APPLICATION BY LONDON LUTON AIRPORT OPERATIONS LTD

(REF APP/B0230/V/22/3296455)

VARIATION OF CONDITIONS RELATING TO EXTENSIONS AND

ALTERATIONS TO THE AIRPORT

LONDON LUTON AIRPORT, AIRPORT WAY, LUTON

Appendices to the proof of evidence of Cait Hewitt

on behalf of LADACAN:

Climate change impacts arising from additional aviation activity

30 August 2022

Appendix		**Page**
A	UK Parliament declares climate change emergency, BBC News, 1st May 2019	3
B	Extract from Letter from the Department for Transport to North Somerset Council, Department for Transport, 13 August 2021, Document INQ/042 at Bristol Airport inquiry 2021	4
C	Letter from CCC providing advice on the UK's 2030 Nationally Determined Contribution, Climate Change Committee, 3rd December 2020	5
D	Letter from CCC providing advice on international aviation and shipping and net zero, Climate Change Committee, 24th September 2019	6
E	Oral evidence transcript for net zero aviation and shipping inquiry, Environmental Audit Committee, 18th May 2022	8
F	Greenhouse Gas Removal methods and their potential UK deployment, Element Energy for BEIS, October 2021	9
G	Sustainable Aviation Fuels as a pathway to net zero aviation, McKinsey for the World Economic Forum, November 2020	10
H	The role of aviation demand reduction in UK decarbonisation, Element Energy for AEF, April 2022	11
I	Definitions and implication of climate-neutral aviation, Brazzola et al, Nature, 25th July 2022	16
J	Greenhouse gas reporting: conversion factors 2020, BEIS, June 2020 (updated July 2020)	17
K	Luton Borough Council declares 'climate emergency', BBC News, 14th January 2020	18
L	Appeal decision letter APP/Y2620/W/16/3143028, Selbrigg Farm, Hempstead NR25 6NF, Planning Inspectorate, 3rd February 2020	20
M	The Sixth Carbon Budget: aviation sector summary, Climate Change Committee, December 2020	21

Appendix A – BBC News Story, May 2019

UK Parliament declares climate change emergency

- Published by BBC News, 1 May 2019

IMAGE SOURCE, REUTERS

MPs have approved a motion to declare an environment and climate emergency.
This proposal, which demonstrates the will of the Commons on the issue but does not legally compel the government to act, was approved without a vote.
Labour leader Jeremy Corbyn, who tabled the motion, said it was "a huge step forward".
Environment Secretary Michael Gove acknowledged there was a climate "emergency" but did not back Labour's demands to declare one.
The declaration of an emergency was one of the key demands put to the government by environmental activist group Extinction Rebellion, in **a series of protests** over recent weeks.
Addressing climate protesters from the top of a fire engine in Parliament Square earlier, Mr Corbyn said: "This can set off a wave of action from parliaments and governments around the globe.
"We pledge to work as closely as possible with countries that are serious about ending the climate catastrophe and make clear to US President Donald Trump that he cannot ignore international agreements and action on the climate crisis."

Labour's motion also calls on the government to aim to achieve net-zero emissions before 2050 and for ministers to outline urgent proposals to restore the UK's natural environment and deliver a "zero waste economy" within the next six months.
The **Welsh** and **Scottish** governments have both already declared a climate emergency, along with dozens of towns and cities, including Manchester and London.

Appendix B – Extract from letter from the Department for Transport to North Somerset Council, August 2021

Annex A – Table of responses

Query No.	Query	Response
1.1	Please provide any and all **impact assessments** of the costs and benefits of the options considered in the Consultation paper which have been undertaken	The department does not hold this information. The request is accordingly refused under regulation 12(4)(a) of the Environmental Information Regulations 2004. No impact assessment has been carried out to accompany this consultation.
1.2	Please could you provide any and all **copies of documentation** explaining why this has not been done notwithstanding the requirements of the Consultation Principles?	See email dated 3 June 2021 at Annex B. An impact assessment was not deemed appropriate or possible at this stage given the consultation is on a broad strategy for achieving net zero aviation rather than setting out detailed policy proposals. Should they be required, the department will carry out impact assessments to accompany subsequent consultations on policy proposals to achieve the goals of this strategy.
2	In the event that **other scenarios** have been assessed, please provide any and all documentation setting out such assessment.	No other scenarios were assessed as part of the analysis feeding into the Jet Zero Consultation. Since that analysis was completed, we have conducted sensitivity analysis on a hybrid option between our Scenario 1 and Scenario 2 options where there is a higher uptake of Sustainable Aviation Fuel (SAF) in 2050. The purpose of this analysis was to understand the potential emissions impacts of additional SAF uptake. Please see Annex C for more detail on this analysis.

Appendix C – Letter from CCC to the Secretary of State, BEIS, 3rd December 2020

The Rt Hon Alok Sharma MP
Secretary of State, Department for Business, Energy & Industrial Strategy
1 Victoria Street SW1H 0ET

Advice on the UK's 2030 NDC

Dear Alok,

We will publish our formal advice on the UK's Sixth Carbon Budget on December 9th. You requested that the Climate Change Committee share our recommendation on the UK's 2030 NDC prior to that date. I am pleased to do so.

We welcome your insistence on ambitious UK climate leadership ahead of COP26. Its importance cannot be overstated. Global ambition for 2030 must increase significantly if the goals of the Paris Agreement are to be met.

We recommend that the UK commits to reduce territorial emissions by at least 68% from 1990 to 2030, as part of the UK's nationally determined contribution (NDC) to the UN process. This would constitute a decisive commitment to a Net Zero emissions trajectory, consistent with the Paris Agreement. It would place the UK among the leading countries in climate ambition.
We encourage the Prime Minister to make a 2030 commitment that is as bold as possible, to inspire other world leaders to follow suit. As such, the Government may choose to go beyond a 68% reduction. My committee would support the use of international credits to do so. We would not expect credits to be used towards the 68% reduction.

This trajectory for UK emissions is eminently achievable, provided effective policies are introduced across the economy without delay. These would bring significant benefits for the UK's economic recovery.

The NDC is more than just a number. It should be accompanied by wider climate commitments, including the development of a policy package and Net Zero Strategy to deliver against the UK goal, clear commitments to reduce international aviation and shipping emissions, and greater support for climate finance, particularly for developing countries. It is also imperative that the NDC is accompanied by strengthened climate change adaptation plans – with new commitments - for the UK to show its leadership on emissions reduction and adaptation.

I look forward to discussing our recommendations for the Sixth Carbon Budget.

Yours,
Lord Deben, Chairman

Appendix D – Letter from CCC to the Secretary of State, DfT, 24 September 2019

Rt Hon Grant Shapps MP
Secretary of State for Transport
Great Minster House
33 Horseferry Road
London SW1P 4DR

24 September 2019

Net-zero and the approach to international aviation and shipping emissions

Dear Secretary of State,

The Government has legislated for the UK to reach net-zero greenhouse gas emissions by 2050. I am pleased the Government clarified to Parliament that the target must cover the whole economy, including international aviation and shipping (IAS) emissions. This letter responds to the Government's request on how to bring IAS emissions formally within the UK's net-zero target, setting out the rationale and the implications for the UK's climate strategy.

Our advice that 2050 is an appropriate date for net-zero is based on formal inclusion of IAS emissions within the target. Without this a more ambitious target is likely to be required.

The rationale for inclusion of IAS emissions in the UK carbon targets

The primary policy approach to reducing IAS emissions should be international. Through the efforts of your Department, the UK has played a key role in progress by both the International Civil Aviation Organisation (to agree a global offsetting scheme for aviation emissions to 2035) and the International Maritime Organisation (to agree to reduce shipping emissions by at least 50% by 2050 compared to 2008 levels and pursue efforts to phase emissions out entirely).

This international framing should not prevent the inclusion of IAS emissions in UK carbon targets, as is already the case for other sectors that are covered by international agreements and potentially exposed to competitiveness pressures (e.g. energy-intensive industry).

Addressing IAS emissions is strategically important. Formal inclusion of IAS emissions in the net-zero target would complement agreed international policies and should not be interpreted as a unilateral UK approach to reducing emissions in these sectors.

- Aviation is likely to be the largest emitting sector in the UK by 2050, even with strong progress on technology and limiting demand. Aviation also has climate warming effects beyond CO2, which it will be important to monitor and consider within future policies.
- Including IAS emissions in UK carbon targets increases confidence that the Government is appropriately prioritising their reduction. That should include pushing for suitably strong international levers, as well as using supplementary UK measures where these do not impact on the competitiveness of the IAS sectors.
- Inclusion of IAS emissions clarifies the requirements for policy development in other sectors (e.g. the scale of deployment needed for options to offset remaining emissions).
- There are no practical barriers to inclusion. Emissions are already estimated and reported to the UN and should be included in UK emissions targets on the same basis. The uncertainty attached to these estimates is no higher than for other sectors covered by carbon budgets.

- Inclusion can be managed through secondary legislation and without any additional costs for achieving net-zero beyond those already agreed by Parliament.

Formal inclusion of IAS emissions would help to guide long-term policy approaches and infrastructure investment decisions.

Achieving net-zero IAS emissions in the UK

The planning assumption for IAS should be to achieve net-zero emissions by 2050. This should be reflected in your forthcoming Aviation Strategy and as the Clean Maritime Plan is taken forward. It means reducing actual emissions in these sectors and is likely to require some use of greenhouse gas removals (GGRs) to offset remaining emissions:

• **Aviation.** Zero-carbon aviation is highly unlikely to be feasible by 2050.

- Aviation emissions could be reduced by around 20% from today to 2050 through improvements to fuel efficiency, some use of sustainable biofuels, and by limiting demand growth to at most 25% above current levels. This is likely to be cost-saving. There is potential to reduce emissions further with lower levels of demand.
- Novel fuels (e.g. synthetic carbon-neutral kerosene, algal biofuels) could allow greater reductions, but their development is highly speculative and should not be relied upon.
- The Government should assess its airport capacity strategy in this context. Specifically, investments will need to be demonstrated to make economic sense in a net-zero world and the transition towards it.

• **Shipping.** Achieving zero-carbon or near zero-carbon shipping by 2050 is likely to be feasible and cost-effective through use of alternative fuels (e.g. zero-carbon hydrogen or ammonia). A transition to these fuels will need to be well underway globally before 2050, with refuelling infrastructure established and a substantial fraction of the fleet already switched, in order to meet the IMO's current 2050 objective.
• **Greenhouse gas removals (GGRs).** For aviation, and to the extent that shipping emissions cannot be eliminated, measures to remove CO2 from the atmosphere will be required to offset remaining emissions. They cannot be a substitute for genuine emissions reductions.

- In the long term offsets can only be based on verifiable emissions removal from the atmosphere. These would ideally be delivered through the international framework (e.g.CORSIA), but may need additional UK policies.
- However, there will not be unlimited access to GGR offsets since their potential is constrained by global land and other resources. The focus should therefore be on highly scalable GGR options rather than those limited in scope (e.g. afforestation).

The Government can take steps towards enabling IAS to reach net-zero emissions in the UK and internationally by establishing a new market for GGRs. Such a strategy could create a significant new global export opportunity for the UK in GGR technology and expertise.

Further detail on the issues covered in this letter is set out in the accompanying annex.

Yours,

Lord Deben
Chairman, Committee on Climate Change

Appendix E – Extract from Environmental Audit Committee oral evidence, 18 May 2022

Q368

Caroline Lucas*:** Do you recognise the precautionary principle? ***Robert Courts: I do understand the precautionary principle, yes.

***Caroline Lucas*:** Sorry, I did not ask if you understood—that would be very patronising. Do you recognise it and the importance of it in this debate?

Robert Courts: I recognise it, yes. I am not saying that that is the right approach to take here, though.

Lee Rowley: Can I just follow up? We have to be careful with our choice of quotations because the Climate Change Committee—I read the independent assessment on the UK's net zero strategy before I came here today—says that demand management, or demand measures as they call them, must be explored further to minimise delivery risks. It is not that they have to be explored further as an end in itself, as could be inferred from your question. It is to minimise delivery risks elsewhere.

It is important that we are clear on what other organisations are saying if we are going to talk about it here. Then they go on to talk about there being a whole range of other benefits that could come with demand management. Fine, but that is a set of policy decisions that are taken more widely in Government. The Climate Change Committee said it is about mitigating delivery risks. I accept that—

***Caroline Lucas*:** Mitigating—

***Chair*:** Caroline, you have asked the question. Could you allow the Ministers to answer?

Lee Rowley: I accept there is a high level of risk, but we have been open and transparent about the high level of risk. My answer to the question to Ian was that we are at an early stage of development here. The fact that there is large risk is not unusual in early stages of development.

What we have to do over the next 28, 29 years is make sure that the combination of the technology options that we are putting forward—which we can talk about in more detail—plus the changes elsewhere in the aviation industry, gets us to the end point.

Appendix F – Extract from Element Energy Report on GHG removals for BEIS, October 2021

Table 1 Summary of GGR costs and scales considered across the deployment scenarios in this work

GGR Option	TRL[a]	Cost £ / tCO_2 gross		Scale Considered $MtCO_2$ gross / year	
		2030	2050	2030	2050
DACCS	6	150-700 (300)	70-250 (130)	0-1.3 (0.5)	0-30 (18)
BECCS Power	7	70-150 (120) [b]	30-170 (100) [b]	0-8 (8)	4-29 (26)
BECCS Industry	7	50-270 (100) [c]	40-300 (90) [c]	0-1 (0)	3-6.5 (3.5)
BECCS EfW	7	60-140 (70) [c]	50-110 (60) [c]	0.5-1.2 (0.6)	2.5-7.5 (5.5)
BECCS Hydrogen & Other	5	50-120 (60) [c]	30-100 (50) [c]	0-2 (1)	10-35 (22)
Wood in Construction	9	Uncertain (0) [d]	Uncertain (0) [d]	0.2-0.6 (0.4)	0.9-2.8 (1.5)
Afforestation	9	2-23 (12.5)	2-23 (12.5)	3-5 (3.73)	16-24 (18.6)
Habitat Restoration - Peat	9	26-48 (34)	26-48 (34)	0-1.5 (0.37)	0-4.6 (1.16)
Habitat Restoration - Saltmarsh	7	17-35 (23.5)	17-35 (23.5)	0-0.3 (0.08)	0-1.0 (0.23)
Soil Carbon Sequestration	8	4-20 (12)	4-20 (12)	0-12 (3.06)	0-15 (3.80)
Enhanced Weathering	4	150-900 (300)	144-865 (288)	0-1.2 (0.30)	0-18 (4.46)
Biochar	5	14-130 (72)	14-130 (72)	0-1.1 (0.34)	0-15 (4.78)

Values in brackets indicate the central estimate taken for costs and the scale deployed in the central balanced deployment scenario. Refer to the sections on individual GGRs for more information on the inclusions/exclusions from the cost methodology.

a: TRLs are stated here with reference to the most developed technological concepts within each category.

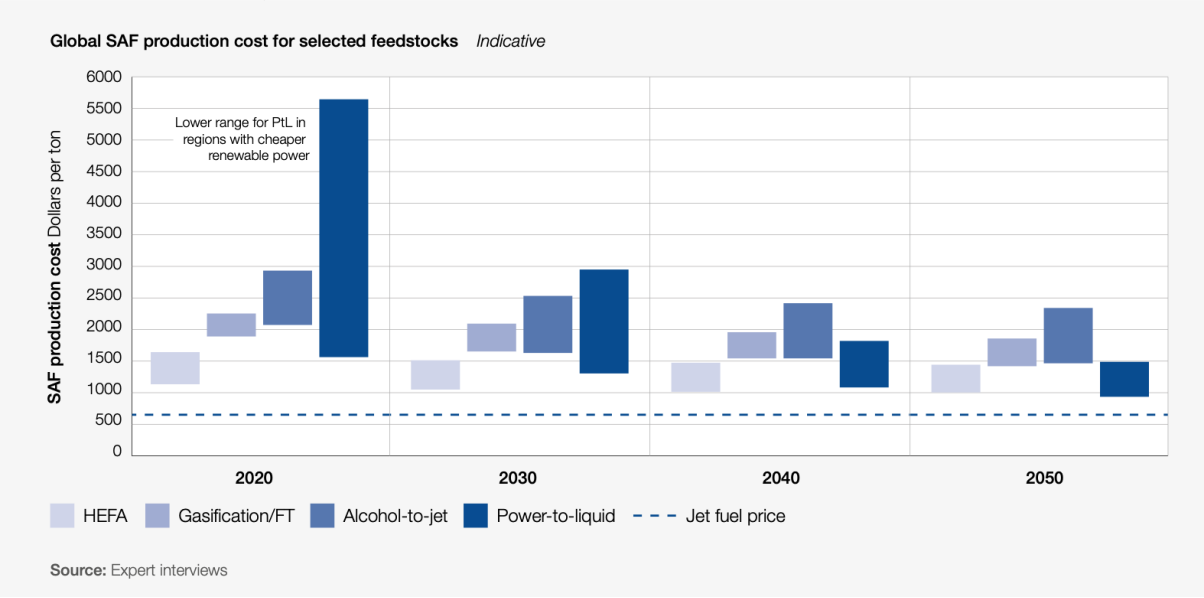
b: Additional cost of power generation compared to other low-carbon power.

c: Cost of CO_2 capture and storage (biogenic only).

d: Incentives are needed to motivate deployment, but costs may be negligible.

Appendix G – McKinsey report on pathways for sustainable aviation fuels, November 2020

FIGURE 15 **SAF production costs vary significantly by pathway**



Appendix H – Element Energy report for AEF on UK aviation decarbonisation, April 2022

Executive Summary

Reducing aviation CO_2 emissions is key to achieving the UK's climate ambitions, including reaching net zero by 2050. To mitigate against the worst effects of climate change, the Climate Change Committee (CCC) has advised a new interim target to reduce emissions by 78% in 2035 from 1990 levels. This interim target has been accepted and adopted by the Government, alongside the requirements for the 6th carbon budget which will include emissions from international aviation and shipping for the first time.

This report reviews the future emission budget for aviation within the context of other sectors to ensure aviation is contributing an achievable but fair level of emission reductions. The work considers two emissions budgets for aviation, the DfT 'Jet Zero' High Ambition aviation scenario (as amended by the technical consultation published by DfT on 21st March 2022) and a new more demanding pathway where aviation delivers emissions reductions more quickly.

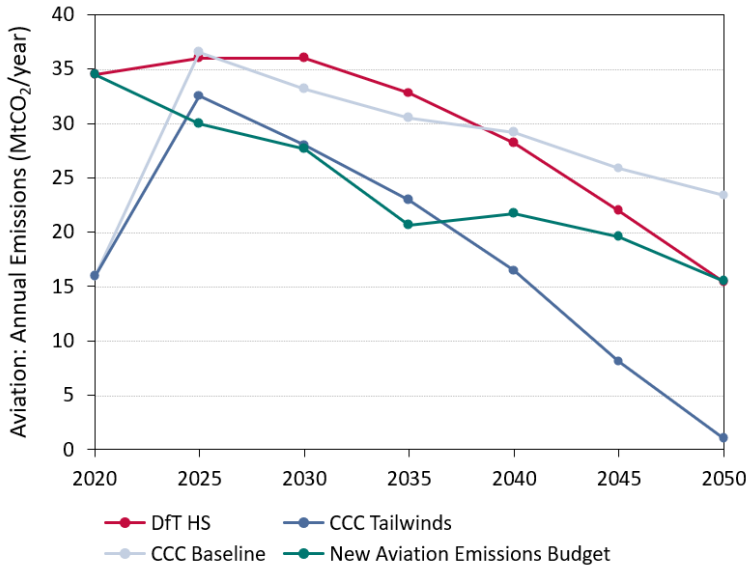
For each scenario the project assesses the range of technological and behavioural changes needed to decarbonise and the risks of relying on any single solution too heavily. The study concludes that targeted aviation demand reduction is required to minimise the risk of missing economy-wide emission reduction targets and that aviation demand reduction is needed to meet the DfT High Ambition scenario and our more ambitious pathway.

Aviation emission scenarios

Figure 1 summarises the emissions budget for aviation for the DfT High Ambition scenario, the Climate Change Committee (CCC) Baseline and Tailwind scenarios and a new Element Energy scenario. The new Element Energy scenario has been designed to demonstrate what a more ambitious behaviour change and lower technology risk scenario could look like. It aims to show that DfT could be far more ambitious in the short term, ensuring aviation does a fairer share of emission reductions this decade. The new scenario starts with the DfT baseline emission growth trajectory and reduces emissions with the following assumptions: SAF at 10% in 2030, rising to 30% in 2050 and corrected for only 60% lifecycle emission savings, no zero-emission planes, a more conservative average annual efficiency improvement of 1.5%/year, and demand reduction similar to the level set out in the CCC tailwinds scenario. The rationale for these assumptions is set out in Chapter 3.

While this new scenario reaches similar annual emissions in 2050 to the DfT High Ambition scenario it delivers emission reductions much faster. The scenarios differ by 12MtCO2 in 2035, meaning the new scenario has much lower cumulative emissions and a much smaller impact on global warming. Overall, the DfT High Ambition scenario (HS) is estimated to result in unabated emissions between 2020 and 2050 of 900MtCO2. This drops in the Element Energy scenario to 720 MtCO2, a saving of 20%. Combined with the fact that the new scenario is lower risk and more equitable we see this as the best pathway for aviation to follow.

Figure 1: Current aviation emission pathways from DfT and CCC compared to new Element Energy pathway



Great ambition for aviation decarbonisation is urgently needed

While the UK has a net zero target in 2050, the 2035 emissions target is as important, both because it will help to limit cumulative emissions and because it helps to ensure that all sectors are on the right trajectory towards net zero. Due to the minimal progress in decarbonising key sectors such as buildings and an overreliance on emerging carbon removal technologies, the UK faces a serious risk of missing the CCC's 6th carbon budget by 15-20MtCO2 in 2035.

Removal technologies represent a significant risk to any strategy, meaning they should only be deployed once both technological and behaviour change options to reduce emissions have been exhausted. By 2050 the CCC assumes 58MtCO$_2$ removal technology has been deployed. This exactly matches the 58MtCO$_2$ emissions remaining from the aviation and agricultural sectors, the only high emitting sectors left at this stage. This shows that the enormous effort and cost the CCC and BEIS assume we will pay in order to deliver CCS is largely to support the status quo in these two sectors at which point the cost effectiveness of such a solution has to be questioned.

The CCC already assumes high uptake of technology in its Balanced Scenario and relying on additional technology fixes to fill this gap would simply exchange one technology risk for another. Behaviour change is urgently needed to mitigate this emissions gap. EE analysis suggests that the emissions gap in 2035 could be met through targeted behaviour change in reduced meat and dairy consumption, reduced flying and reduced private road transport.

Aviation is one of only two sectors expected to still have residual emissions in 2050, with very high cost carbon removals required to mitigate this. Aviation demand is forecast to increase by over 70% between 2018 and 2050 in the DfT's Jet Zero High Ambition scenario. Even with optimistic carbon pricing, DfT forecasts the average price of a flight will fall in the near term, with average international fares not expected to exceed the price of a ticket in 2020 levels until 2039. Given that flying is a privilege disproportionately accessed by high income groups and the UK is not on track to meet its climate targets, it is questionable whether this generous treatment of the sector is compatible with the UKs legal requirement to tackle emissions.

There are significant risks in the DfT High ambition scenario

As summarised in Figure 2, the DfT's High Ambition scenario is over-reliant on emerging high-risk technologiesanduncertainpolicyintheforecastingoftheemissionabatementsin2035.Keyriskfactors include:

- **System efficiencies:** A slow-down in aircraft manufacturer R&D spend, in part due to the ongoing Covid impact, means that it is unlikely that system efficiency improvements will achieve a step-change growth to 2.0% annually from beyond well-established historic levels of 1.5%.
- **SAF uptake levels:** There is currently negligible SAF production in the UK, and large public investment would be required to achieve the higher levels of SAF demand required by 2035 to meet DfT High Ambition scenarios, with imports uncertain due to competition created by high EU and global demand.
- **SAF emissions abatement:** SAFs are assumed to provide 100% emissions saving for aviation (as production emission are assumed to be accounted for under fuels), despite the UK SAF mandate aiming for well-to-wake emissions saving of only 60% as a minimum requirement and the fact that emissions from imported fuels are not counted in this method. This provides a misleading portrayal of SAF emissions abatements and the total emissions from the aviation sector.
- **Non-CO2 impact:** The exclusion of non-CO2 aviation effects means that the DfT pathways are substantially underestimating the warming impact of aviation emissions. The DfT currently excludes non-CO2 emissions as they feel scientific understanding is lacking but this is unlikely to be the case by 2035 when it could be included in the modelling. This presents a major risk that the aviation emission budget could suddenly become much more challenging to reduce with limited time to respond with new technology solutions.
- **CORSIA carbon pricing:** substantial emission abatement in 2050 relies on CORSIA carbon pricing on long haul flights reaching ETS levels. The future of CORSIA is highly uncertain and it's unlikely that the price of eligible offsets sourced from the voluntary carbon markets will reach parity with the capped and regulated carbon markets (UK ETS). UK long haul routes, which make up around 72% of total UK aviation emissions, are effectively unpriced in the short to medium term.

ETS free allowances: In 2021, the total free allowances under the UK ETS represented just over 4.3 Mt/CO2e for aviation alone. This represents at least 41% of total emissions of the estimated in-scope carbon emissions covered under the ETS. While this free allowance is projected to decrease by an average of 2.1% a year between 2021-25, this is significantly less than the 4.1% annual decrease under the comparative EU ETS, with the EU Commission proposing to completely remove free allowances by 2027.

Figure 2: overall risk assessment of DfT High Ambition scenarios in 2035

Overall, it is unclear how DfT plans to deliver these high rates of technological improvements, SAF uptake and aircraft efficiencies. Expanding carbon pricing, with EE estimations suggesting that only about 17% of total aviation emissions are currently priced, would also be essential to support the rapid uptake of new technologies by airlines but would rely on breakthroughs at ICAO in terms of the level of ambition in CORSIA and future arrangements for a market-based measure after 2035.

Calculating the emissions gap

Taking the uncertainties in technology readiness into account EE has assessed whether the likely emission reductions from in-sector measures are sufficient to meet the DfT's High Ambition scenario and EE's new aviation emissions budget. For the High Ambition scenario, the results show there is an emissions gap of at least 2Mt/CO2 in 2035 rising to 14MtCO2 in 2050 if more achievable technology assumptions are used (see Figure 3). However, when measured against EE's new aviation budget scenario, the gap is estimated to be16Mtin2035and24Mtin2050(seeFigure4). The large disparity in the respective 2035 values is due to the DfT High Ambition scenario targeting only limited emission reductions by 2035, relying on residual emissions to be abated through other sectors.

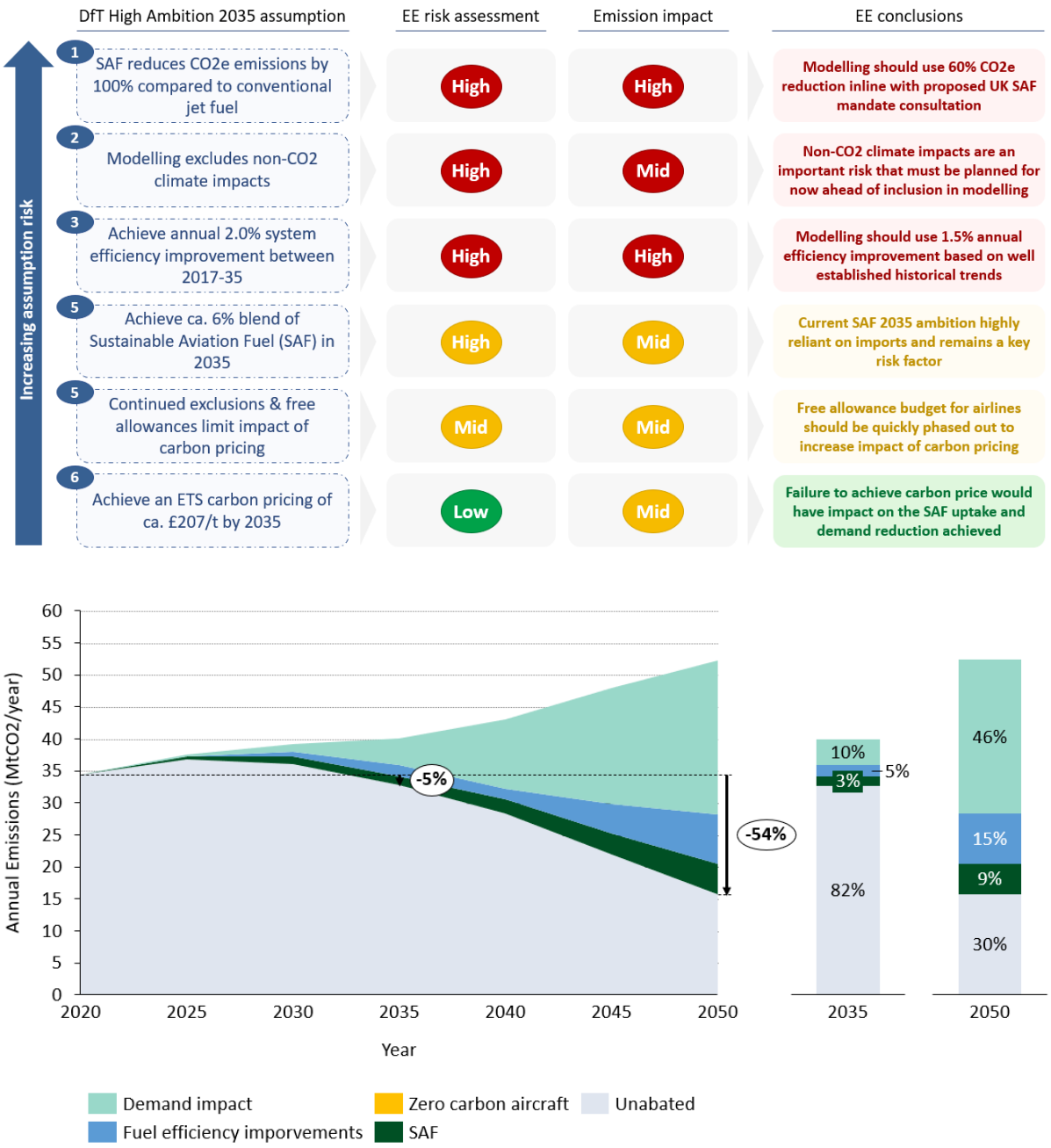


Figure 3: DfT High Ambition scenario with reduced risk technology rollout, emission reduction breakdown

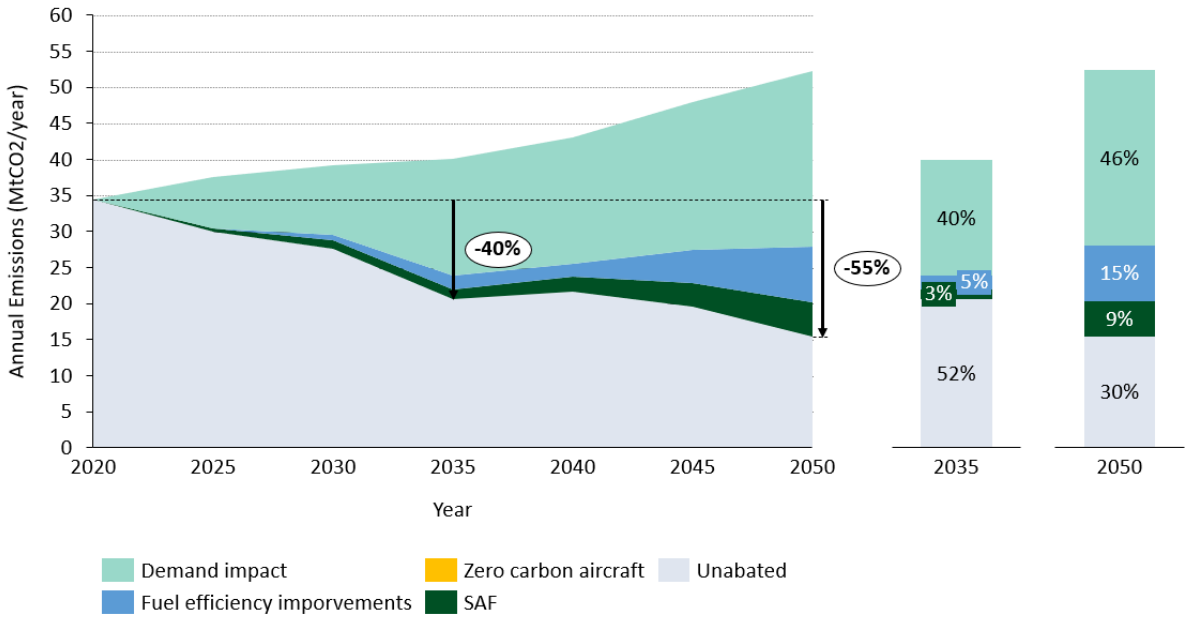
Figure 4: Element Energy fair aviation emission budget with reduced risk technology rollout, emission reduction breakdown

Demand reduction measures are necessary for a pathway to fair decarbonisation

Based on this analysis, the current approach set out by DfT through their High Ambition scenarios opts to rely on long term and uncertain technological solutions, with substantial abatement requirement through other sectors in the short term, rather than introduce policy to reduce aviation demand.

Demand management policies could take several forms, reducing passenger demand for flying through carbon pricing, an air miles or frequent flyer levy, fuel duty, VAT or reforms to Air Passenger

Duty, and/or restricting the availability of flights through management of airport capacity. Additional non-financial behaviour change interventions could include improved marketing of domestic tourism opportunities and consumer information about the CO2 impacts of flights.



Next steps for government include expanding carbon pricing to impact international long-haul flights and rapidly reducing the free allowances of emissions under the UK ETS. The Government should also urgently review its policy on airport capacity expansion, as any increase in capacity limits the UK's ability to manage long-term aviation demand. Constraining demand now through airport capacity is far easier and more reliable than allowing capacity and demand to grow and then rapidly trying to reduce demand in the future through pricing mechanisms. We conclude that there should be no airport expansion until and unless it is clear that both in-sector (aircraft technology) and out-of-sector (carbon removal) emissions reductions are on track to meet a fair emissions reduction for 2035 and beyond.

Appendix I – Extract from Brazzola et al, Nature, August 2022

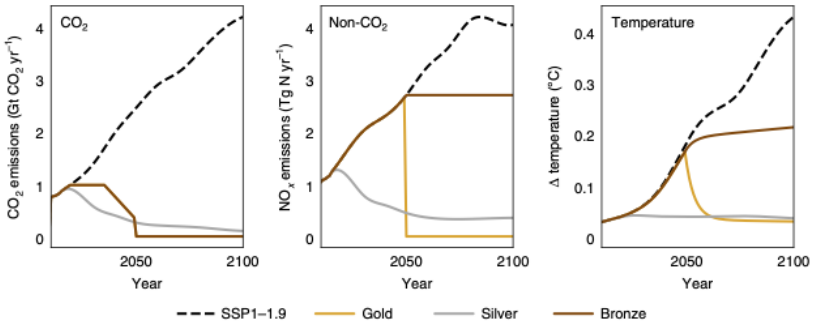


Fig. 3 | Schematics of the three plausible definitions of climate-neutral emissions identified in this study. Below the three definitions, we show the time series of CO_2 emissions (left), non-CO_2 emissions (using NO_x as explanatory example, centre) and the resulting temperature outcome of the different climate neutrality definitions (right). At the onset of climate neutrality, under the Gold definition, all aviation emissions reach net zero. Under the Silver definition, emissions follow SSP1-1.9. Under Bronze, CO_2 emissions are eliminated while non-CO_2 emissions are stabilized. Before 2050, emissions follow the ICAO's mid-century targets (Methods) in all but the Silver definition. The dashed line shows the emission and temperature trajectory in the SSP5–8.5 scenario (an intermediate socioeconomic scenario) for the case in which no climate neutrality framework is introduced.

currently account for 67% of aviation's total historical ERF (38–77% when considering the whole uncertainty range)[14], their future contribution could substantially change. The non-CO_2 term is largely dominated by the ERF of contrail cirrus, followed by the short-term O_3 increase caused by NO_x emissions. Under the *Fossil jet fuels* scenarios, CO_2 emissions are only partially mitigated (for example, via energy efficiency and CO_2 intensity reductions) and thus their ERF continues increasing. For contrail cirrus and other short-term forcing, the growth trajectory of emissions determines whether short-term forcing decreases in the second half of the century (as in SSP1–2.6) or continues increasing (as in SSP5–8.5). Under assumptions of undisturbed sectorial growth as in SSP5–8.5, the share of ERF due to CO_2 decreases from the observed 38% (27–67%) in 2018 to 26% (18–52%) in 2100, while the contribution of contrail cirrus rises from 58% (30–69%) to 71% (42–81%). In SSP1–2.6, the non-CO_2 ERF terms peak at 79% (53–86%) before 2060 and shrink to 61% (31–73%) by 2100 because of decreasing emissions.

A rapid transition to cleaner-flying technologies changes the breakdown of ERF by aviation species. For instance, the 100% transition to zero-carbon fuels by 2050 in the *Zero-CO_2 fuels* scenario eliminates CO_2 emissions, stabilizing the ERF of CO_2. As a result, the relative contribution of non-CO_2 effects to the total ERF increases, despite zero-carbon fuels partially mitigating some of these effects. Consequentially, by 2100 CO_2 contributes only 13% (8–36%) to the total aviation ERF under SSP5–8.5, while contrail cirrus contributes 78% (39–86%). While in this scenario, the short-term increase in O_3—an indirect effect of NO_x emissions—seems to play a prominent role, it is almost completely compensated by NO_x cooling effects.

In the exploratory *No-emissions aircraft* scenario, about a quarter of the flights are emissions free by 2050 and all of them by 2080, eliminating all short-term ERF contributions and lowering the total ERF by the end of the century. Only a rapid shift to no-emissions aviation would thus justify the current standard of excluding non-CO_2 effects from mitigation efforts[7–9,32]. Yet such a transition relies on very optimistic assumptions about technology development and diffusion that might well not materialize. For this reason, aviation's non-CO_2 forcing should be addressed through climate neutrality targets.

Definitions of climate neutrality

We identify three plausible baselines and formalize three corresponding definitions of climate-neutral aviation (Fig. 3). Our definitions include the complexities arising from the short-lived effects of aviation, particularly the fact that climate-neutral aviation does not require all aviation emissions to reach net zero to stabilize ERF[19,33]. Instead, climate-neutral aviation depends on the specific ERF baseline relative to which the climate is stabilized.

The most ambitious and stringent baseline, which we label *Gold*, considers aviation to be climate neutral compared with a world without aviation emissions. After the onset date of climate neutrality (2050), all aviation climate effects must be down to net zero. The complete elimination of short-lived aviation species from the atmosphere, such as short-lived greenhouse gases and aerosols, leads to the neutralization of short-term indirect effects, too, thus reducing forcing and ultimately temperatures relative to 2050 levels.

The second baseline, which we label *Silver*, considers the climate to be neutral relative to a world on a 1.5 °C trajectory, which is achieved by limiting aviation forcing to that in the SSP1–1.9 scenario. This causes about 0.04 °C warming by 2100, which we refer to as the 1.5 °C-compatible contribution of aviation.

The third baseline, which we label *Bronze*, considers aviation to be climate neutral compared with its contribution at the onset date of climate neutrality (2050) by stabilizing aviation forcing after 2050 owing to a balance between sources and sinks of aviation emissions. To do so, all long-lived emissions need to be net zero, while short-lived forcing must stabilize at the levels reached at the onset date of climate neutrality, allowing for offsets between the two.

Impacts of different definitions of climate neutrality

To assess the Gold, Silver and Bronze definitions of climate neutrality, we model their CO_2 removal requirements and absolute temperature changes using empirical sensitivity parameters, the GWP* metric and a reduced-complexity climate model, FaIR (as detailed in Fig. 1 and Methods). Without further efforts to mitigate emissions, the projected growth in aviation causes 0.10 ± 0.05 °C of warming under SSP1–2.6 and 0.44 ± 0.22 °C of warming under SSP5–8.5 in 2100, as shown in Fig. 4 for the *Fossil jet fuels* scenario. This temperature increase is roughly one order of magnitude larger than the 0.04 °C temperature increase from aviation in the 1.5 °C-compatible SSP1–1.9 scenario (Fig. 4, '1.5 °C compatible' dashed line). Given that global mean temperature has consistently been more than 1 °C warmer than the pre-industrial mean since 2014, these additional temperature increases alone would lock in about 1.5 °C global warming.

Setting a carbon neutrality target—that is, offsetting via CO_2 removal all aviation CO_2 emissions that remain after demand reductions and technological improvements—mitigates up to only 20% (14–41%) of the warming due to the aviation sector.

Appendix J - Extract from Greenhouse gas reporting: conversion factors 2020, BEIS, June 2020 (updated July 2020)

"Guidance

● Emissions from aviation have both direct (CO_2 , CH_4 and N_2O) and indirect (non-CO_2 emissions e.g. water vapour, contrails, NOx) climate change effects. Two sets of emission factors are presented here; one that includes the indirect effects of non-CO_2 emissions and one that represents direct effects only.

● Organisations should include the indirect effects of non-CO_2 emissions when reporting air travel emissions to capture the full climate impact of their travel. However, it should be noted that there is significant scientific uncertainty around the magnitude of the indirect effect of non-CO_2 aviation emissions and it is an active area of research. Further information can be found in paragraphs 8.37-8.41 in the Methodology Paper.

● Organisations should produce comparable reporting. Therefore, they should avoid reporting emissions including indirect effects of non-CO_2 emissions in one year and direct effects only in another year as this may skew the interpretation of their reporting.

FAQ: My organisation has previously reported using factors for direct effects of CO_2, CH_4 and N_2O emissions only, what should I do?

Users should generally use the 'including indirect effects of non-CO_2 emissions' factors, which incorporate a 90% increase in CO_2 emissions to approximate the indirect impact of non-CO_2 emissions from aviation (such as water vapour, contrails and NOx). If the user's historical data do not include these indirect effects, then they should rebaseline their historical dataset to include the effect going forward. However, users should be aware of the significant scientific uncertainty surrounding the quantification of these impacts. If organisations do not wish to include the indirect effects, then they should continue to select the 'Direct effects from CO_2, CH_4 and N_2O emissions only' factors."

Appendix K – BBC News article, January 2020

Luton Borough Council declares 'climate emergency'

- Published 14 January 2020

IMAGE SOURCE, GETTY IMAGES

Image caption,
Luton Borough Council has been "working alongside" Extinction Rebellion in a bid to become carbon neutral by 2040

A town has declared a climate emergency and activated a plan to become carbon neutral by 2040.

Luton Borough Council hopes to cut carbon emissions from homes and cars as well as London Luton Airport.

Labour councillor Tom Shaw, portfolio holder for the environment, said the council could charge cars for driving into the town centre.

Mr Shaw said the council had been "working alongside" Extinction Rebellion in compiling the plan. "The airport has been told that by 2040 they've got to be carbon neutral and we expect them to come up with their own plan," he said.

IMAGE SOURCE, LONDON LUTON AIRPORT
Image caption,
London Luton Airport will be expected to become carbon neutral by 2040

At a meeting on Monday, councillors agreed to spend £200,000 a year for the next five years on improving insulation in council-owned properties.

The council will also aim to develop "more cycle tracks" and "encourage kids to get on their bikes going to school". Mr Shaw said the council was looking at setting up its own bus company to implement routes which are not provided by other bus companies.
A "workplace driving scheme", which would charge cars driving into the town, could fund the new bus company, Mr Shaw said.

"Where there's hundreds of cars coming into one place we can say we want £2 per car a week off you to pay for this bus company," he said. Mr Shaw said the climate change activist movement Extinction Rebellion had attended several meetings about the "action plan".

"We have had Extinction Rebellion working alongside us preparing the plan and they are going to be a part of future plans when we look at how we can save energy in schools," he said.

Appendix L – Extract from Appeal Decision, Selbrigg Farm, October 2019

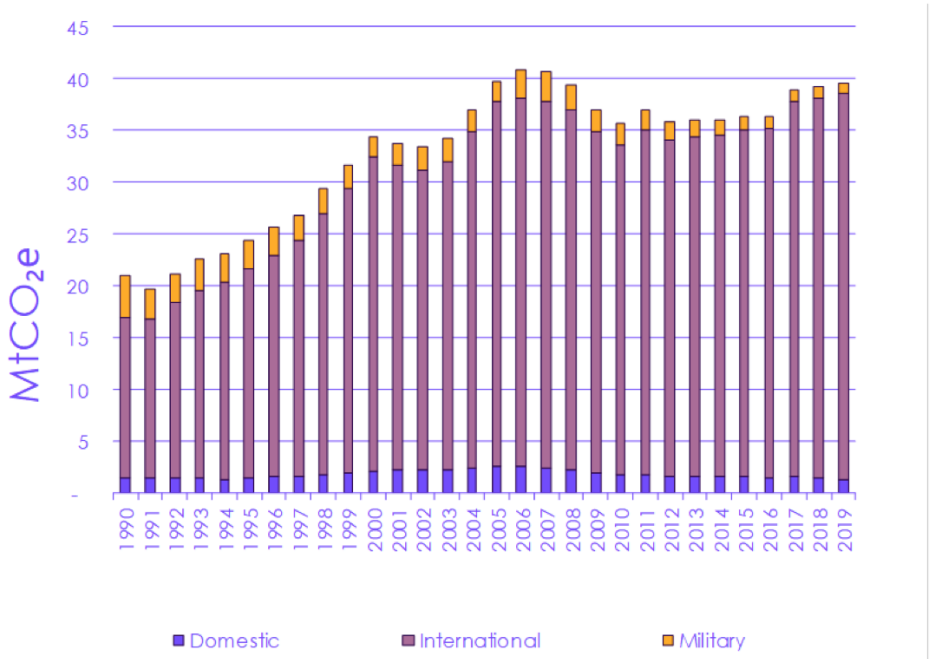
87. There have been other important developments too, since the latest version of the Framework was published in February 2019. Presaging the decision of the UK Parliament to do so on 1 May 2019, North Norfolk District Council agreed a motion declaring a climate emergency on 24 April 2019.

88. With the motion, the Council acknowledged: the devastating impacts that climate change and global temperature increases will have on the lives and livelihoods of people around the world, including on the health, safety and wellbeing of North Norfolk residents; the urgent need for action to be taken fast enough for there to be a chance of further climate change being limited to avoid the worst impacts of drought, floods, and extreme heat; the opportunity for individuals and organisations at all levels to take action on reducing carbon emissions, from both production and consumption; the need to enable low carbon living across society through changes to laws, taxation, infrastructure, policies and plans; and the Council's responsibility to help secure an environmentally sustainable future for residents and in relation to the global effects of climate change.

89. The Council has already supported many policy compliant renewable energy schemes onshore and is playing an active part in Nationally Significant Infrastructure Projects. That is laudable but in light of the matters the Council acknowledged in declaring a climate emergency, it would be something of a contradiction to resist further policy-compliant schemes in the District. The proposal at issue here readily complies with the Council's policy on renewable energy – a policy that was itself arrived at through an open process in which residents of the District had the opportunity to participate in.

Appendix M – Extract from CCC's Sixth Carbon Budget: aviation sector summary, December 2020

Figure M8.2 Breakdown of aviation sector emissions (1990-2019)



Source: BEIS (2020) *Final UK greenhouse gas emissions national statistics 2018*; BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; BEIS (2020) *Energy Trends*; CCC estimates for 2019.

Table M8.1
Aviation scenario composition

	Passenger demand growth by 2050 from 2018 levels	Average efficiency improvement 2018-2050 (%/year)	Use of biomass FT jet (TWh, % of liquid fuel demand in 2050)	Use of HEFA biojet (TWh, % of liquid fuel demand in 2050)	Use of bio-waste FT jet (TWh, % of liquid fuel demand in 2050)	Use of synthetic jet (TWh, % of liquid fuel demand in 2050)	Use of fossil jet (TWh, % of liquid fuel demand in 2050)
Balanced Net Zero Pathway	**+25%, with no net expansion**	**+1.4%**	**14 (11%)**	**8 (6%)**	**-**	**10 (8%)**	**94 (75%)**
Headwinds	+25%, with expansion	+1.4%	14 (11%)	11 (9%)	-	-	101 (80%)
Widespread Engagement	-15%, no expansion	+1.6%	14 (16%)	4 (4%)	5 (5%)	-	61 (74%)
Widespread Innovation	+50%, with expansion	+2.1%	23 (19%)	9 (7%)	-	30 (25%)	58 (49%)
Tailwinds	-15%, no expansion	+2.1%	23 (33%)	12 (18%)	-	30 (44%)	4 (5%)
Baseline	+64%, with expansion	+0.7%	-	-	-	-	205 (100%)