and industry in recent months. This results in SAF contributing to emissions savings of 28 $MtCO_2e$ in 2050, compared to the 20 $MtCO_2$ in the High Ambition with a breakthrough on SAF scenario in the Jet Zero Consultation.[23]

3.28 This scenario now also uses the same ‘mid’ carbon price assumptions as scenarios 2 and 4. This differs from the Jet Zero Consultation analysis where both ‘breakthrough’ scenarios used higher carbon price assumptions than Scenarios 1 and 2. In the Jet Zero Consultation analysis, it was determined that for the uptake rates assumed in the ‘breakthrough’ scenarios to be realised, there would need to be a higher carbon price to incentivise the required investment. Given the new DfT ‘mid’ carbon price

[23] This is based on the assumption that SAF leads to 100% direct emission savings relative to kerosene. This is explained in Annex A.

series is considerably higher than the old 'central' series (and is very similar to the old 'high' series), we have determined that the new DfT 'mid' series is suitable for use in the breakthrough scenarios.

3.29 Using the new DfT 'mid' carbon price assumptions leads to emissions savings of 14 $MtCO_2e$ from the demand impact of carbon pricing. This compares to emissions savings of 5 $MtCO_2$ in the initial consultation from using the old 'high' series. A significant proportion of the increase is due to the modelling updates outlined in paragraph 3.5.

3.30 All other changes to the results of this scenario are due to broader updates to the aviation model or input assumptions (e.g., economic growth assumptions) which are described in more detail throughout this document and in *Jet Zero: modelling framework*[ii] document.

Scenario 4: High ambition with breakthrough on Zero Emission Aircraft

3.31 The scenario is a speculative, extremely ambitious scenario that includes Class 3 aircraft entering service in 2035 and a new, mid-size hydrogen powered aircraft entering service in 2035. This enables 38% of ATMs to be flown by zero emission aircraft by 2050. SAF uptake, carbon price and efficiency assumptions are kept consistent with Scenario 2. Passenger demand in this scenario is the same as in Scenario 2.

	Initial Jet Zero Consultation assumptions	***Updated assumptions***	***Rationale / Source***
Demand[24]	58% increase in UK terminal passengers by 2050	70% increase in UK terminal passengers by 2050	Updated DfT demand forecasts
Carbon price series (2020 £ prices)	BEIS high carbon price on all flights, reaching £346/tCO2 in 2050	DfT Mid ETS price series (£150/t in 2030, £378/t in 2050) and Mid CORSIA price series (£6/t in 2030, £378/t in 2050).	New DfT carbon price assumptions for aviation modelling
Capacity	Jet Zero Consultation airport assumptions	Updated airport capacity assumptions	See *Jet Zero: modelling framework*[ii] document for more detail
Fuel efficiency improvements	2.0% pa (2017-2050)	2.0% pa (2017-2050)	Based on 'optimistic, nominal'

[24] The increase in terminal passengers is relative to the level of terminal passengers in 2018.

			scenario from ATA research
SAF uptake	30% by 2050	50% by 2050	Based on expert judgement and increased ambitions on SAF.
Zero emission tech uptake	53% of ATMs by 2050	38% of ATMs by 2050	Entry into service for zero emission Class 1 & 2 and 3 aircraft (<250 seats) in 2035. Additional 'mid-size' concept aircraft (280 seats) entry into service from 2035.

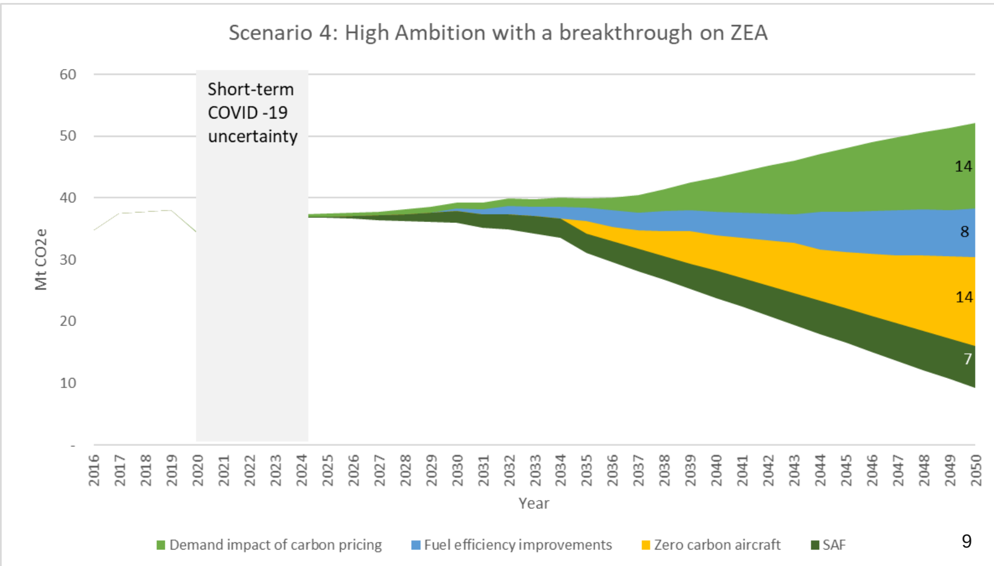
Figure 10. Assumptions used in Scenario 4

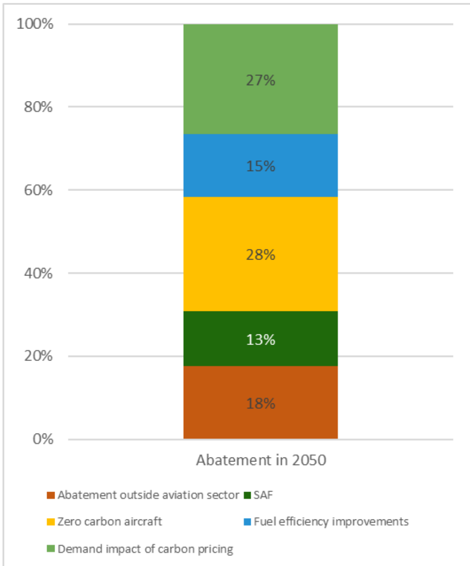
Key Challenges

3.32 For such a scenario to be realised, several challenges will need to be overcome. For example, a step change in technological advancements will be required, certification and safety regulations will need to keep up with new technologies as they emerge, airport infrastructure (e.g., re-fuelling infrastructure for hydrogen and electricity supply for charging electric aircraft) will need a coordinated change to facilitate the use of new aircraft types, and airlines will need to be able to quickly incorporate new aircraft types into their fleets.

Results

3.33 This scenario results in 9 $MtCO_2e$ of residual emissions which will need to be abated outside the sector in 2050. This compares to residual emissions of 17 $MtCO_2$ in the initial Jet Zero Consultation in the same scenario. Terminal passenger numbers are the same as in Scenarios 2 and 3, reaching 482 million in 2050. A breakthrough on





Zero Emission Aircraft means that this technology contributes 28% to the total reduction in emissions in 2050.

Figure 11. Scenario 4 – High ambition with a breakthrough on zero emission aircraft

Year		2030	2040	2050
Change on 2018 CO_2 emission levels	Initial Consultation analysis (MtCO2)	+1%	-25%	-54%
	Further consultation analysis ($MtCO_2e$)	-5%	-37%	-76%

Figure 12. Comparison of Scenario 4 to 2018 aviation emissions

Key changes from the initial consultation

3.34 One key change in terms of what we assume about abatement measures compared to the initial consultation is an increase in the uptake of SAF from 30% in 2050 previously, to 50% in this analysis. This reflects the increased ambition announced by government and industry in recent months. The results from the modelling show that the emissions reductions from SAF are very similar in the updated analysis compared to the initial consultation – both lead to savings of approximately 7 $MtCO_2e$ in 2050. Even though we assume SAF is contributing to a higher proportion of drop-in fuel in this updated scenario, the increased emissions reductions delivered by hydrogen-powered zero emission aircraft mean a lower total quantity of liquid drop-in fuel is required.

3.35 We have also changed the zero emission aircraft assumptions in this breakthrough scenario. Whereas previously in the first consultation, we used this scenario to test the impacts of zero emission aircraft entering service 5 years earlier than in our 'High Ambition' scenario, we are now using this scenario to test the impacts of including a new 'mid-size' concept zero emission aircraft in the fleet mix. In this scenario, all modelled zero emission aircraft enter service in 2035. By including a mid-size, hydrogen powered aircraft which can be used on long-haul routes, the emission savings in 2050 for zero emission aircraft have increased from 7 $MtCO_2$ in the initial consultation to 14 $MtCO_2e$ in this updated analysis. The percentage of ATMs flown by zero emission aircraft in 2050 have decreased slightly from the initial consultation analysis given we are no longer reflecting an earlier entry-into-service date for zero emission aircraft in this scenario.

3.36 This scenario now also uses the same 'mid' carbon price assumptions as scenarios 2 and 3. This differs from the consultation analysis where both 'breakthrough' scenarios used a higher carbon price series than Scenarios 1 and 2. In the consultation analysis, it was determined that for the uptake rates assumed in the 'breakthrough' scenarios to be realised, there would need to be a higher carbon price to incentivise the required investment. Given the new DfT 'mid' carbon price series is now considerably higher than the old 'central' series (and is very similar to the old 'high' series), we have determined that the DfT 'mid' carbon price series is suitable for use in the breakthrough scenarios.

3.37 Using the new DfT 'mid' carbon price series leads to emissions savings of 14 $MtCO_2e$ from the demand impact of carbon pricing. This compares to emissions savings of 5 $MtCO_2$ in the initial consultation from using the old BEIS high series. A significant proportion of the increase is due to the modelling updates outlined in paragraph 3.5.

3.38 All other changes to the results of this scenario are due to broader updates to the aviation model or input assumptions (e.g., economic growth assumptions) which are described in more detail throughout this document and in *Jet Zero: modelling framework*[ii] document.

4. Summary

4.1 As shown in Figure 13, the four scenarios we have updated result in residual in-sector emissions of between 36 $MtCO_2e$ for the continuation of current trends scenario and 0 $MtCO_2e$ for the High Ambition with a breakthrough on SAF scenario in 2050. **For scenarios 2, 3 and 4, residual emissions in 2050 are lower than in the initial consultation. Scenario 1 has very slightly higher residual emissions in 2050 compared to the initial consultation.** These results are driven by a combination of updates to the aviation modelling suite, updates to carbon prices and updates to our assumptions around abatement measures, particularly regarding SAF. A full comparison between the results in the initial consultation and this updated analysis can be seen in Figure 14 below.

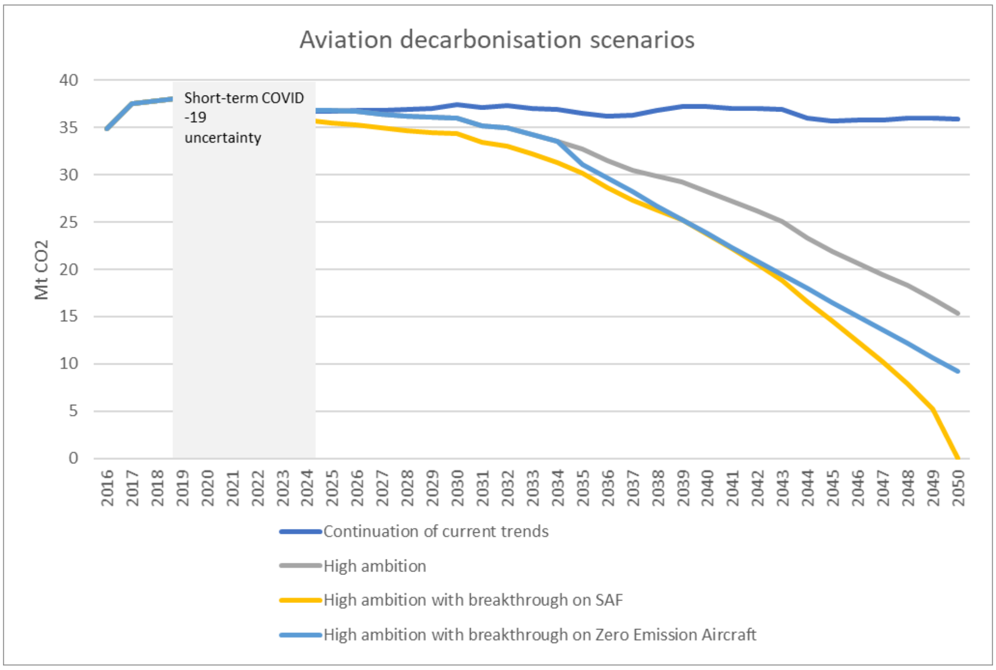


Figure 13. In-sector aviation decarbonisation scenarios

Scenario		2030	2040	2050
Continuation of current trends	Initial Consultation analysis ($MtCO_2$)	40.1	37.1	35.7
	Further consultation analysis ($MtCO_2e$)	37.4	37.2	35.9
High Ambition	Initial Consultation analysis ($MtCO_2$)	39.1	30.5	20.9
	Further consultation analysis ($MtCO_2e$)	36.0	28.2	15.4
High Ambition with a breakthrough on SAF	Initial Consultation analysis ($MtCO_2$)	37.7	27.2	8.6
	Further consultation analysis ($MtCO_2e$)	34.3	23.7	0.0
High Ambition with a breakthrough on zero emission aircraft	Initial Consultation analysis ($MtCO_2$)	38.3	28.3	17.4
	Further consultation analysis ($MtCO_2e$)	36.0	23.8	9.2

Figure 14. Comparison of residual emissions for each scenario between initial consultation and this further consultation

4.2 The scenarios still show that significant in-sector abatement is possible if we make substantial progress with new technologies. In fact, the updated scenarios indicate that greater levels of in-sector abatement are possible than in the scenarios we published in the initial consultation. However, making the required technological progress will be very challenging and there are many barriers that will need to be overcome, especially for the final two 'breakthrough' scenarios. The updated scenarios also continue to indicate that net zero aviation (or Jet Zero) can be met by 2050 with future capacity assumptions consistent with government's airport expansion policies.

4.3 All scenarios except Scenario 3 continue to see some residual emissions from aviation remaining in 2050, though these are lower in some scenarios than others. Therefore, for aviation to meet net zero, some abatement outside the sector is likely to be required. We have updated a band of illustrative net emissions trajectories for aviation, and this is presented in Figure 15 for Scenario 2.[25] We have presented a range to reflect alternative ways in which a net trajectory could be defined. The ultimate shape of this trajectory will depend on the development of market-based measures and removal technologies.

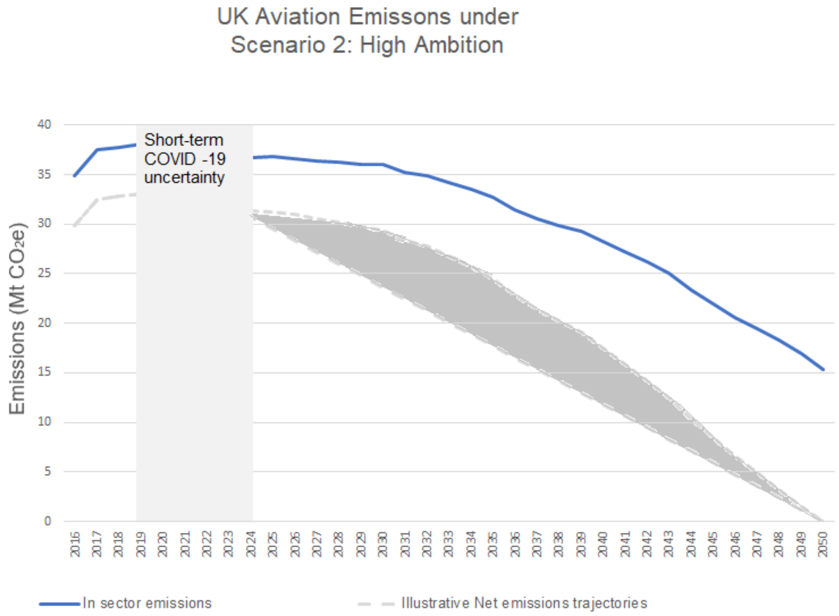


Figure 15. Illustrative net emissions trajectory under Scenario 2

Year		**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	Initial Consultation analysis (MtCO2)	-14 to 39%	-49 to 70%	-100%
	Further consultation analysis ($MtCO_2e$)	-22 to 38%	-54 to -69%	-100%

Figure 16. Comparison of net emissions trajectory to 2018 aviation emissions

4.4 There is significant uncertainty surrounding the abatement potential, uptake and costs of the measures described in this document and therefore these scenarios present illustrative pathways rather than forecasts. Achieving the emissions

[25] This analysis assumes that the current emissions savings from market-based measures, notably the UK ETS are $5MtCO_2$ per year, in line with analysis from the Final Stage Aviation EU ETS Impact Assessment: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685816/Aviation_EU_ETS_-_Final_Stage_Impact_Assessment.pdf

reductions shown in these scenarios will also require substantial international effort and coordination.

What will happen next

A summary of responses to this further technical consultation, and the Jet Zero Consultation, including the next steps, will be published within three months of the consultation closing on www.gov.uk. Paper copies will be available on request.

If you have questions about this consultation, please contact:

NZaviationconsultation@dft.gov.uk

Consultation principles

The consultation is being conducted in line with the Government's key consultation principles. Further information is available at https://www.gov.uk/government/publications/consultation-principles-guidance

If you have any comments about the consultation process, please contact:

Consultation Co-ordinator
Department for Transport
Zone 1/29 Great Minster House
London SW1P 4DR
Email consultation@dft.gsi.gov.uk

Public Sector Equality Duty

The Public sector equality duty came in to force in April 2011 (s.149 of the Equality Act 2010) and public authorities are now required, in carrying out their functions, to have due regard to the need to achieve the objectives set out under s149 of the Equality Act 2010.

The Department of Transport has assessed the strategic approach set out in the Jet Zero Consultation with regard to Public Sector Equality Duty, and found that overall, climate change mitigation policies could advance equality of opportunity. Work will continue as individual policies are implemented.

We continue to invite comment on how the Jet Zero Strategy could further achieve the objectives as set out under s149 of the Equality Act 2010 to:

• eliminate discrimination, harassment, victimisation and any other conduct that is prohibited by or under the Equality Act 2010;

• advance equality of opportunity between persons who share a relevant protected characteristic and persons who do not share it;

• foster good relations between persons who share a relevant protected characteristic and persons who do not share it.

Annex A: Modelling methodology for SAF and Zero emission aircraft

SAF

A.1 Uptake of SAF is not calculated within the aviation model, instead an uptake trajectory is assumed and fed into the department's aviation CO_2 model as an input. The SAF uptake trajectory assumed in this modelling is based on the analysis for the 'Mandating the use of sustainable aviation fuels' consultation.[xv] We assume 100% direct CO_2e emission savings for the aviation sector for these fuels. This is consistent with the approach taken by the CCC and is in line with formal GHG accounting rules.[xvi] On a lifecycle basis, we expect SAF use to deliver over 70% emission savings relative to the use of kerosene (depending on the type of SAF used). It is envisaged that some SAF production pathways, with the integration of carbon capture and storage into the production process, will likely be able to achieve 100% lifecycle savings. However, due to the current early stages of SAF (and carbon capture) development, there is significant uncertainty around the types of SAF that will make up the fuel mix in future.

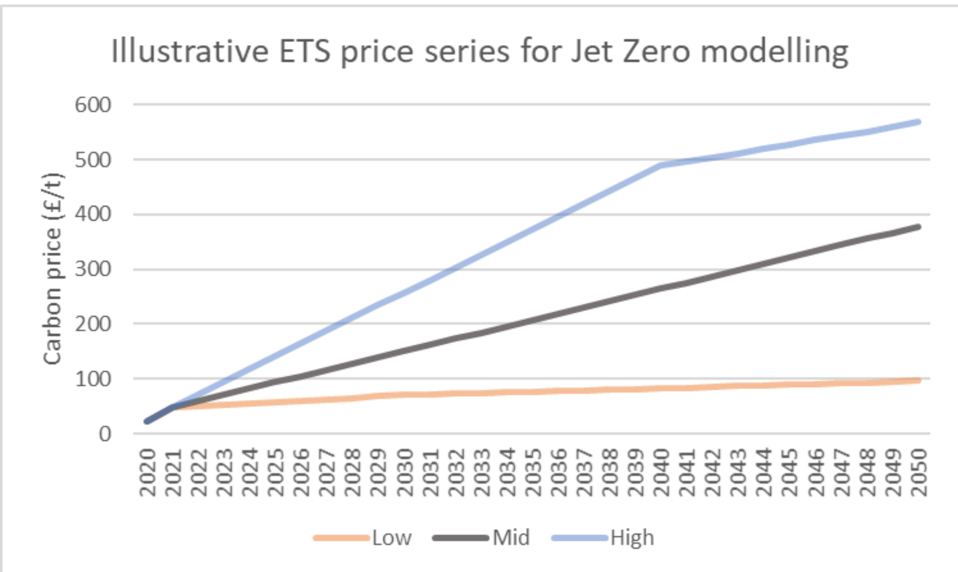
Zero emission aircraft

A.2 Zero emission aircraft enter the modelling via the fleet mix component of the National Air Passenger Allocation Model (NAPAM) described in chapter 4 of *Jet Zero: modelling framework*[ii] document. For the 'High Ambition' scenario, two new hypothetical aircraft types (one for Class 1 and 2, one for Class 3) with zero tailpipe emissions are modelled to enter the fleet from 2035 and replace existing aircraft in these classes at existing replacement rates (22-25 years). For the 'High Ambition with a breakthrough on Zero Emission Aircraft' scenario, an additional 'mid-size' concept aircraft with zero tailpipe emissions is assumed to also enter the fleet from 2035.

Annex B: Illustrative Carbon Price Assumptions

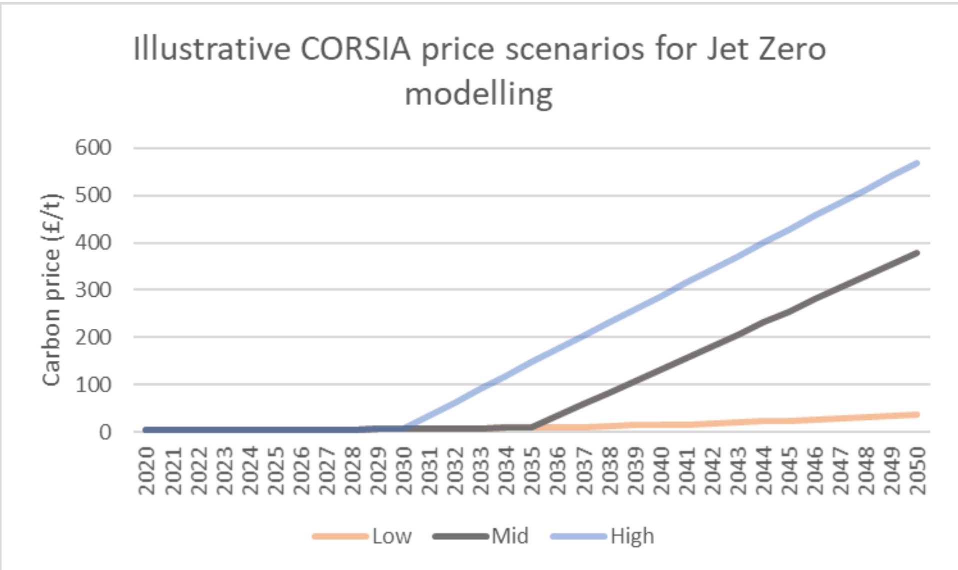
B.1 This annex provides further details on the illustrative carbon price assumptions DfT have constructed for use in the modelling undertaken for this further technical consultation. These assumptions are designed to illustrate the potential range of carbon prices faced by airline operators in future for use in scenario analysis. The assumptions do not represent the UK Government's view on the most likely evolution of market prices under any carbon pricing mechanism.

UK ETS



ETS Price Assumptions	Rationale
Low – The 2021 value is based on the average UK ETS auction clearing price for May 2021 to October 2021. We assume a rough anchor point of £71/t in 2030 based on ICIS projections[xvii] which implies ~4.5% annual growth to 2030. From 2030 onwards we assume an annual growth rate of 1.5% (this is the same as the annual growth rate assumed in the revised approach to valuing greenhouse gas emissions in policy appraisal published by BEIS in September 2021[26]).	This methodology aims to reflect a scenario in which carbon prices under a UK ETS scheme remain relatively low. This series implies there is no global market-based mechanism with a net zero consistent target by 2050.
Mid - The 2021 value is based on the average UK ETS auction clearing price for May 2021 to October 2021. We then interpolate linearly to the new BEIS central appraisal carbon value by 2050.	This methodology is based on that underpinning the previous BEIS traded sector appraisal series historically used in our aviation model. This methodology reflects both the current prices faced by operators and the introduction of a global market-based mechanism with a Paris Agreement-consistent goal by 2050.
High - The 2021 value is based on an average UK ETS auction clearing price for May 2021 to October 2021. We then interpolate linearly to the new BEIS high appraisal carbon value in 2040. The series follows BEIS' high appraisal carbon value series thereafter.	This methodology is also based on that underpinning the previous BEIS traded sector appraisal series historically used in our aviation model. This methodology reflects both the current prices faced by operators and the introduction of a global market-based mechanism with a Paris Agreement-consistent goal being in place by 2040.

CORSIA



[26] https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

CORSIA Price Assumptions	Rationale
Low - based on CAEP ICAO post-COVID modelling for 2021 – 2026.[xviii] The same growth rate of 9.5% per year is then applied consistently thereafter.	This methodology aims to reflect a scenario in which carbon prices under CORSIA (or a similar international scheme post 2035) remain relatively low. This series implies the scheme continues beyond its current 2035 endpoint but is not adjusted or replaced to converge with a Paris Agreement consistent emission reduction goal by 2050.
Mid - based on CAEP ICAO post-COVID modelling for 2021 – 2026. The same growth rate of 9.5% per year is then applied consistently until 2035. After 2035 we linearly interpolate up to BEIS' new central appraisal value in 2050.	This methodology aims to reflect a scenario in which CORSIA continues as designed until its current end point in 2035 and thereafter it is adjusted or replaced such that carbon prices converge with BEIS new central appraisal value by 2050.
High - based on CAEP ICAO post-COVID modelling for 2021 – 2026. The same growth rate of 9.5% per year is then applied consistently until 2035. After 2030 we linearly interpolate up to BEIS' new central appraisal value in 2050.	This methodology aims to reflect an ambitious scenario in which CORSIA continues in its current design until 2030 and is then adjusted or replaced such that carbon prices grow to meet BEIS' new high appraisal values by 2050.

Sensitivity of modelling results to carbon price assumptions

B.2 We have run sensitivity tests using DfT's new illustrative low and high ETS and CORSIA series in scenarios 2,3 and 4 to understand the scale of their impact on the results. As outlined in Chapter 3, using our 'mid' ETS and CORSIA price series, the demand impact of carbon pricing results in emissions savings of 14 $MtCO_2e$ in 2050 in scenarios 2, 3 and 4.

B.3 By incorporating DfT 'low' ETS and CORSIA series instead, the emissions savings from the demand impact of carbon pricing in 2050 reduce to 2 $MtCO_2e$. This is because the lower carbon prices result in lower costs to airlines, lower fares to passenger, and therefore less demand suppression than when higher carbon prices are assumed.

B.4 Incorporating the DfT 'high' ETS and CORSIA price series leads to savings of 17 $MtCO_2e$ in 2050. This is because the higher carbon price series feed through into higher costs to operators and therefore higher fares which result in lower levels of demand.

Illustrative ETS price series used in Jet Zero modelling

2020 £/t CO2	Low	Mid	High
2020	21	21	21
2021	48	48	48
2022	50	59	71
2023	53	71	95
2024	55	82	118
2025	57	94	141
2026	60	105	164
2027	63	116	187
2028	65	128	211
2029	68	139	234
2030	71	150	257
2031	73	162	280
2032	74	173	303
2033	75	185	327
2034	76	196	350
2035	77	207	373
2036	78	219	396
2037	79	230	419
2038	81	241	443
2039	82	253	466
2040	83	264	489
2041	84	276	496
2042	85	287	504
2043	87	298	511
2044	88	310	519
2045	89	321	527
2046	91	332	535
2047	92	344	543
2048	93	355	551
2049	95	367	559
2050	96	378	568

Illustrative CORSIA price series used in Jet zero modelling

2020 £/t CO2	Low	Mid	High
2020	3	3	3
2021	3	3	3
2022	3	3	3
2023	3	3	3
2024	4	4	4
2025	4	4	4

2026	4	4	4
2027	5	5	5
2028	5	5	5
2029	6	6	6
2030	6	6	6
2031	7	7	34
2032	7	7	62
2033	8	8	90
2034	9	9	118
2035	10	10	147
2036	10	34	175
2037	11	59	203
2038	13	83	231
2039	14	108	259
2040	15	132	287
2041	16	157	315
2042	18	181	343
2043	20	206	371
2044	22	231	399
2045	24	255	428
2046	26	280	456
2047	28	304	484
2048	31	329	512
2049	34	353	540
2050	37	378	568

Annex C: Demand driver uncertainty

C.1 As described in paragraph 3.9, there is inherent uncertainty around many of the drivers of future aviation demand. This annex presents the results varying the main economic drivers of demand, relating to economic growth and oil prices, on the emissions modelled for Scenario 2: High Ambition. The table below shows the central assumptions for these drivers that are used in all the Jet Zero scenarios outlined in Chapter 3 and the low and high assumptions we have used in these sensitivity tests.

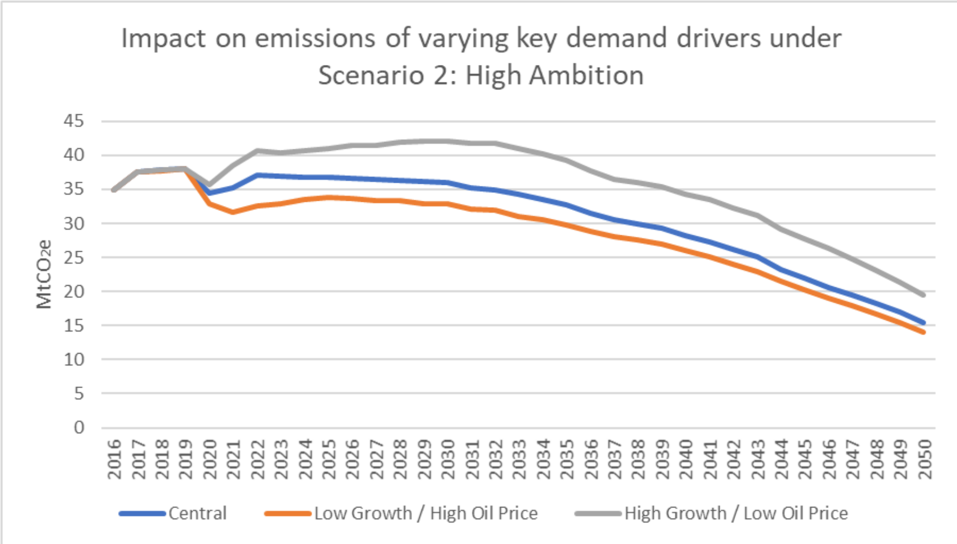
Model Input	*Central assumptions*	*Low growth / High oil price assumptions*	*High growth / Low oil price assumptions*
UK GDP Growth Rates	2015-2020 ONS, August 2021 2021-2050 OBR, October 2021	2015-2020 ONS, August 2021 2021-2025, OBR, October 2021 Low Scenario 2026-2050: -0.5% of Central scenario	2015-2020 ONS, August 2021 2021-2025, OBR, October 2021 High Scenario 2026-2050: +0.5% of Central scenario
UK Consumption Expenditure Growth Rates	2015-2019 OBR, March 2019/2020/2021 2020-2025 OBR, October 2021 2026-2050 The same growth rates as central assumptions of UK GDP	The same growth rates as Low growth assumptions of UK GDP	The same growth rates as High growth assumptions of UK GDP

Foreign GDP Growth Rates	2015-2026 IMF, April 2021 2027-2050 OECD, July 2018	Rest of World: -1%;Southern Europe, Rest of Europe, OECD: -0.5% of Central scenario (for all years)	Rest of World: +1%;Southern Europe, Rest of Europe, OECD: +0.5% of Central scenario (for all years)
Oil Prices	2015-2040 BEIS, February 2020 2040-2050: Held constant	2015-2040: High BEIS series 2040-2050: Held constant	2015-2040: Low BEIS series 2040-2050: Held constant

C.2 The table below shows the impact of varying the economic growth and oil price assumptions on modelled terminal passengers in 2030, 2040 and 2050. The terminal passenger numbers shown in the 'Core assumptions' row are the modelled outputs for Jet Zero Scenarios 2, 3 and 4 presented in the main body of this document (using central economic growth and oil price assumptions).

Terminal Passengers (millions)	*2030*	*2040*	*2050*
Core assumptions	355	422	482
Low Growth / High Oil Price assumptions	314	366	391
High Growth / Low Oil Price assumptions	400	501	575

C.3 The graph below shows the impact of varying the economic growth and oil price assumptions on our emissions forecasts under Scenario 2: High Ambition. Our modelling shows that applying the higher economic growth / lower oil price assumptions could lead to a 4.2 $MtCO_2e$ (27%) increase in residual emissions in Scenario 2 in 2050 (to 19.6 $MtCO_2e$). Applying the lower economic growth / higher oil price assumptions could lead to a 1.4 $MtCO_2e$ (9%) decrease in residual emissions in Scenario 2 in 2050 (to 16.8 $MtCO_2e$). More details on the other input demand drivers used in the modelling can be found in Figure 4 of the accompanying *Jet Zero: modelling framework*[ii] *document*.



Impact on emissions of varying key demand drivers under Scenario 2: High Ambition
MtCO2e
45
40
35
30
25
20
15
10
5
0
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
Central
Low Growth / High Oil Price
High Growth / Low Oil Price

References

[i]ATA (2018) Understanding the potential and costs for reducing UK aviation emissions. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785685/ata-potential-and-costs-reducting-emissions.pdf

[ii] https://www.gov.uk/government/publications/jet-zero-modelling-framework

[iii] Department for Transport (2021) Mandating the use of sustainable aviation fuels in the UK. https://www.gov.uk/government/consultations/mandating-the-use-of-sustainable-aviation-fuels-in-the-uk

[iv] Department for Business, Energy and Industrial Strategy (2021) Net Zero Strategy: Build Back Greener. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

[v] Department for Transport (2022) Mandating the use of sustainable aviation fuels in the UK: summary of responses. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1059075/sustainable-aviation-fuels-mandate-consultation-summary-of-responses.pdf

[vi] European Parliament (2021) ‘Fit for 55’ legislative package: ReFuel EU Aviation. https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/699466/EPRS_BRI(2021)699466_EN.pdf

[vii] Federal Aviation Administration (2021) United States 2021 Aviation Climate Action Plan. https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

[viii] Clean Skies for Tomorrow, World Economic Forum (2021) 2030 Ambition Statement. https://www3.weforum.org/docs/WEF_EMBARGOED_CST_Ambition_Statement_for_Signatories.pdf

[ix] Aerospace Technology Institute (2021) Zero-carbon emission flights to anywhere in the world possible with just one stop https://www.ati.org.uk/news/one-stop-zero-carbon-emission-global-flight/

[x] Department for Business, Energy and Industrial Strategy (2021) Valuation of Greenhouse Gas Emissions for policy appraisal and evaluation https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

[xi]Department for Business, Energy and Industrial Strategy (2019) Updated short-term traded carbon values used for UK policy appraisal. https://www.gov.uk/government/publications/updated-short-term-traded-carbon-values-used-for-uk-policy-appraisal-2018

[xii] Department for Business, Energy and Industrial Strategy (2021) Greenhouse gas removal methods: technology assessment report. https://www.gov.uk/government/publications/greenhouse-gas-removal-methods-technology-assessment-report

[xiii] Department for Business, Energy and Industrial Strategy (2021) Greenhouse gas removal methods: technology assessment report. https://www.gov.uk/government/publications/greenhouse-gas-removal-methods-technology-assessment-report

[xiv]Vivid Economics (2019) Greenhouse Gas Removal (GGR) policy options – Final Report. https://www.vivideconomics.com/wp-content/uploads/2019/09/Greenhouse_Report_Gas_Removal_policy_options.pdf

[xv] Department for Transport (2021) Mandating the use of sustainable aviation fuels in the UK. https://www.gov.uk/government/consultations/mandating-the-use-of-sustainable-aviation-fuels-in-the-uk

[xvi] Department for Business, Energy and Industrial Strategy (2020) 2020 Government greenhouse gas conversion factors for company reporting. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/901692/conversion-factors-2020-methodology.pdf

[xvii] ICIS 2021 https://www.icis.com/explore/resources/news/2021/05/14/10640017/insight-uk-carbon-trading-system-launch.

[xviii] International Civil Aviation (2021) Update to Scenario Based Analyses of Potential Impacts of Covid19 on CORSIA Organization. https://www.icao.int/environmental-protection/CORSIA/Documents/CAEP_Update%20COVID-19%20impact%20analyses.pdf