Department
for Transport

Jet Zero Consultation: Evidence and Analysis

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1. Introduction

1.1 The Jet Zero Consultation sets out the principles for delivering aviation net zero by 2050 and outlines the range of solutions needed to reach this goal. It is expected that net zero will be achieved through a mix of different technologies, including the adoption of sustainable aviation fuels (SAF) and the use of zero emission flight (ZEF) and all parts of the sector will need to work together. However, many of the technologies needed to achieve net zero aviation are in the early stages of development and there is significant uncertainty regarding the expected cost, availability and uptake of these technologies over the coming decades.

1.2 This supporting analytical document summarises evidence provided by the Climate Change Committee (CCC), industry, academics, and others, on the potential emissions reductions, uptake and cost of abatement measures in aviation. Based on this evidence, we have modelled four different scenarios[1] with a different mix of technologies to illustrate different pathways for reaching net zero aviation by 2050.

2. Measures to deliver net zero

2.1 This section summarises the evidence on abatement potential and costs for each of the five measures highlighted in the consultation.

System Efficiency

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 Research by Air Transportation Analytics (ATA)[2], commissioned by the Government jointly with the CCC, suggested that efficiency improvements such as these could 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. Over the period from 2017-2050 this translates to a fuel efficiency improvement of between 1.5 and 2.0% per annum (for the 'Likely' and 'Optimistic' scenarios referenced in the research). This is in line with both long-run historic rates of fuel efficiency improvement, and with current and future industry ambitions. According to the International Council on Clean Transportation (ICCT), 1960-2008 saw 1.5% annual fuel efficiency improvement on average[3] (though this does mask variation over time). The International Air Transport Association (IATA) set a target of 1.5% annual fuel efficiency improvement from 2009-2020[4], which the Air Transport Action Group (ATAG) suggest has been surpassed[5], while The International Civil Aviation Organisation (ICAO) has set a goal of 2% annual fuel efficiency improvement through to 2050[6].

2.4 The ATA research also found that the fuel cost savings from the more efficient technology and practices considered, outweigh the capital and ongoing costs of implementing them and reduce costs for airlines and passengers at the same time as reducing emissions.

Sustainable Aviation Fuels (SAF)

2.5 Current SAF use in UK aviation is negligible[7] and there is significant uncertainty around the availability and cost of SAF in the future. While certain SAF production pathways from waste oils and fatty acids are already commercial, the vast majority of

SAF technologies have been certified and proven at demonstration stage but have yet to be rolled out at commercial scale.

2.6 Different SAF pathways differ in their lifecycle emissions savings, and not all SAF is necessarily sustainable, for example, due to the emissions, or direct and indirect land use change potentially arising from the production, cultivation and transportation of the feedstocks. To comply with the Renewable Transport Fuel Obligation[8], SAF must meet strict sustainability criteria including limits on the types of feedstocks and land biomass which SAF can be produced from, and a requirement to reduce greenhouse gas (GHG) emissions by at least 60% relative to a set fossil fuel comparator.

2.7 A wide range of estimates exist in the literature as to what the future uptake of SAF could look like. Analysis by E4Tech for Sustainable Aviation[9] suggests that, if UK SAF production grows in line with global forecasts, SAF could provide just over 30% of UK aviation fuel demand in 2050. More optimistically, the World Economic Forum (WEF) *Clean Skies for Tomorrow* report[10] finds that advanced and waste feedstocks alone could supply almost 500 Mt of SAF per year by 2030, which amounts to 120% of projected 2030 global jet fuel demand. There are likely to be competing demands for these feedstocks from other sectors, so high uptake rates in aviation are likely to be as dependent on cross-economy prioritisation decisions as on the total availability and use of feedstocks.

2.8 The costs of SAF are high and uncertain. A recent ICCT report suggested that, in general, SAF is around two to three times the cost of kerosene, and potentially up to eight times the cost of kerosene for certain pathways (for example Alcohol-to-Jet)[11]. Based on a range of evidence, we estimate the abatement costs of SAF to currently be broadly in the range of £200-600/tCO_2 , though it is expected that these should fall over time as production scales up. The ICCT has found that used cooking oil-derived HEFA is currently the most cost-effective SAF pathway, at an abatement cost of €200/tCO_2e (or around £170/tCO_2e), followed by gasification of municipal solid waste and lignocellulosic feedstocks, at around €400-500/tCO_2e (or £350-430/tCO_2e). The WEF *Clean Skies for Tomorrow* report suggests that production costs could fall by 20-70% by 2050, depending on the fuel pathway, mainly driven by economies of scale and reductions in the cost of input feedstocks.

Zero Emission Flight[12]

2.9 Both hydrogen-powered and all-electric aircraft may have the potential to reduce tailpipe carbon-emissions from flights over shorter distances by 100%, provided the hydrogen and electricity is produced sustainably. These emerging technologies are still in the early stages of development for use in commercial fleets, however industry experts believe that they could start to play a role within the next decade, with 2035 often suggested as a plausible entry-into-service (EIS) date for short-haul zero emission aircraft that could carry a significant number of passengers.

2.10 IATA[13] expects that from 2035 battery-powered all-electric aircraft will enter the market for short-haul flights, while Wright Electric[14] is aiming for a single-aisle electric aircraft (carrying up to 186 passengers on short and medium haul routes) to enter service in 2030. For hydrogen, the *Clean Sky 2* report[15] suggests that hydrogen-powered commuter-regional aircraft could enter service from 2030, with hydrogen-powered aircraft making up 40% of all aircraft by 2050 in their ‘Efficient decarbonisation scenario’ and 60% in their ‘Maximum decarbonisation scenario’. In September 2020, the first test flight of a commercial-grade, hydrogen-electric plane took place[16], while Airbus revealed three concepts for hydrogen-powered zero emission commercial aircraft which they aim to bring to market by 2035[17]. ZeroAvia[18] is aiming to bring to market the first hydrogen-electric powertrain suitable for aircraft up to 19-seats by 2023 and to scale this technology to power a 100-seat single-aisle aircraft by 2030, with a vision to power 200+ seater aircraft from 2040.

2.11 However, the timelines for zero emission flight are still uncertain and depend on continual progression in battery, fuel cell and liquid hydrogen propulsion technologies. There is currently limited available evidence on the costs of these technologies. For hydrogen, the *Clean Sky 2*[19] report suggests abatement costs could be \$40-80/tCO_2e (or around £30-55/tCO_2e) for regional aircraft and \$160-350/tCO_2e (or around £110-250/tCO_2e) for long-range aircraft. These costs assume hydrogen will be widely adopted and the necessary infrastructure and fuel supply systems will be available. Any substantial difference in capex costs of hydrogen aircraft or longer refuelling times would increase these abatement cost estimates. In the initial years, as the technology first begins rolling out on commercial aircraft, it is likely that the abatement costs will be considerably higher than these estimates. In the *Destination 2050*[20] study, the abatement cost for Hydrogen aircraft is estimated to be €225/tCO_2 (or around £195/tCO_2).

Markets and Removals

Markets

2.12 Market-based economic measures will play an important part in reducing the emissions from the aviation sector in a cost-effective way. Schemes which place a price on carbon via tradeable permits or offsetting obligations will increase costs to airlines. Airlines are likely to pass at least some of these costs on to consumers[21] in the form of increased ticket prices and this may reduce demand for air travel, depending on the scale of the price increase and on how price sensitive consumers are. There is likely to be some variation in this reduced demand between long-haul and short-haul flights as passengers on short-haul flights tend to be more price sensitive. Some airlines may also make different decisions about the extent to which to pass costs onto consumers[22].

2.13 As of 1st January 2021, CO_2 emissions from UK domestic flights, flights from the UK to the European Economic Area (EEA) and flights between the UK and Gibraltar are covered by the UK Emissions Trading Scheme (ETS). The UK ETS has important design features to guard against instability in the early years of the market including an Auction Reserve Price (ARP) and the Cost Containment Mechanism (CCM).

2.14 The transitional ARP is set at £22 and is the minimum price for bids in primary-UK ETS auctions. At the other end of the scale, the CCM is intended to mitigate sustained high prices and is more responsive than its equivalent in the EU ETS, providing a powerful tool for the UK ETS Authority to intervene if prices are elevated for a sustained period. In 2021 and 2022, the CCM will be triggered if the average allowance price on the end of year futures market is 2 times and 2.5 times respectfully, the average carbon price in the UK for the preceding 2-year period, for 3 consecutive months[23].

2.15 The UK ETS secondary market and the first UK ETS auction took place on the 19th of May. The first auction fully cleared at a price of £43.99 and the first day of trading closed, with the December-21 contract at £45.25[24]. However, the trajectory that the price of UK ETS allowances will follow in the future is uncertain. For example, this will depend on the outcome of the planned consultation to appropriately align the UK ETS cap with a net zero trajectory.

2.16 International flights between participating states are also subject to the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA is a global market-based measure to address CO_2 emissions from international aviation, aimed at achieving ICAO's medium-term climate goal of Carbon Neutral Growth from 2020 (CNG2020), 88 states volunteered to participate in CORSIA from the start of the Pilot Phase from 1 January 2021[25] including the UK. Future prices of CORSIA eligible emission units are also uncertain. In 2016, estimates for 2020 used in ICAO analysis ranged from $6/$tCO_2e$ to $20/$tCO_2e$[26]. However, these estimates are considerably higher than the prices of CORSIA eligible emission units in recent years[27].

2.17 We have reflected the in-sector impacts of a carbon price fluctuation in our modelling. We have not sought to assess the full impact of these schemes on CO_2 emissions across the economy i.e. taking account of emissions reductions outside of the aviation sector, due to the uncertainty around the trajectory of these impacts to 2050.

2.18 As noted above, there is uncertainty surrounding the values to use when modelling future carbon prices. For this analysis, BEIS's traded carbon value series to 2050, taken from guidance on valuing GHG emissions for appraisal, has been used[28]. These values are slightly higher than BEIS's short-term carbon values for modelling series up to 2030 which estimate the future cost of purchasing allowances under the EU ETS[29]. More generally, the value the government places on changes in carbon emissions is currently under review, now that the UK has increased its domestic and international ambitions by committing to net zero. Accordingly, current BEIS central carbon values are likely to undervalue GHG emissions in the long term, though the scale of undervaluation is still unclear, as they are consistent with the UK's old decarbonisation target of 80% reduction in emissions by 2050. The potential impact of placing a higher value on GHG emissions has been explored by using the existing BEIS high carbon values series in our scenarios, in addition to the prescribed central values[30].

Removals

2.19 A report by the Royal Society and Royal Academy of Engineers found that greenhouse gas removals (GGRs) could reach a potential of 50 $MtCO_2$ of bioenergy with carbon capture and storage (BECCS) and 25 $MtCO_2$ of direct air carbon capture and sequestration (DACCS) in the UK in 2050, alongside a further 50 Mt of other types including land-based solutions such as biochar[31]. BEIS is currently updating its evidence based on the deployment potentials for these technologies, and figures are subject to change. GGRs will likely be necessary to compensate residual emissions from several of the hardest to abate sectors in the economy, including the aviation sector. In the CCC's report on the Sixth Carbon Budget, their 'Balanced Pathway' scenario suggests that approximately 97 Mt[32] of removals could be needed across the economy (including up to 23 Mt of these to compensate for residual emissions from aviation). Deployment trajectories are inherently uncertain; however, our analysis suggests that there would be sufficient GGR capacity to offset the residual aviation emissions that are estimated in all the scenarios we present below. We define residual emissions as those which remain after efforts to decarbonise the aviation sector have been made.

2.20 Cost estimates vary widely due to the early stage of these technologies, the uncertainty surrounding potential cost reductions over time and the predicted capacity of GGRs that will be required to reach net zero. At the lower end, in their Sixth Carbon Budget report, the CCC suggest that BECCS costs could be around £50-160/tCO2e removed, and DACCs costs around £120-£180/tCO_2e removed in 2050[33]. Research by Vivid Economics, which considers how GGRs may support a net zero target, finds the costs of BECCS may be around £80-230/tCO_2, and DACCS around £160-470/tCO_2[34]. The costs of GGRs are therefore in a similar range to those of SAF and, given that some later generation SAF pathways rely on captured carbon as a feedstock, it is possible that GGRs will be cheaper and more cost-effective than SAF in future. However, further 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 to compensate residual emissions from the aviation sector.

Influencing Consumers

2.21 In order to achieve the CCC's proposed demand limit of a 25% increase in passenger numbers on today's levels by 2050, our modelling suggests a carbon price substantially higher than £600/t could be necessary. However, given the current evidence on the costs of SAF and hydrogen, we think before carbon prices reached this level, they would be sufficient to incentivise technologies to reach net zero GHG emissions by 2050.

2.22 This analysis suggests that capping demand may not be necessary to reduce emissions to levels which can be offset by GGRs to achieve net zero (such as the level suggested by the CCC's Balanced Net Zero Pathway, 23 Mt in 2050). There is much uncertainty however, and clearly there could be many combinations of technology improvements, GGR costs and demand growth which would achieve net zero. The challenge is to provide the right incentives and support to achieve this aim in the least restrictive and most cost-effective way possible.

3. Pathways to net zero

3.1 Based on the policy framework set out in the consultation document, where we prioritise in-sector abatement and ensure that any residual emissions are offset, we have modelled four scenarios that seek to illustrate alternative possible ways in which UK aviation could reach net zero by 2050[35]. The scenarios are based on different assumptions about how the measures available to reduce carbon emissions might evolve. The assumptions made about how much abatement each measure could deliver have been informed by the available evidence summarised in the previous section.

3.2 The scenarios presented here are not prescriptive. The uncertainty surrounding the future costs of the measures mean that it is not possible to assess the relative cost effectiveness of the scenarios. 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 - these scenarios will not be possible based on domestic action alone.

3.3 In our analysis, as a simplifying assumption recognising the uncertainty surrounding future carbon prices, all of our scenarios assume a common carbon price is applied to all flights departing from the UK. Whilst this is not reflective of the current policy landscape, this illustrates the impacts of our ambition to ensure that the carbon pricing policies covering UK aviation are consistent with meeting our net zero goals. Apart from the application of a carbon price, none of our scenarios assume any additional demand management measures.

3.4 All scenarios are compared to a '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 57 $MtCO_2$ in 2050.

3.5 Our scenarios are based on 2017 DfT forecasts of passenger demand and therefore do not take into account 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. However, it is likely that the impacts of COVID-19 on passenger behaviour and demand will continue to be felt long after this. For example, Waypoint 2050 estimates that long-term global air traffic forecasts could be around 16% lower in 2050 than previously predicted[36]. This is a key limitation of our scenarios and should be considered when interpreting the results.

Scenario 1: Continuation of current trends

3.6 This scenario represents a continuation of current trends in UK aviation. There is no step-up in ambition on SAF or annual efficiency improvements, nor any introduction of zero-emission aircraft. This scenario does, however, include a carbon price on international flights that are not currently captured by the ETS and this will require significant effort and international cooperation to achieve.

	Assumptions	**Rationale / Source**
Demand	60% increase in passengers by 2050[37].	2017 published DfT aviation forecasts[38]
Carbon price	BEIS central carbon price on all flights, reaching £231/tCO$_2$ in 2050 (2018 prices)	BEIS guidance on carbon valuation[39]
Capacity	Updated airport assumptions	See 'Modelling Net Zero' section for further detail
Fuel efficiency improvements	1.5% pa (2017-2050)	Based on central case from ATA research[40]. This is within the range of average historic improvements and future expectations[41].
SAF uptake	5% of total aviation fuel use in 2050	Based on expert judgement and external evidence[42]
Zero emission tech uptake	None by 2050	Based on more conservative views 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

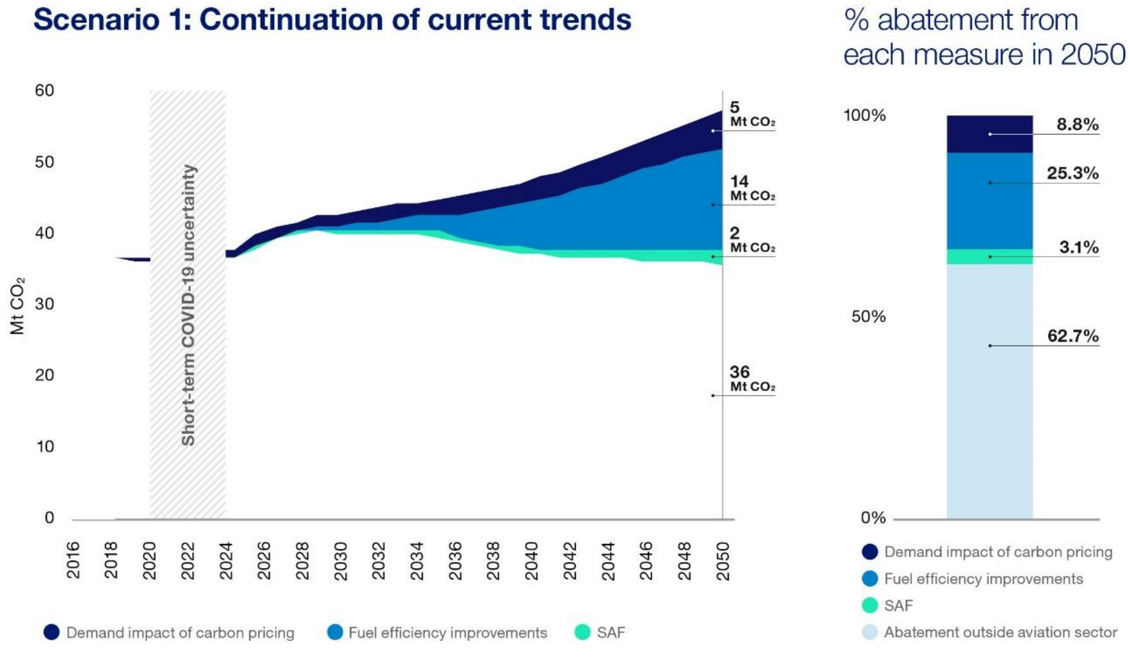
Key Challenges

3.7 While this scenario should be relatively easy to achieve, there are still some uncertainties and deliverability challenges surrounding the assumptions. Firstly, a common carbon price is assumed to apply to all flights departing the UK, however, currently, different carbon prices are applied: domestic flights, flights from the UK to EEA countries, and flights between the UK and Gibraltar are included under the UK ETS; while international flights from the UK or its territories are subject to CORSIA, subject to certain exemptions. CORSIA only applies until 2035 and offset prices are currently much lower than those expected in the UK ETS. Secondly, though in line with historic trends, our assumptions on 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, meaning it remains more cost-effective to offset the majority of emissions.

Results

3.8 This scenario results in around 36 Mt CO_2 of residual emissions in 2050, which will need to be abated outside of the aviation sector in order to reach net zero emissions. While passenger numbers grow by around 60% on 2018 levels (from 273 million terminal passengers in 2018 to 466 million in 2050), emissions remain fairly constant over the time horizon due to the impact of continuous fuel efficiency improvements and the small uptake of sustainable fuels.

3.9 Although there is a long-run trend towards greater levels of carbon pricing, it may be overly ambitious in this scenario to assume the carbon price on all flights reaches the same level. To account for this, we have also explored how different the results would be if we only assume a carbon price on flights within the UK and EEA (the current scope of the UK ETS), as a conservative assumption. This results in residual emissions being 3 Mt higher in 2050.



Source: DfT analysis

Figure 2. Scenario 1 – Continuation of current trends

Figure 3. Comparison of Scenario 1 to 2018 aviation emissions

Year	2030	2040	2050
Change on 2018 CO_2 emission levels [43]	+6%	-2%	-5%

Scenario 2: High ambition

3.10 This scenario is more ambitious than Scenario 1. It includes the same assumptions on demand, carbon price and capacity but there is a step-up in ambition on efficiency improvements, SAF uptake and the introduction of zero-emission aircraft.

	Assumptions	**Rationale / Source**
Demand	60% increase in passengers by 2050.	2017 published DfT aviation forecasts
Carbon price	BEIS central carbon price on all flights, reaching £231/tCO_2 in 2050 (2018 prices)	BEIS guidance on carbon valuation
Capacity	Updated airport assumptions	See ‘Modelling Net Zero’ section for further detail
Fuel efficiency improvements	2.0% pa (2017-2050)	Based on optimistic scenario from ATA research and in line with ICAO aspirational goal[44]
SAF uptake	30% by 2050	In line with the Sustainable Aviation SAF Roadmap[45] and the CCC’s Balanced Net Zero Pathway[46]
Zero emission tech uptake	21% of ATMs[47] 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[48]

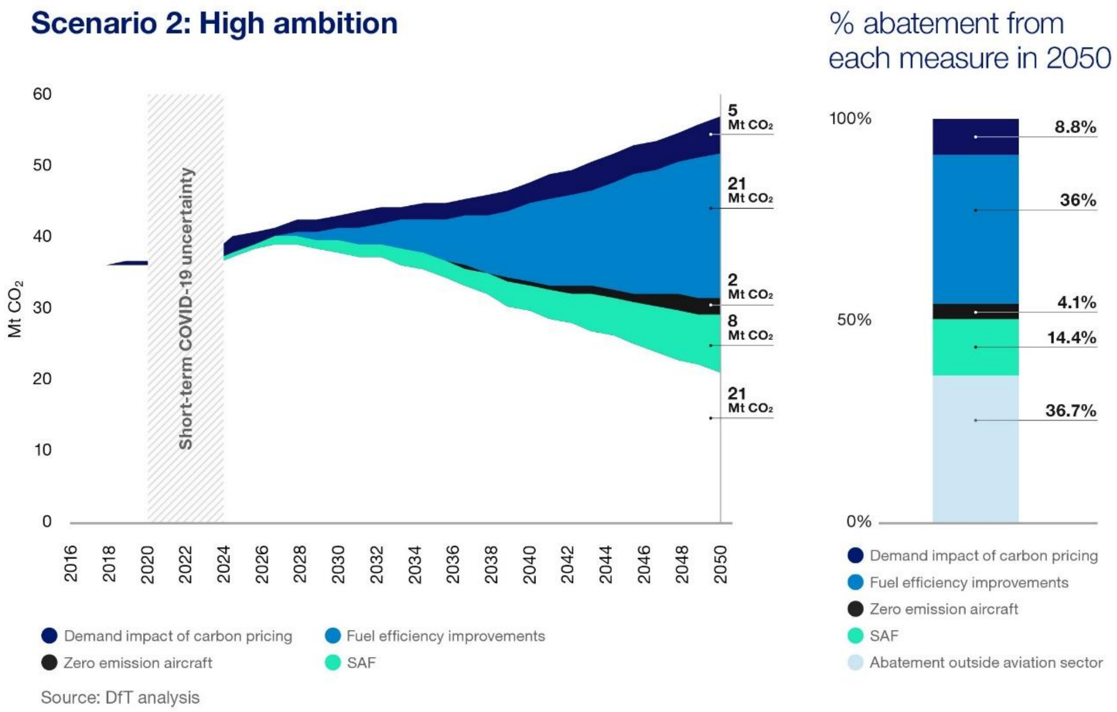
Figure 4. Assumptions in Scenario 2

Key Challenges

3.11 Several things may need to happen for this scenario to materialise. CCC[49] analysis suggests that use of biomass would need to be prioritised in aviation over other sectors in order to support this level of SAF uptake, though other forms of SAF should also be available. Achieving such a high rate of fuel efficiency improvement will also be challenging, and may not be met if airlines cannot afford to invest in modernising their fleets at sufficient speed, or if the aerospace sector cannot afford to invest in creating the necessary aircraft advancements (made even more likely by the huge financial impact of Covid-19 on the aviation industry). Finally, most crucial for realising the introduction of zero emission aircraft by 2035 is the necessary technological progress in battery and hydrogen technology within this decade, as future aircraft availability by 2035 requires technology readiness by 2027-2030. A common carbon price is also assumed to apply to all flights departing the UK, which will require high levels of international cooperation.

Results

3.12 As with Scenario 1, passenger numbers reach 466 million in 2050. More ambitious assumptions on efficiency and SAF uptake, alongside the introduction of some zero emission aircraft, mean that residual emissions in 2050 are much lower, at 21 Mt CO_2. While zero emission aircraft enter the fleet in 2035, these have a minimal impact on total emissions in 2050. This is because these only enter into service on the shortest routes, and standard replacement rates mean that only 21% of all ATMs (air traffic movements) are zero emission by 2050, making up just 12% of total ATM-kms in 2050. However, within the domestic market, 41% of ATMs are zero emission in 2050.



Source: DfT analysis

Figure 5. Scenario 2 – High ambition

Figure 6. Comparison of Scenario 2 to 2018 aviation emissions

Year	**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	+3%	-19%	-45%

Scenario 3: High ambition with a breakthrough on SAF

3.13 The third scenario is a speculative scenario in which carbon prices prove to be higher than under Scenario 2 and SAF emerges as a more cost-effective solution, comprising a very high proportion of aviation fuel usage by 2050.

	Assumptions	**Rationale / Source**
Demand	58% increase in passengers by 2050	2017 published DfT aviation forecasts[50] adjusted for BEIS high carbon price
Carbon price	BEIS high carbon price, reaching £346/tCO$_2$ in 2050 (2018 prices)	BEIS guidance on carbon valuation[51]
Capacity	Updated airport assumptions	See 'Modelling Net Zero' section for further detail
Fuel efficiency improvements	2.0% pa	Based on optimistic scenario from ATA research and in line with ICAO aspirational goal[52]
SAF uptake	75% by 2050	Based on a range of upper estimates for SAF uptake in external evidence[53]
Zero emission tech uptake	21% 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 in Scenario 3

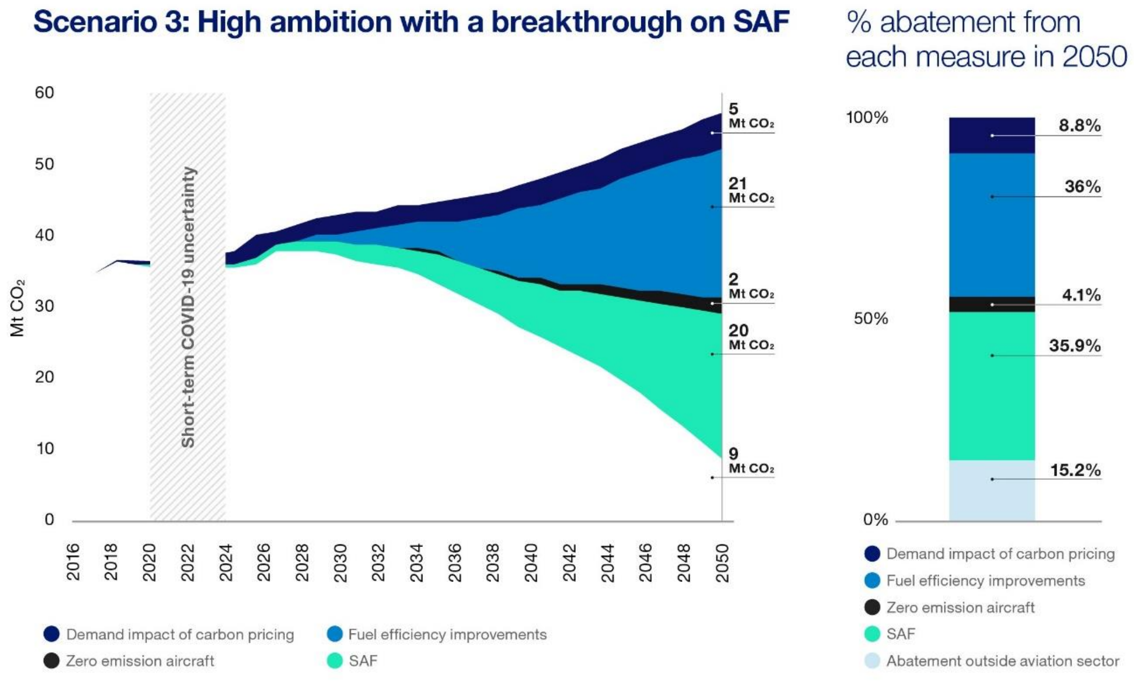
Key Challenges

3.14 Several developments will need to happen for a scenario like this to occur. Most crucially, the costs of SAF will need to fall significantly, or 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 a high share of more advanced SAF pathways in particular (such as power-to-liquids), which are currently much more expensive than others. 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, the high risk for investors due to low technological maturity, the stringent certification requirements for new fuel pathways and blend limits (there are currently only eight certified SAF pathways), the lack of secure and sustainable supply chains for feedstocks, competition for feedstocks with other sectors (such as biomass used in road fuels), potential changes needed to aircraft engines and re-fuelling infrastructure to be compatible with SAF at blends higher than 50%, and the lack of a domestic market. Only if these challenges are overcome, in addition to those discussed in the previous scenarios, will such a scenario be plausible.

Results

3.15 This scenario sees the abatement of 85% of 2050 aviation emissions within-sector – the largest of the four scenarios. SAF deliver the largest proportion of this abatement.

Just 9 Mt of residual emissions remain in 2050, which will need to be abated outside the aviation sector. The higher carbon price has a limiting effect on demand, such that terminal passenger numbers reach 461 million in 2050. However, this does not have a significant impact on carbon emissions, as demand is diverted away mostly from flights in the domestic and short-haul markets (which make up a lower share of emissions – domestic flights produced just 4% of 2019 UK aviation emissions), due to the fact that, on average, in these markets more of the high carbon price is passed through to passengers, ticket prices are lower and passengers are more price sensitive.



Scenario 3: High ambition with a breakthrough on SAF

% abatement from each measure in 2050

Source: DfT analysis

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

Figure 9. Comparison of Scenario 3 to 2018 aviation emissions

Year	**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	0%	-28%	-77%

Scenario 4: High ambition with a breakthrough on zero emission aircraft

3.16 The final scenario considered is a speculative scenario in which carbon prices are higher than under Scenario 2 and there is a significant advance in zero emission technology (far higher than past rates of improvement in battery technology), alongside an acceleration of current aircraft replacement rates. SAF uptake is kept consistent with Scenario 2.

	Assumptions	**Rationale / Source**
Demand	58% increase in passengers by 2050	2017 published DfT aviation forecasts[54], adjusted for BEIS high carbon price

Carbon price	BEIS high carbon price, reaching £346/tCO_2 in 2050 (2018 prices)	BEIS guidance on carbon valuation[55]
Capacity	Updated airport assumptions	See ‘Modelling Net Zero’ section for further detail
Fuel efficiency improvements	2.0% pa	Based on optimistic scenario from ATA research and in line with ICAO aspirational goal[56]
SAF uptake	30% by 2050	Broadly in line with the Sustainable Aviation SAF Roadmap[57] and the CCC’s Balanced Net Zero Pathway[58]
Zero emission tech uptake	53% of ATMs by 2050	All retiring class 1 and class 2 aircraft replaced by zero emission aircraft from 2030, further 50% of retiring class 3 aircraft replaced with zero emission aircraft from 2035. Early retirement of certain aircraft types in 2040[59].

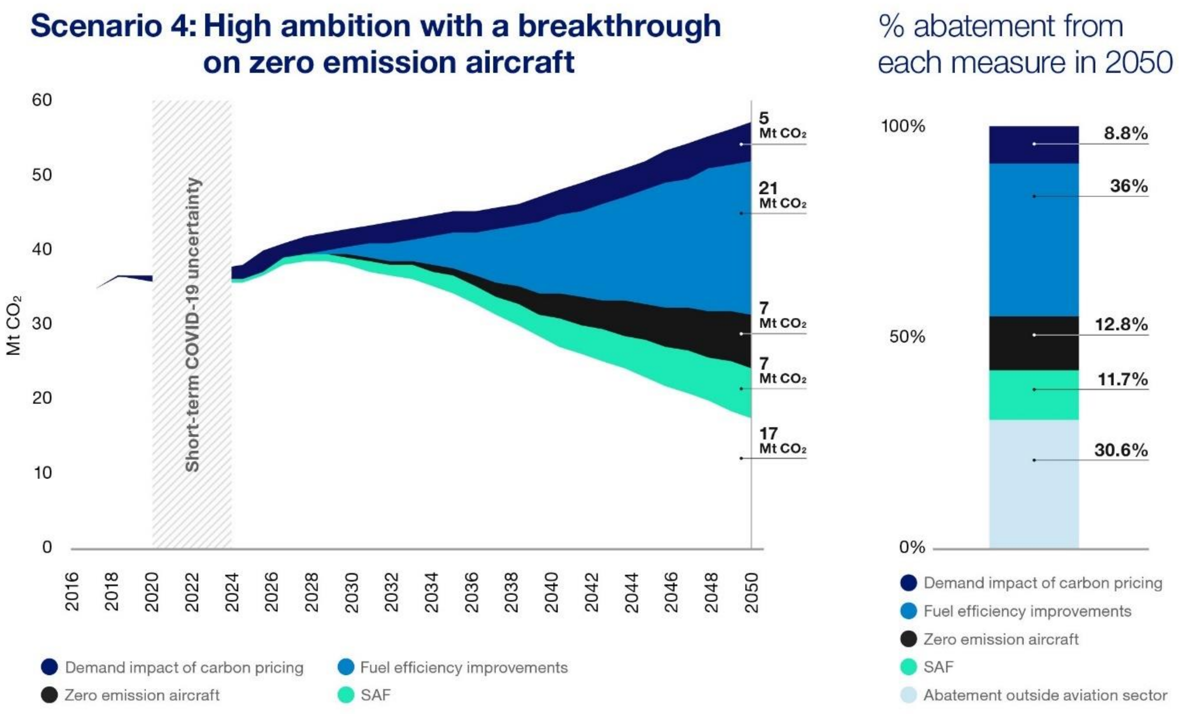
Figure 10. Assumptions used in Scenario 4

Key Challenges

3.17 In order for such a scenario to be feasible, a number of challenges will need to be overcome. For example, a step change in battery density improvements and other technological advancements will be required (enabled by a greater investment in R&D), 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. For hydrogen specifically, the development of a hydrogen strategy and supply-chain across the economy is crucial. Furthermore, for both electric and hydrogen aircraft, the costs of these technologies will ultimately need to fall so that zero emission aircraft offer a cost-effective approach to decarbonisation, relative to using SAF or GGRs.

Results

3.18 The requirement for removals in 2050 is 17 $MtCO_2$ in this scenario. Class 3 (150-250 seat) zero emission aircraft enter into service from 2040, at accelerated replacement rates. These aircraft still operate mainly on domestic and short-haul routes, meaning that although 53% of ATMs are zero emission by 2050, only 34% of ATM-kms are zero emission. Passenger numbers are the same as in Scenario 3 (reaching 461 million in 2050).



Source: DfT analysis

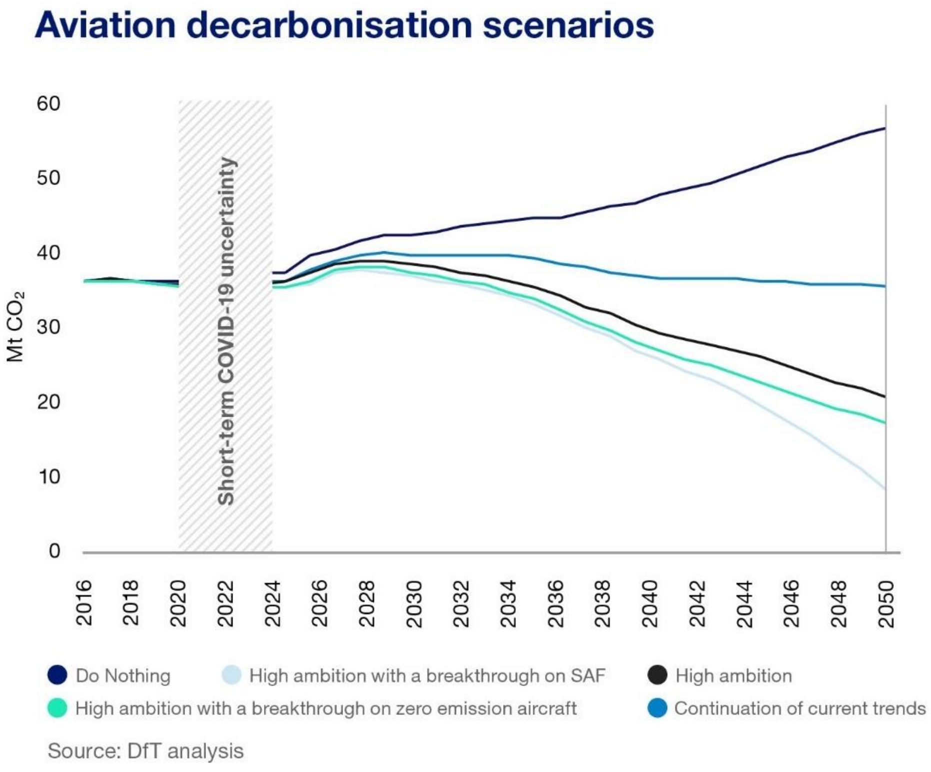
Figure 11. Scenario 4 – High ambition with a breakthrough on zero emission aircraft

Figure 12. Comparison of Scenario 4 to 2018 aviation emissions

Year	**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	+1%	-25%	-54%

4. Summary

4.1 As shown in Figure 13, the four scenarios we have modelled result in residual in-sector emissions of between 9 Mt and 36 Mt in 2050. The scenarios show that significant in-sector abatement could be possible if we make substantial progress with new technologies. 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 scenarios. Our trajectories also indicate that aviation net zero can be met by 2050 with future capacity assumptions consistent with Making Best Use policy and the Airports National Policy Statement.

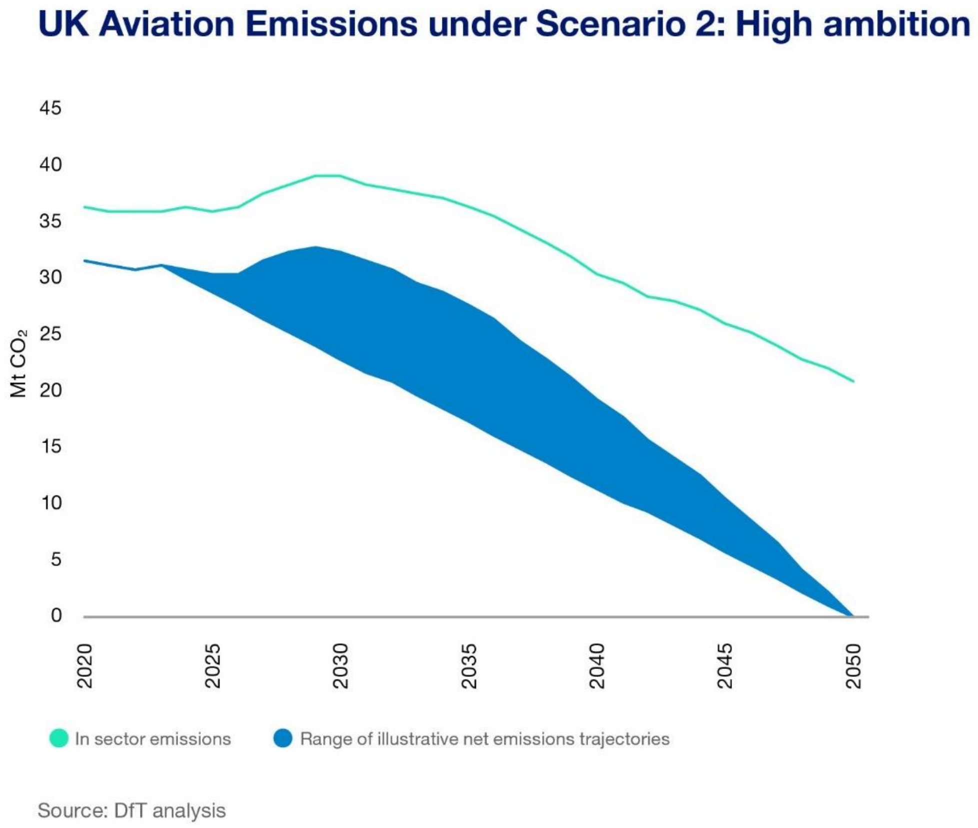


Aviation decarbonisation scenarios

Source: DfT analysis

Figure 13. In-sector aviation decarbonisation scenarios

4.2 All scenarios see 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 will be required. A band of illustrative net emissions trajectories for aviation is presented in Figure 14, for Scenario 2[60]. 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.



Source: DfT analysis

Figure 14. Illustrative net emissions trajectory under Scenario 2

Figure 15. Comparison of net emissions trajectory to 2018 aviation emissions

Year	**2030**	**2040**	**2050**
Change on 2018 CO_2 emission levels	-14 to -39%	-49 to -70%	-100%

4.3 There is significant uncertainty surrounding the abatement potential, uptake and costs of the measures described in this document and therefore these scenarios should be seen as illustrative pathways rather than forecasts. Achieving the emissions reductions shown in these scenarios will also require substantial international effort and cooperation. International cooperation will also minimise risks of carbon leakage and adverse impacts on the competitiveness of UK industry.

4.4 We will continue to build our evidence base on the costs and potential of these measures and the scenarios analysis will be reviewed alongside the overall strategy every five years. We will also seek to analyse the impacts of domestic and international policy as they develop.

4.5 We would welcome any views on the range of scenarios we have presented or any additional evidence. These can be fed in via the Jet Zero Consultation.

Annex A: Modelling net zero

A.1 Our analysis uses the Department's aviation model, which is also used by the CCC. The model forecasts air passenger demand for UK-departing flights and allocates across the UK's airports based on a number of factors, including a passenger's final destination, location of and accessibility to airports, availability of flights, travel times, costs, and the capacity of airports to accommodate projections of passengers and flights to 2050 and beyond.[61]

A.2 CO_2 forecasts are produced by combining these outputs with assumptions about the future fuel efficiency of planes. These assumptions are based on a fleet model, which determines the size and type of aircraft for any given flight, and the fuel efficiency of these aircraft.

A.3 The modelling of the emissions scenarios presented here does not explicitly take account of the costs of different measures due to uncertainty. The modelling does however take account of the impact of the carbon price, and so implicitly assumes that the cost of the measures (/tCO_2e) are less than the carbon price assumed in each scenario.

A.4 The version of the model used for this analysis is based on the 2017 version of the model which is described in detail in the DfT's 2017 forecast publication[62]. The forecasts are therefore subject to update given the availability of new data since 2017. Some updates have already been made. These are described below:

Airport capacity assumptions.

A.5 In June 2018, the Government set out its support for airports to make best use of their existing runways[63] (“MBU”) and a new runway in the South East in the Airports National Policy Statement, subject to related economic and environmental considerations. We have revised the capacity assumptions in our modelling to reflect this, while also updating capacities for several airports where more up-to-date evidence has become available. Our assumptions also reflect plans for a third runway at Heathrow (with a phased introduction).

A.6 The capacity assumptions that have been made are not intended to pre-judge the outcome of future planning applications. However, in order to conduct the modelling, specific assumptions have to be made on a number of inputs, including about the future capacity of the main airports in the UK. In line with a precautionary approach to the level of future carbon emissions, and to reflect the uncertainty around future developments in this area, we have assumed capacities that are consistent with the planning applications that have been made by airports, and also increased the capacity of others where our forecasting suggests there will be significantly higher demand in the future. Increasing capacity limits in this way allows us to focus the analysis on testing the potential of abatement technologies to meet the challenge of net zero, without capacity constraints arbitrarily restricting demand.

A.7 The modelling scenario that we have used should **not** therefore be seen as a prediction of what DfT thinks will happen with regard to future capacity expansion, but as a reasonable upper bound of possible future airport capacity levels and therefore associated emissions, in order to better test the potential of measures to meet net zero.

Updated fleet mix modelling assumptions.

A.8 DfT recently updated the fleet mix component of the aviation model to better reflect the age profile of aircraft operating in the UK. This is the module that forecasts the type of aircraft that service the flights predicted by the model.

Revised fuel efficiency assumptions

A.9 DfT, jointly with the CCC, commissioned research from a consortium of academics and industry experts to examine the scope for fuel efficiency improvements of the fleet used in UK aviation[64]. This includes improvements from engine and airframe design, operational measures that are within the control of airlines and air traffic management. We have used this analysis as an input to our modelling. Our modelling also includes the positive rebound impact on demand due to efficiency improvements lowering the costs of flying.

SAF

A.10 Uptake of SAF is not calculated within the aviation model, instead an uptake trajectory is assumed and fed into the CO_2 model as an input. To calculate this trajectory, we make an assumption on the proportion of SAF in 2050 and fit an exponential uptake up to this point, to reflect the fact that progress is likely to be backloaded. We assume 100% CO_2 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[65].

Zero emission aircraft

A.11 Zero emission aircraft enter the modelling via the Fleet Mix Model. 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 2030-35, and replace existing aircraft in these classes at existing replacement rates (22-25 years). For scenario 4, early replacement of class 3 Airbus A319Neo, Airbus A320Neo, Boeing 737 Max 8, and

Boeing 737 Max 9 is assumed (as these are the main aircraft forecast to be operating in this class at this time).

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[5] ATAG Factsheet (January 2019) *Tracking Aviation Efficiency*. https://aviationbenefits.org/media/166506/fact-sheet_3_tracking-aviation-efficiency.pdf

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