Jet Zero illustrative scenarios and sensitivities

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Introduction

1.1 The Jet Zero Strategy sets out the Government's vision for decarbonising aviation focussing on the rapid development of technologies in a way that maintains the benefits of air travel and maximises the opportunities that decarbonisation can bring for the UK.

1.2 To inform the Jet Zero Strategy, we have modelled four scenarios with a different mix of technologies to illustrate alternative pathways for reaching net zero aviation by 2050. We have considered increases in system efficiencies (both improvements in existing engine and airframe design and operational improvements) and we have looked at what future technology could be introduced through Sustainable Aviation Fuel (SAF) and Zero Emission Flight (ZEF). We have also produced a set of illustrative assumptions for use in our aviation model which are designed to show the potential range of carbon costs faced by airline operators in the future. Finally, we have looked at Greenhouse Gas Removal (GGR) methods which could be a cost-effective removal measure in the future, to compensate for residual emissions.

1.3 We have considered a wide range of sources of evidence in developing the scenarios. This includes evidence produced domestically and internationally, including from the UK Climate Change Committee (CCC), the World Economic Forum, the International Council on Clean Transportation (ICCT), the European Union, the United States and the International Civil Aviation Organization (ICAO). We have published two Jet Zero consultations which have presented our scenarios and supporting evidence. We received a significant number of responses to these consultations from members of the public, academics and industry stakeholders and have used this feedback to further inform our analysis. Throughout this process we have also worked in close collaboration with other Government departments.

1.4 This document presents the latest illustrative scenarios, the assumptions underpinning them and the sensitivity of the scenarios to changes in key assumptions. Further detail about the evidence we have considered can be found in the *Jet Zero Consultation: evidence and analysis*[i] *and Jet zero: further technical consultation*[ii] documents.

1.5 The scenarios presented in this document are similar to the scenarios published in the *Jet Zero: further technical consultation*[iii] document. We have considered the responses to that consultation in detail and concluded that in all but one case the evidence submitted through the responses was in keeping with the evidence we had previously reviewed and so did not justify any further changes to the assumptions or analysis.

1.6 However, we have made one change to the methodology we use to produce the scenarios to reflect the responses to the consultation. In the two Jet Zero consultations, the emissions savings from sustainable aviation fuel (SAF) were reported in a way consistent with Greenhouse Gas (GHG) accounting rules for whole economy reporting on net zero, under which SAF is best presented as delivering c.100% direct emission savings in transport relative to the use of kerosene. In the illustrative scenarios presented in this document we report the emission savings delivered by SAF, as a percentage of kerosene emissions, as falling in the range 67-75%, in line with the assumed life cycle emission savings relative to kerosene underpinning the *'Mandating the use of sustainable aviation fuels*'[iv] consultation published by the department last year. We also report the level of residual emissions for each scenario assuming SAF delivers c.100% direct emission savings relative to kerosene, to enable comparison with analysis performed under whole economy GHG accounting rules (e.g. the analysis presented in the *Net Zero Strategy*[v]*)*. Further information on this change can be found in Annex B. In addition to this methodology change, we have also updated our assumptions on SAF uptake to be in line with the latest policy ambition. This means the High Ambition and High Ambition with a breakthrough on zero emission aircraft scenarios now reach 10% SAF by 2030, as set out in the government response to the SAF mandate consultation published alongside this document.

1.7 The scenarios presented are not prescriptive and the uncertainty surrounding the future costs of the measures mean it is not possible at this point 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. The 5-year reviews of the Jet Zero Strategy will be an opportunity to reflect on any new evidence and analysis on the potential and costs of abatement measures. 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.

1.8 All scenarios are presented alongside a 'Policy-Off' baseline where there are no carbon markets, no action on SAF or zero emission aircraft, and only minor annual efficiency improvements. In this case, total UK aviation emissions reach 52.2 MtCO2e in 2050.

1.9 The scenarios are based on the updated passenger demand scenarios that were produced using the DfT's aviation model for the *Jet Zero: Further technical consultation*[vi] document. The scenarios do not fully take account of the impact of COVID-19 on aviation demand. To address the short-term fall in emissions an uncertainty band has been added to the graphs covering 2020-2024[vii].

1.10 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. 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.

1.11 There are also other important drivers of passenger demand which are inherently uncertain, including economic growth and oil prices. The scenarios presented below are based on the official forecasts of these drivers[viii], however the uncertainty around these should be considered when interpreting the results and future emissions may be higher or lower than those illustrated if, for example, future GDP growth rates or oil prices are significantly different from the forecasts. Annex A shows how employing reasonable alternative assumptions about the main economic drivers of demand, relating to economic growth, oil prices, future carbon prices and the short- term impact of Covid-19, impact on the emissions modelled for Scenario 2: High Ambition.

1.12 Whilst the 2050 'jet zero' target covers commercial and military aviation emissions, the modelling results and scenarios presented in this document do not include emissions from military aviation. The aviation model is not an appropriate tool to forecast military aviation. We are exploring options to enable us to model military aviation emissions in future. *According to the National Atmospheric Emissions Inventory* (*NAEI)*[ix] military aviation emissions in the five years prior to the pandemic were quite stable at around 1.1-1.2 $MtCO_2e$ per annum.

1.13 More detail on the DfT aviation model that has been used to conduct the scenarios analysis and key modelling assumptions can be found in the *Jet Zero: modelling framework*[x] document that was published alongside the *Jet Zero: further technical consultation*[xi] document.

Scenario 1: Continuation of Current trends

2.1 This scenario represents a continuation of current trends in UK aviation. There is some limited step-up in ambition on SAF and annual fuel efficiency improvements, but no introduction of zero-emission aircraft. This scenario assumes ETS and/or CORSIA applies to all flights arriving and departing in the UK, with the specific price assumptions varying by carbon market.

	Assumptions	***Rationale* / Source**
Demand[xii]	74% increase in UK terminal passengers by 2050.	Updated DfT demand forecasts produced *for Jet Zero: Further technical consultation*[xiii] document
Carbon price series (2020 £ prices)[xiv]	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).	See *Jet Zero: Further technical consultation document Annex B: Illustrative Carbon Price Assumptions* [iv] for detail
Capacity	Updated airport capacity assumptions	See *Jet Zero: modelling framework document*[xv] for more detail
Fuel efficiency[xvi] **improvements**	Central Efficiency 1.5% pa (2017-2050)	Based on 'likely, nominal' case from ATA research[xvii]. This is within the range of average historical improvements and future expectations.
SAF uptake	10% by 2050 4% by 2040 2% by 2030	Relatively conservative uptake scenario based on DfT review of available evidence and SAF ambitions in UK and internationally.
Zero emission tech uptake	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 used in Scenario 1

Challenges

2.2 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 the UK ETS continues to apply to flights departing the UK and inside its scope until 2050. While the UK ETS is currently only legislated to continue until 2030, the UK government and devolved administrations are committed to the

UK ETS as a key policy lever to ensure the UK reaches its ambitious climate targets, including net zero emissions by 2050, cost-effectively.[xviii] This scenario also assumes that beyond 2035 (the end of the period in which CORSIA currently applies) an equivalent scheme to CORSIA continues to apply to international flights departing the UK outside the scope of UK ETS and results in the carbon price remaining at a similar level to that assumed in the period leading up to 2035.

2.3 Secondly, though in line with historical 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 COVID19 on the aviation industry).

2.4 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.

Results

2.5 This scenario results in 37 MtCO2e of residual emissions in 2050 (or 35.9MtCO2e under whole economy GHG accounting rules), which will need to be offset to reach net zero emissions. 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 some uptake of sustainable fuels.

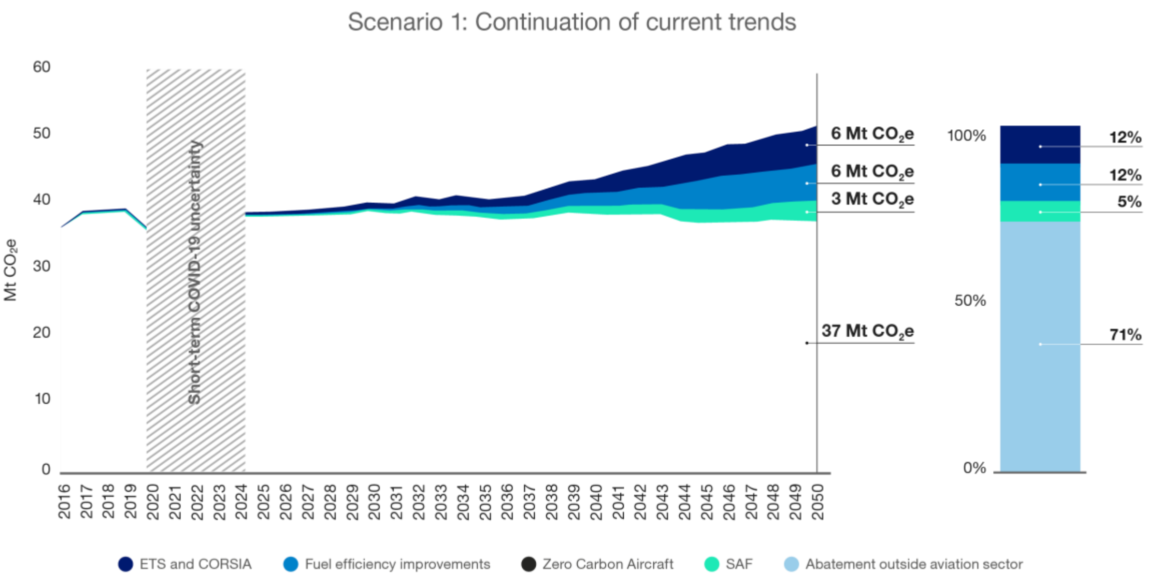

Figure 2 Scenario 1 – Continuation of current trends[xix]

Scenario 2: High Ambition

3.1 This scenario is more ambitious than Scenario 1. It includes the same assumptions on UK and EU ETS and capacity but higher carbon prices under CORSIA. There is also a step-up in ambition on fuel efficiency improvements, SAF uptake and the introduction of zero emission aircraft.

	Assumptions	***Rationale / Source***
Demand[xx]	70% increase in UK terminal passengers by 2050	Updated DfT demand forecasts produced for *Jet Zero: Further technical consultation*[xxi] document
Carbon price series (2020 £ prices)	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).	See Jet Zero: Further technical consultation document, Annex B: Illustrative Carbon Price Assumptions[xxii] for detail
Capacity	Updated airport capacity assumptions	See Jet Zero: modelling framework[xxiii] document for more detail.
Fuel efficiency improvements	2.0% pa (2017-2050)	Based on 'optimistic, nominal' scenario from ATA research[xxiv]
SAF uptake	50% by 2050 22% by 2040 10% by 2030	Ambitious uptake scenario based on DfT review of available evidence and latest SAF ambitions in UK and internationally.
Zero emission tech uptake	27% ATMs[xxv] zero emission by 2050 5% of ATMs zero emission by 2040 None in 2030	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 3 Assumptions used in Scenario 2

Challenges

3.2 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 level applying to flights that are in scope of the UK ETS. This will require significant international cooperation to achieve.

3.3 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.

3.4 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.

3.5 Finally, most crucial for realising the 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

3.6 In this scenario, terminal passenger numbers increase by 70% on 2018 levels reaching 482 million in 2050. The scenario results in slightly more than half the residual emissions forecast in Scenario 1, 19.3 MtCO2e in 2050 (or 15.4 MtCO2e under whole economy GHG accounting rules). 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.

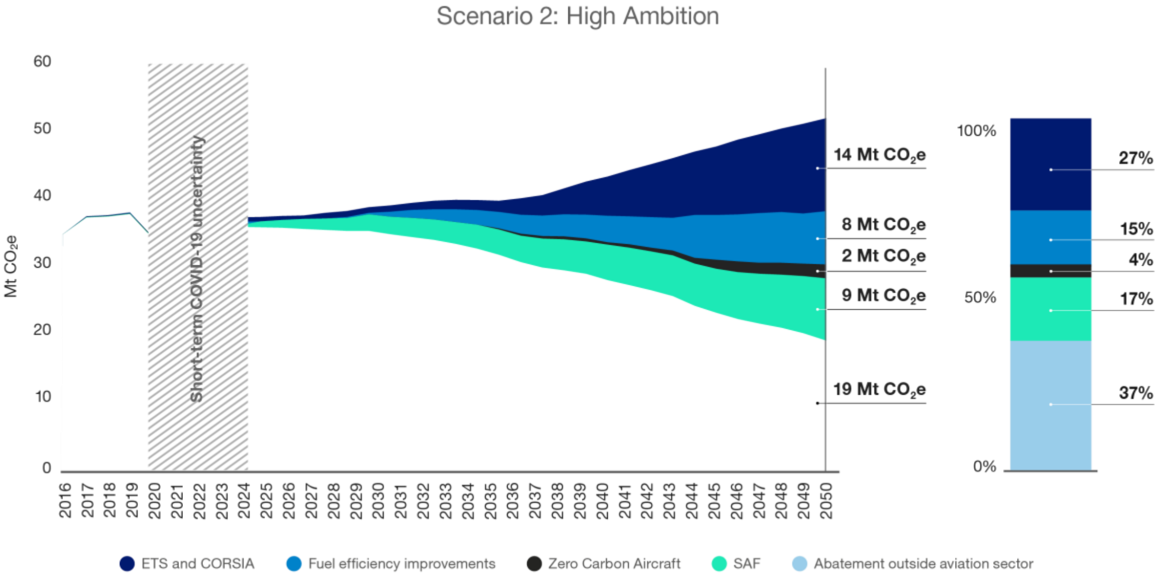

Figure 4 Scenario 2 – High Ambition

Scenario 3: High ambition with a breakthrough on SAF

4.1 The third scenario is a speculative, extremely ambitious scenario. Fuel efficiency and ETS and CORSIA 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.

	Assumptions	Rationale / Source
Demand[xxvi]	70% increase in UK terminal passengers by 2050	Updated DfT demand forecasts produced for *Jet Zero: Further technical consultation*[xxvii] document
Carbon price series (2020 £ prices)	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).	See *Jet Zero: Further technical consultation document, Annex B: Illustrative Carbon Price Assumptions*[xxviii] for detail
Capacity	Updated airport capacity assumptions	See *Jet Zero: modelling framework*[xxix] document for more detail.
Fuel efficiency improvements	2.0% pa (2017-2050)	Based on 'optimistic, nominal' scenario from ATA research[xxx]
SAF uptake	100% by 2050 32% by 2040 10% by 2030	Extremely ambitious uptake scenario based on DfT review of available evidence and SAF ambitions in UK and internationally.
Zero emission tech uptake	27% of ATMs zero emission by 2050 5% of ATMs zero emission by 2040 None in 2030	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 5 Assumptions used in Scenario 3

Challenges

4.2 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/or the costs of using 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.

4.3 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

4.4 This scenario results in 8.6 MtCo2e of residual emissions (or 0 MtCO2e under whole economy GHG accounting rules) with SAF delivering the largest proportion of this abatement (38% in 2050). Passenger numbers are the same as in Scenario 2 at 482 million in 2050 (70% above the 2018 level) and, as in Scenario 2, zero emission aircraft contribute 4% to the total emissions abated in 2050.

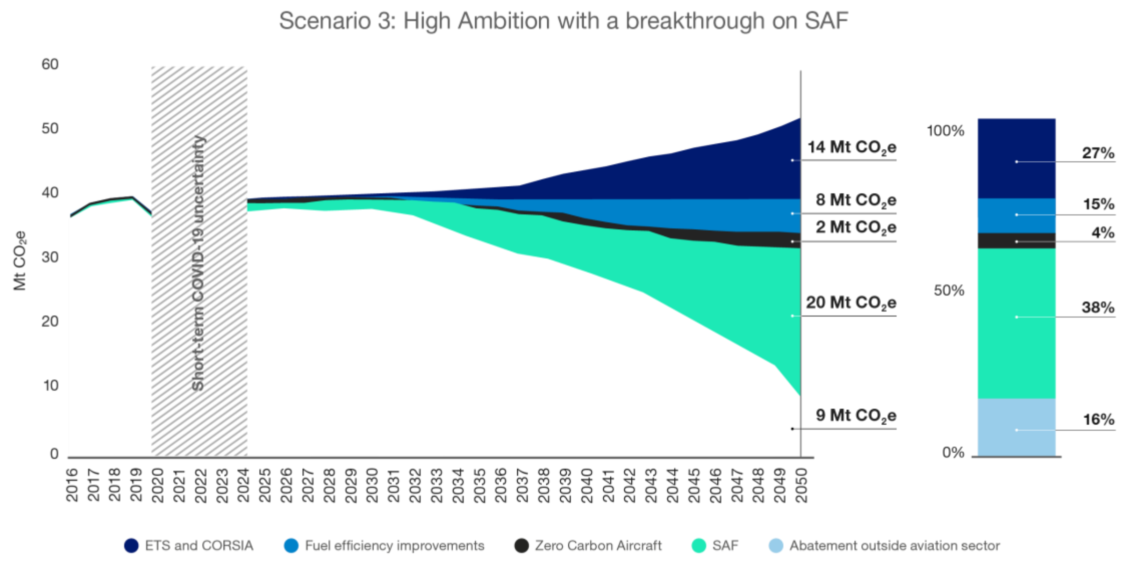

Figure 6 Scenario 3 – High Ambition with a breakthrough on SAF

Scenario 4: High ambition with a breakthrough on Zero Emission Aircraft

5.1 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, ETS, CORSIA and efficiency assumptions are kept consistent with Scenario 2.

	Assumptions	**Rationale / Source**
Demand[xxxi]	70% increase in UK terminal passengers by 2050	Updated DfT demand forecasts produced for *Jet Zero: Further technical consultation*[xxxii] document
Carbon price series (2020 £ prices)	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).	See *Jet Zero: Further technical consultation document, Annex B: Illustrative Carbon Price Assumptions*[xxxiii] for detail
Capacity	Updated airport capacity assumptions	See *Jet Zero: modelling framework document*[xxxiv] for more detail.
Fuel efficiency improvements	2.0% pa (2017-2050)	Based on 'optimistic, nominal' scenario from ATA research[xxxv]
SAF uptake	50% by 2050 22% by 2040 10% by 2030	Ambitious uptake scenario based on DfT review of available evidence and latest SAF ambitions in UK and internationally.
Zero emission tech uptake	38% of ATMs by 2050 11% of ATMs by 2040 None in 2030	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 7 Assumptions in Scenario 4

Challenges

5.2 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. Only if all these challenges are overcome, in addition to those discussed in scenarios 1 and 2, could such a scenario be plausible.

Results

5.3 This scenario results in 11.3 MtCO2e of residual emissions (or 9.2 MtCO2e under whole economy GHG accounting rules) which will need to be abated outside the sector in 2050. 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.

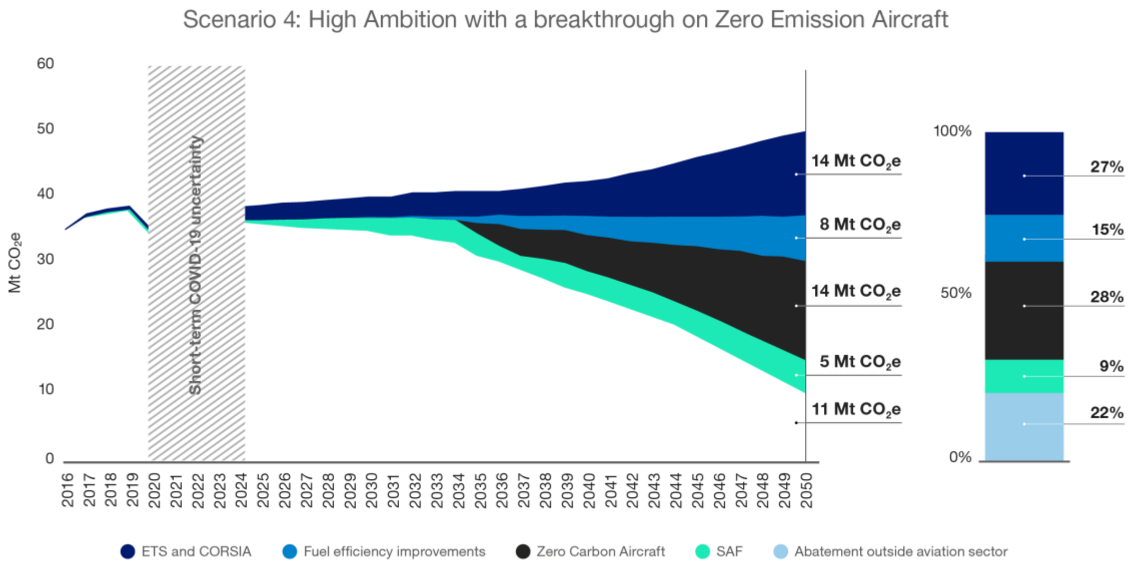

Figure 8 Scenario 4 – High Ambition with breakthrough on zero emission aircraft

Summary

6.1 As shown in Figure 9, the four scenarios we have modelled result in residual in-sector emissions of between 8.6 MtCO2e (or 0 MtCO2e under whole economy GHG accounting rules), for the High Ambition with a breakthrough on SAF scenario, and 37 MtCO2e (or 35.9 MtCO2e under whole economy GHG accounting rules), for the Continuation of Current Trends scenario, in 2050.

6.2 The scenarios show that significant in-sector abatement is possible if we make substantial progress with new technologies. However, making the required technological progress will be challenging and many barriers will need to be overcome, especially for the final two 'breakthrough' scenarios.

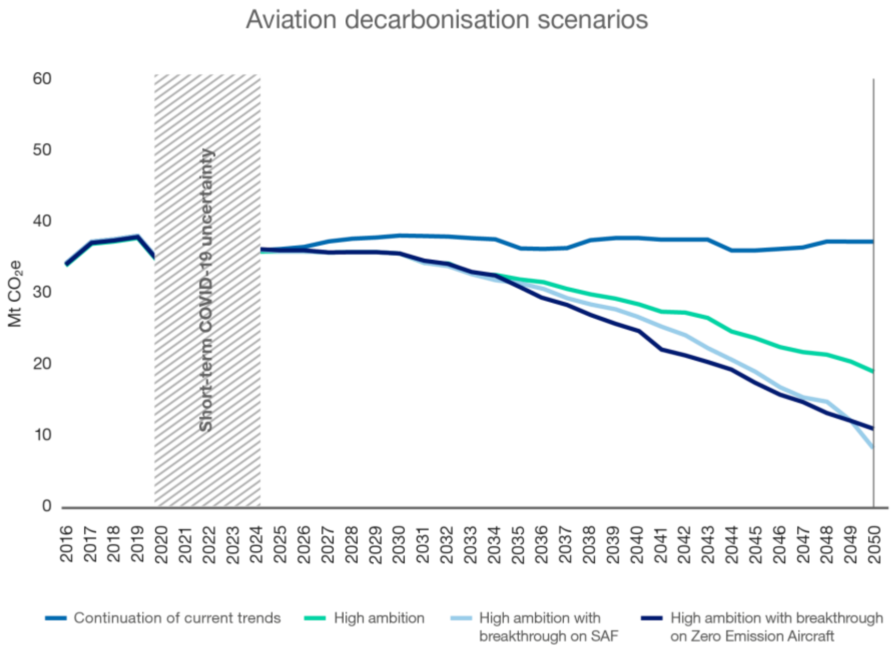

Figure 9 In-sector aviation decarbonisation scenarios

6.3 All scenarios 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 via greenhouse gas removals is likely to be required.

6.4 We have modelled a band of illustrative net emissions trajectories for aviation, and this is presented in the chart below for Scenario 2[xxxvi]. 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.

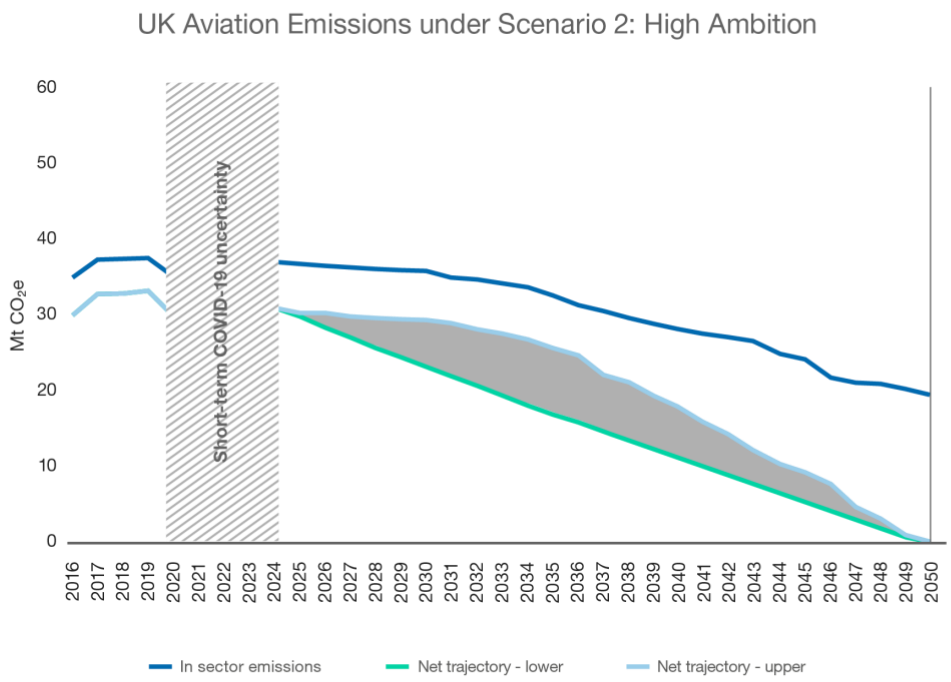

Figure 10 Illustrative net emissions trajectories under Scenario 2

Annex A: Sensitivity Analysis

A.1 There are a number of important drivers of passenger demand which are very uncertain. These include economic growth, oil prices, future carbon prices and the impact of COVID-19. We have carried out sensitivity tests in order to understand the impact of varying the assumptions relating to these drivers on the emissions modelled for Scenario 2: High ambition. The results of these tests are presented in this annex.

Economic growth and oil price uncertainty

A.2 Analysis has been carried out which shows how employing reasonable alternative assumptions about the main drivers of demand relating to economic growth and oil prices impacts on the emissions modelled for Scenario 2:

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

Figure 11 Assumptions for economic growth and oil prices used for sensitivity analysis

A.3 Our modelling shows that applying the 'higher economic growth / lower oil price' assumptions could lead to a 5.4 MtCO2e (28%) increase in residual emissions in Scenario 2 in 2050 (to 24.7 MtCO2e). Applying 'lower economic growth / higher oil price' assumptions could lead to a 1.8 MtCO2e (9%) decrease in residual emissions in Scenario 2 in 2050 (to 17.5 MtCO2e). More details on the other input demand drivers used in the modelling can be found in Figure 4 of the *Jet Zero: modelling framework document.*[xxxvii]

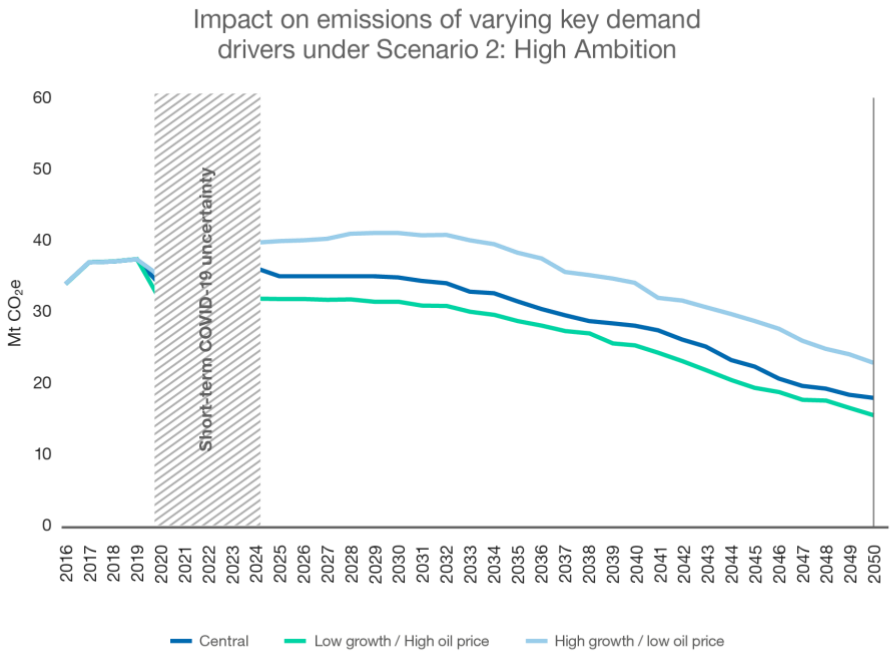

Figure 12 Illustrative impact on emissions of varying key demand drivers under Scenario 2

Carbon price uncertainty

A.4 DfT has constructed illustrative carbon price assumptions for use in the modelling of the Jet Zero scenarios. These assumptions are designed to illustrate the potential range of carbon prices in the future. The assumptions do not represent the UK Government's view on the most likely evolution of market prices.

A.5 More detail on the specific illustrative assumptions used in the modelling can be found in Annex B in the *Jet Zero: further technical consultation*[xxxviii] document.

A.6 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. Using our 'mid' ETS and CORSIA price series results in emissions savings of 14 MtCO2e in 2050 in scenarios 2, 3 and 4.

A.7 By incorporating DfT 'low' ETS and CORSIA series instead, the emissions savings in 2050 reduce to 2 MtCO2e. Incorporating the DfT 'high' ETS and CORSIA price series leads to savings of 17 MtCO2e in 2050.

COVID-19 uncertainty

A.8 We have also undertaken a sensitivity test which explores plausible ranges of recovery following COVID-19 on the carbon emissions modelled for Scenario 2: High Ambition. These tests are not intended to capture all possible outcomes and are highly uncertain. The sensitivity test only considers the recovery of passenger demand up to 2030.

A.9 There remains further uncertainty as to whether COVID-19 will impact longer-term travel behaviour and decisions (e.g. a permanent reduction of business flight because of switch to remote working, or passengers respond differently to income or air fares), something which will not become apparent for several years. For this reason, long-term impacts of COVID-19 are only reflected in economic inputs such as GDP and oil prices, but not passenger behavioural changes due to COVID-19.

A.10 The scenarios are all presumed to recover to the same growth path as experienced when not accounting for direct disruptions of COVID-19, once passenger demand has recovered following COVID-19.

A.11 The sensitivity test explores three possible scenarios for the evolution of COVID-19, considering factors such as the characteristics of future variants – transmissibility, severity, and the ability to escape immunity from vaccination - and the response to the pandemic by governments - such as the desire to reintroduce domestic restrictions. The scenarios reflect variation in the capability of different countries (at a world region level) to respond to the pandemic, for example due to differences in vaccine coverage and approach to restrictions

A.12 It is then possible to interpret these scenarios to consider what the impact of each scenario could be on UK passenger demand, creating scenarios that can be used in the Department's Aviation Model. It is important to note that these scenarios are designed to illustrate a range of potential demand recovery pathways rather than to estimate the level of demand at a fixed point in time. For example, where a scenario assumes that a severe VOC emerges in future, this impacts the general pace of recovery rather than being identifiable as a fall (and subsequent recovery) in demand in a particular future year.

A.13 The three scenarios developed for this sensitivity test are:

a. Manageable outbreaks – A scenario whereby COVID-19 has no significant impact on passenger demand as all outbreaks are manageable. There is a fast recovery in demand, such that in this scenario demand to all global regions recovers by 2023.

b. Bumpy road to end of acute phase – A scenario with slower recovery, with the potential for VOCs to reduce passenger confidence to travel. There is inequality between the recovery of passenger demand in different global regions.

c. VOCs outpace ability to respond – A scenario characterised by major economic and social implications from COVID-19. There is significant inequality between the recovery of passenger demand between different global regions.

A.14. Note these scenarios only take account of COVID-19, and do not consider the potential for any other pandemics. Likewise, these scenarios make no assumptions about the war in Ukraine or the current increases in the cost of living.

A.15. These scenarios have been designed using both post COVID-19 economy and COVID-19 recovery assumptions. The economy assumptions aid the identification of the underlying level of passenger demand. Underlying demand is passenger demand had the pandemic only impacted known drivers of long run aviation demand, such as GDP and oil prices, calculated using 2019 demand as a base year. The COVID-19 recovery assumptions identify how long it will take each global region in the National Air Passenger Demand Model (NAPDM) to return to the underlying level of demand.

A.16. Other than the COVID-19 recovery assumptions, we hold all other assumptions constant for the scenarios considered in this sensitivity test, and they are identical to those used within 'High Ambition' scenarios in the strategy, as outlined in the Jet Zero: modelling framework[xxxix]. This means that these sensitivity tests capture the sensitivity from potential COVID-19 recovery profiles, and their impact on carbon emissions within the 'High Ambition' scenario.

A.17. **These scenarios should not be considered as an accurate projection for the recovery of the sector**. Rather, they represent alternative possible passenger demand recovery pathways, recognising the high degree of uncertainty. These estimates should not be used to estimate the recovery of the sector at specific points in time; but instead are designed to illustrate a range of recovery pathways, given the uncertainty associated with COVID-19. In addition, these scenarios do not consider any long-term changes in behaviour as a result of COVID-19, due to insufficient evidence at this point.

A.18. The table below provides some further detail for when passenger demand is estimated to recover to their underlying level of demand (as determined by drivers such as economy inputs) in each of the three scenarios. These recovery estimates have been produced using the scenarios outlined above and have been informed by trends in the observed data thus far in 2022 - passenger demand has experienced strong recovery during 2022 and the Manageable Outbreaks scenario presumes this trend will continue.

Year of Recovery (100% of underlying levels)	Manageable Outbreaks	Bumpy road to end of acute phase	VOCs outpace ability to respond
Domestic	2023	2023	2026

Southern Europe	2023	2024	2027
Rest of Europe	2023	2024	2027
OECD	2023	2024	2027
Rest of World	2023	2025	2027

Figure 13 Recovery path of passenger demand under three COVID-19 scenarios

A.19 These COVID-19 scenarios are incorporated into the aviation models to test the sensitivity of terminal passenger numbers and carbon emissions up to 2030. The number of years and speed that different markets take to return to their underlying demand levels are applied to NAPDM using overrides.

A.20 By 2030, all markets' demand returns to their underlying levels, and the long-term annual growth rate of demand (produced by NAPDM) resumes. As different markets recover at different speeds to one another, the relevant override years vary by markets.

A.21 The chart below shows the impact of COVID-19 scenarios on modelled terminal passengers up to 2030. The 'High Ambition' terminal passenger numbers are the modelled outputs for the 'High ambition' scenario presented in the main body of this document (without COVID-19 scenarios), along with the three COVID-19 scenarios.

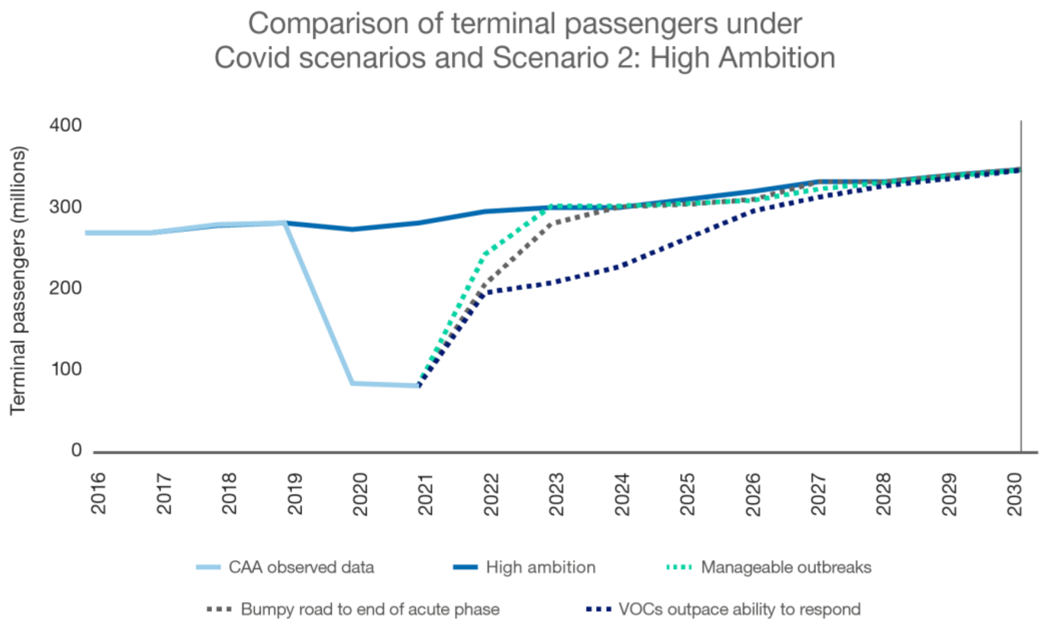

Figure 14 Comparison of terminal passengers under COVID-19 scenarios and Scenario 2

A.22 The graph below shows the impact of COVID-19 scenarios on our emissions forecasts under Scenario 2: High ambition. This shows that emissions converge to the underlying level by 2030. As noted above, COVID-19 scenarios are highly uncertain, and this sensitivity test is to illustrate a broad range of possible recovery paths rather than to estimate the level of demand or carbon emissions at a fixed point in time.

A.23 The emission trajectories are not shown beyond 2030 because they all converge with the underlying ‘High ambition’ scenario by this point and no further assumptions have been included in these model runs to assess any potential longer-term behaviour changes.

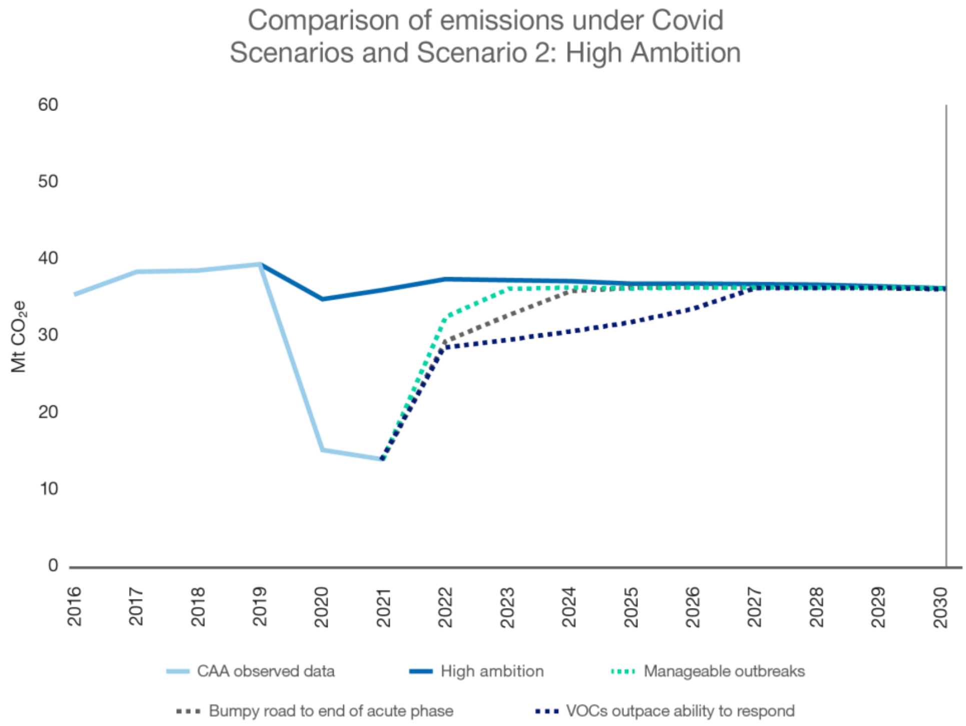

Figure 15 Carbon emission trajectory under COVID-19 scenarios and Scenario 2

Annex B: Modelling methodology for SAF and Zero emission aircraft

SAF

B.1 Uptake of SAF is not calculated within the aviation model. Instead, an uptake trajectory is assumed and fed into the department's aviation CO2 model as an input. The SAF uptake trajectories assumed in this modelling are based on the analysis for the *'Mandating the use of sustainable aviation fuels' consultation*[xl]. The one change we have made to these uptake trajectories is to reflect the latest ambition for 10% SAF by 2030 in our High Ambition and High Ambition with a breakthrough on zero emission aircraft scenarios.

B.2 In the scenarios analysis published as part of the two Jet Zero consultations we assumed 100% direct CO2e emission savings for the aviation sector for SAF fuels. This is consistent with the approach taken by the CCC and is in line with international GHG inventory guidelines and GHG accounting rules consistent with whole economy reporting on net zero[xli]. The rationale for this approach is to avoid any double-counting of emissions across the economy. Under this approach, while savings from SAF are reported as 100% within the transport sector, their production emissions are not excluded from economy-wide projections as they are captured in other sectors. However, we also recognised that on a lifecycle basis, we would expect SAF to deliver less than 100% emission savings relative to the use of kerosene (depending on the type of SAF used).

B.3 Several respondents to the *Jet Zero: further technical consultation*[xlii] document suggested that following the Net Zero Strategy whole economy reporting approach - presenting SAF as delivering c.100% direct emission savings relative to kerosene - in the illustrative scenarios is misleading in that it overstates the emission reductions SAF delivers and means that the residual emissions under each scenario overstate the level of greenhouse gas removals required in 2050.

B.4 The emissions reductions delivered in practice by SAF will depend on the type of SAF used in future. It is envisaged that some SAF production pathways, with the integration of carbon capture and storage into the production process, will 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.

B.5 In the illustrative scenarios presented in this document we present the emission savings delivered by SAF as a percentage of kerosene emissions in line with the assumed life cycle emission savings relative to kerosene underpinning the '*Mandating the use of sustainable aviation fuels' consultation'*.[xliii] The assumptions vary through time and by uptake scenario, in the range 67-75% emissions savings relative to kerosene.

B.6 We also report the residual emissions for each illustrative scenario assuming SAF delivers 100% direct CO2e emission saving relative to kerosene, as required under international GHG inventory guidelines and whole economy GHG accounting rules.

This is to enable comparison with analysis undertaken elsewhere in line with those rules (e.g. the analysis presented in the *Net Zero Strategy*[xliv]).

B.7 We are in the process of reviewing the assumptions underpinning the 'M*andating the use of sustainable aviation fuels*'[xlv] consultation in preparing to launch a further consultation on introducing a SAF mandate later this year. The Department also plans to work with other government departments and other relevant stakeholders in reviewing the way we account for SAF use in monitoring progress towards achieving Jet Zero.

Zero emission aircraft

B.8 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*[xlvi] 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.

Endnotes

[i] Department for Transport (2021) Jet zero: Evidence and analysis
Jet Zero Consultation: Evidence and Analysis (publishing.service.gov.uk)
[ii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[iii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[iv] 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
[v] Department for Business, Energy & Industrial Strategy (2021) Net Zero Strategy: Build Back Greener - GOV.UK (www.gov.uk)
[vi] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[vii] Aviation demand statistics are available for more recent years however the aviation model is only validated against these statistics to 2019 and therefore the impacts of COVID-19 are not included in the model runs and the uncertainty band therefore covers 2020-2024.
[viii] For details, please see Department for transport (2022) Jet zero: modelling framework
https://www.gov.uk/government/publications/jet-zero-modelling-framework
[ix] NAEI, UK National Atmospheric Emissions Inventory - NAEI, UK (beis.gov.uk)(2022)
[x] Department for transport (2022) Jet zero: modelling framework
https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xi] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xii] The increase in terminal passengers is relative to the level of terminal passengers in 2018.
[xiii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation
https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xiv] 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.
[xv] Department for transport (2022) Jet zero: modelling framework
https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xvi] By fuel efficiency, we are referring to all the system efficiency improvement incorporated in the modelling.
[xvii] 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/at a-potential-and-costs-reducting-emissions.pdf
[xviii] Developing the UK Emissions Trading Scheme (UK ETS) (publishing.service.gov.uk)
[xix] The emission savings labelled ETS and CORSIA in this and figures 4, 6 and 8 refer to the emission savings expected due to the impact of UK ETS, EU ETS and CORSIA on passenger demand.
[xx] The increase in terminal passengers is relative to the level of terminal passengers in 2018.
[xxi] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation
https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xxii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation

https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xxiii] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xxiv] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xxv] Air Transport Movements (ATMs) represent a take-off or a departure.
[xxvi] The increase in terminal passengers is relative to the level of terminal passengers in 2018.
[xxvii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation

[xxviii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xxix] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xxx] 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/at a-potential-and-costs-reducting-emissions.pdf
[xxxi] The increase in terminal passengers is relative to the level of terminal passengers in 2018.
[xxxii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xxxiii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xxxiv] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xxxv] 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/at a-potential-and-costs-reducting-emissions.pdf
[xxxvi] In this diagram the emissions trajectory presents SAF as delivering 67-75% emission savings relative to kerosene. It is not consistent with GHG accounting rules used in the analysis for the Net Zero Strategy, under which SAF is presented as delivering 100% emission savings relative to kerosene in the aviation sector.
[xxxvii] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xxxviii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation
[xxxix] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework
[xl] 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
[xli] 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
[xlii] Department for Transport (2022) Jet zero: updated evidence and analysis to inform our strategy for net zero aviation

https://www.gov.uk/government/consultations/jet-zero-updated-evidence-and-analysis-to-inform-our-strategy-for-net-zero-aviation

[xliii] 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

[xliv] Department for Business, Energy & Industrial Strategy (2021) https://www.gov.uk/government/publications/net-zero-strategy

[xlv] 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

[xlvi] Department for transport (2022) Jet zero: modelling framework https://www.gov.uk/government/publications/jet-zero-modelling-framework