**Green Alliance policy insight**
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# The flight path to net zero

## Making the most of nature-based carbon offsetting by airlines

# Summary

Aviation presents a serious challenge to the ability of the world to limit global heating to 1.5°C and of the UK to achieve its net zero carbon obligation. Unlike most other sectors of the economy, aviation's emissions are projected to increase globally, and there is significant uncertainty about whether technology for zero carbon long haul flights will be commercially available by 2050.

Short of stopping long haul flying all together, it is unlikely that aviation will achieve zero emissions by 2050. This means any remaining emissions will need to be offset by equivalent removal and storage of $CO_2$ from the atmosphere to meet net zero. This can be done with natural sinks, like forests and soils, or via technologies like bioenergy with carbon capture and storage (BECCS) or direct air carbon capture and storage (DACCS).

**The potential of offsetting**

There has been significant interest from the aviation industry in the potential of carbon offsetting to help reduce its impact on the climate. UK airlines have announced plans to offset their emissions and there is an international agreement, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), to offset growth in emissions between 2020 and 2035. This scheme is estimated to raise between £4 billion and £18 billion per year from airlines by 2035.

It will be important to make the best use of this investment. However, offsets have a bad track record: at least 73 per cent of Clean Development Mechanism (CDM) offsets are unlikely to deliver the emissions reductions claimed. As CORSIA will only offset emissions above a 2020 baseline up to 2035, even if they are reliable, there will be no overall reduction in net emissions between 2020 and 2035, and there are no solid plans for emissions after this. In its current form CORSIA is incompatible with both global and UK climate targets.

## Avoiding the risks of offset failure

While ambition and action to reduce aviation emissions needs to increase, income from selling offsets to airlines could be a source of significant funding to scale up natural climate solutions, like tree planting and peat restoration. There are two major problems with selling UK nature-based offsets to airlines, but we believe these can be mitigated.

First, there is evidence that the ability to purchase offsets can lead to less effort being made to reduce actual emissions, while the physics of climate change means that both rapid reductions in emissions and rapid increases in carbon removals will be required.

Second, because natural climate solutions are cheap and can be procured into the future, simply allowing the aviation sector to buy the bulk of cheap removal credits now means that sectors like agriculture or the public will have to pick up the bill for more expensive removals (like BECCS and DACCS) as they are developed.

To limit these risks and take advantage of this new stream of funding for nature, we propose that the government should create a new 'office for carbon removal' to regulate the industry. Amongst other actions, this body should, as a priority:

**Set two separate targets: one for emissions reduction and one for carbon removals.** This will ensure that maximum effort is made to bring emissions down to a level that can be met by equivalent removals, shared fairly across sectors. The 'office for carbon removal' would be charged with managing and overseeing the fair allocation of greenhouse gas removal capacity across all sectors of the economy that need it.

**Release only a limited number of UK carbon credits for sale to airlines through CORSIA**, and end the sale of nature-based carbon credits to airlines altogether by 2035. The initial cap should be set by the 'office for carbon removal'. This would provide a significant boost to the carbon credit market, but leave additional sequestration after 2035 available for sectors like agriculture to reach net zero. So that farmers can take full advantage of the new funding, the government should develop a new Farm and Soil Carbon Code, based on the model of the existing Woodland Carbon Code. This would expand the scope for quality checked and marketable services for plant and soil carbon sequestration in the UK.

The government should also factor in the UK's share of international aviation emissions to its domestic net zero obligation, and secure an international agreement to reduce global aviation emissions, in line with the Paris climate agreement goal to limit global heating to 1.5°C.

Once the two risks of offsetting are addressed, there will be considerable advantages in the approach we describe: it will fund vital carbon removals in parallel with action to reduce emissions, and it will allow high standard providers of carbon removals to show what a good carbon credit looks like. This will set a quality benchmark for other CORSIA participants, and help to build an exemplary carbon removal industry in the UK, which will be necessary to comply with the net zero law.

# Introduction

"It is likely that airlines will invest between £4 billion and £18 billion per year in offsets between now and 2035."

As the world makes the transition to a low carbon economy, international aviation is likely to be responsible for an increasing share of the carbon emissions left. It is a rapidly growing sector, with passenger numbers expected to double over the next twenty years.[1] And, unlike other sectors, new technologies and fuels are unlikely to replace fossil fuel entirely for aviation before 2050.

The Intergovernmental Panel on Climate Change's (IPCC's) *Global warming of 1.5°C* report showed that radical emissions reductions are needed to avoid the worst effects of climate change. To have a 50 per cent chance of keeping global heating to within 1.5 °C above pre-industrial levels, the global economy must reach net zero emissions around the middle of the century.

To reach net zero, all aviation emissions will have to be fully offset by the removal and storage of $CO_2$ from the atmosphere. At present the main way to do this is through natural sequestration by trees and soils. In the future, it is expected that new technologies, most notably bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS), will be deployed at a much larger scale. However, these are limited by the availability of land and other resources, and their cost and potential scale is still unclear. As endless carbon offsetting is also not possible, it is vital that the aviation industry achieves rapid and deep reductions in its overall emissions.

The international aviation sector has negotiated an agreement to offset the growth in its emissions between 2020 and 2035. This initiative is called the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

After 2035, the sector aims to halve emissions by 2050. No details have been given about how it will be achieved and this level of ambition is still not compatible with limiting heating to 1.5°C or with the UK's net zero target. Further action at a domestic and international level is needed to reduce emissions and reach net zero by 2050.

However, through CORSIA, it is likely that airlines will invest between £4 billion and £18 billion per year in offsets between now and 2035.[2] It is vital that this money is invested in offsets that are real, accurately measured and sufficient to contribute towards reaching net zero.

We convened a series of workshops to explore the potential to direct some of this new funding towards natural climate solutions in the UK. These concluded that it could have multiple environmental benefits, in addition to carbon sequestration, but that there are also significant risks and challenges which we discuss in this report.

We make recommendations for how the UK can make the most of aviation offset funding to meet domestic environmental goals, and ensure that aviation emissions are brought down to a level that can be sustainably met by carbon removals to reach net zero. We outline the role that high quality nature-based offsetting could play in the short term, while more scalable greenhouse gas removal techniques are developed, and then we analyse what else needs to happen to decarbonise the aviation sector by 2050.

# The potential of natural climate solutions

"A significant new stream of funding for offsets from the aviation sector could speed up nature restoration."

Natural climate solutions are measures which depend on plants absorbing carbon dioxide from the atmosphere and then storing it, also known as sequestration, either within the plants or in the soil. In this report we consider three major types of carbon sequestration: tree planting, peat restoration and building up organic carbon in agricultural soils. These can be measured and turned into carbon credits which can be purchased to offset emissions.

The international aviation sector will invest significantly in offsetting between 2020 and 2035. As well as CORSIA offsetting, some airlines have recently announced plans to go further and offset emissions outside the scope of the scheme. For example, IAG, the owner of British Airways, has announced that it has a target to achieve net zero by 2050 and will start by offsetting all British Airways domestic flights from 2020.[3] Easyjet has also announced that it will purchase offsets for the fuel used on all its flights.[4]

UK based nature restoration projects could use this new funding from aviation offsetting to achieve the goals of England's 25 year environment plan. To mitigate climate change and reverse nature's decline it is estimated that tree planting rates in the UK will have to increase by a factor of five; between 50 and 75 per cent of peatland needs to be restored; and agricultural practices need to change so they also protect water, soil health, wildlife and reduce impacts on climate change.

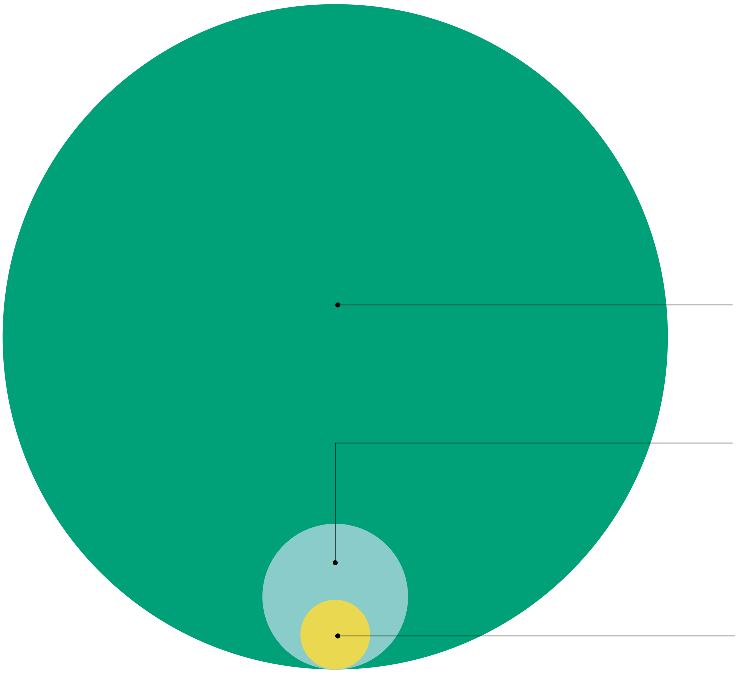
Funding for the environment is expected to increase with the introduction of a new Environmental Land Management system (ELMS), which will be based on the principle of 'public money for public goods'. But, as the 25 year environment plan makes clear, additional private funding will also be necessary to achieve all the ambitions it sets out.

Selling credits from schemes like the UK's Woodland Carbon Code is one way to do this. This standard was set up by the UK government to enable landowners to earn extra income for planting woodland through the sale of verified carbon credits. However, the market is voluntary, relying on businesses that choose to offset their emissions for ethical or reputational reasons. Since it started in 2011, the Woodland Carbon Code has resulted in modest amounts of tree planting.[5] The newer Peatland Code, modelled on the Woodland Carbon Code, validated its first project in 2017, and has several projects under development.

A significant new stream of funding for offsets from the aviation sector could amplify these markets and speed up nature restoration. Compared to current levels of funding, even a small investment from the aviation sector would make a big difference to the UK's carbon market. The total estimated lifetime sequestration of projects validated under the Woodland Carbon Code between 2012 and 2018 was 2.5 $MtCO_2e$, and projects can have timescales up to 100 years. Assuming an average project lifetime of 25 years, this represents an average 0.1 $MtCO_2e$ sequestered per year. Using data from the Committee on Climate Change and the Royal Society, we estimate that new woodland and soil improvements could sequester around 8.7 $MtCO_2e$ per year by 2030.[6] Even if aviation only paid for five per cent of this available capacity, there would be a fourfold increase in delivery compared to what the voluntary market in the UK has achieved so far (illustrated on page six).

"A new boosted market for carbon credits from aviation is an opportunity to create new carbon sinks on farms."

**Even a small proportion of aviation offsetting would be a big boost to the UK's natural carbon market** [7]




However, aviation's demand for credits will be much higher than this which raises a question about how much natural sequestration capacity the sector should be allowed to take compared to other sectors which will also need to offset. We explore this further below.

From a funding perspective, the government has committed to buying £50 million worth of carbon credits from Woodland Carbon Code projects over 30 years, at an average of £1.7 million per year. However, at a carbon price of £10 per tonne, the total value of additional UK nature-based sequestration per year in 2030 would be £87 million a year, suggesting considerable scope for private funding for offsets to boost delivery. [8]

A new boosted market for carbon credits from aviation is an opportunity to create new carbon sinks on farms, alongside food production. The current Woodland Carbon Code and Peatland Code are not applicable to many activities on working farms which could also sequester carbon, such as small scale tree planting, agroforestry (integrating trees amongst crops or livestock), increasing hedgerows or building up organic carbon in soils. Farmers in the UK are already experimenting with these methods. A new Farm and Soil Carbon Code could enable them to access new income streams for 'carbon farming'. We discuss this in more detail on pages 14-17.

Nature-based projects have two advantages over other types of offset, such as renewable energy or reducing the release of landfill methane. First, they offer direct carbon removal, rather than just a reduction or avoidance of emissions in another sector, so they can help to reach net zero. Peat restoration is an exception to this, where the vast majority of the benefit would be in stopping the degradation of peat and the emissions that causes. Second, if done well, they have significant other benefits for communities and the wider environment, including better water quality, flood risk management and providing habitats for more wildlife (see pages 15 and 17).

# Reducing the risks of offsetting

"Most scenarios which limit global heating to 1.5$^{O}$C already rely on carbon removals as well as deep emissions cuts."

The role of offsetting in keeping global heating to 1.5$^{O}$C is highly contested. It is true that previous offsetting schemes have failed to create genuine credits, and that paying for reductions in, or avoidance of, emissions in other sectors is not sufficient to reach a net zero target. But there are two good reasons to consider it and the role it could play. First, it is almost certain that the CORSIA offsetting scheme will go ahead from 2020 regardless, and so it makes sense to use the subsequent investment it offers to the environment in the most worthwhile way. Second, globally and in the UK there is a need to develop capacity fast to remove and store carbon from the atmosphere, to offset any emissions that cannot be eradicated by 2050. The expansion of aviation offsetting is an early opportunity to direct more money towards this goal. Nevertheless, there are significant problems with CORSIA as it stands, and there will be risks for the UK in selling its domestic carbon credits to international airlines. Below, we describe the three major challenges of offsetting through schemes like CORSIA and how to address them:

## 1. Reliance on offsetting could delay emission reduction

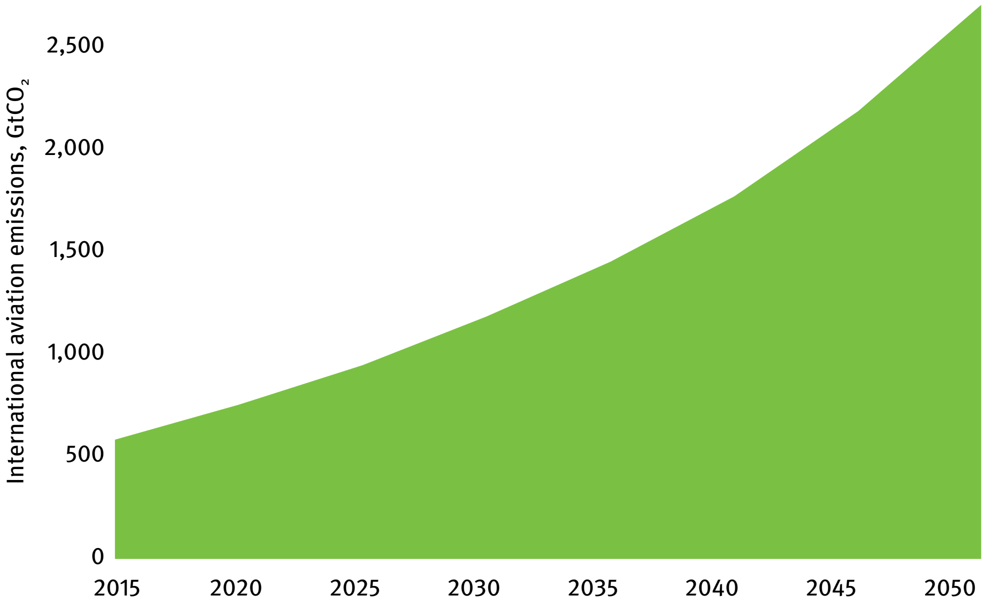
Offsetting's role in limiting global temperature rises is far from straightforward. A major challenge with proposed schemes, including CORSIA, is that they allow actual emissions to continue to rise. This is a climate risk, because it enables lock-in to high carbon infrastructure far into the future, while the capacity to offset emissions with carbon removals is limited by the availability of land and energy, resources which are already under severe pressure.

It is tempting for businesses to assume that they will be able to continue with significant levels of emissions because they can simply offset them. But this is a mistaken assumption, as most scenarios which limit global heating to 1.5$^{O}$C already rely on carbon removals as well as deep emissions cuts. Foregoing deep emissions cuts on the basis that net zero can be reached with carbon removals will, in turn, require even more carbon removal capacity. Afforestation and soil carbon sequestration are important, but they are limited in their potential scale, while carbon removal technologies such as bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS) are expected to be high cost and are, so far, unproven.

The graph overleaf shows how global emissions from international flights, not including domestic flights, are expected to grow if further action is not taken to reduce emissions. If reliance on offsets allows this emissions growth to happen then international aviation alone would use up nearly a third (32 per cent) of estimated global carbon removal capacity in 2050.[9] This is a large proportion for a sector which directly contributes just one per cent of global GDP, and indirectly supports 3.6 per cent.[10]

"Most offset projects involve paying to avoid or reduce emissions in other sectors of the economy, rather than removing $CO_2$ from the atmosphere."

Business as usual expected international aviation emissions growth (excluding domestic aviation)[11]




## 2. The problem of ineffective offsetting

CORSIA assumes that all offsets are effective and will reduce emissions by the amount claimed. However, this is not a reasonable assumption. While the International Civil Aviation Organization (ICAO) has developed eligibility criteria for carbon credit programmes selling to airlines, designed to ensure that offsetting has real environmental value, the past record of international offsetting is extremely poor. Only seven per cent of the potential credits issued between 2013 and 2020 by the largest and most established scheme, the UN's Clean Development Mechanism (CDM), are likely to be additional and not over estimated.[12] CDM is one of the major global offsetting programmes which has applied for eligibility for CORSIA. Therefore, it is highly unlikely that all growth in emissions after 2020 will be effectively offset.

Furthermore, most offset projects involve paying to avoid or reduce emissions in other sectors of the economy, such as funding renewable energy, rather than removing $CO_2$ from the atmosphere. While these projects 'buy time' by suppressing the accumulation of greenhouse gases in the atmosphere, they will not enable the global economy to reach net zero.

Finally, other aspects of aviation cause significant heating effects on top of those caused by $CO_2$, such as contrail formation and $NO_x$ emissions, which are currently estimated to have almost twice the atmospheric heating impact of $CO_2$ emissions alone.[13] The non-$CO_2$ heating impacts of aviation are not currently accounted for. Therefore, just offsetting carbon emissions will still result in an increasing global heating effect. Since the important goal is to limit global temperature rise, it is vital to mitigate these non-$CO_2$ heating effects, not just offset emissions. Further research would be beneficial to progress our understanding of non-$CO_2$ heating effects and how these can best be addressed.

“Emissions in 2050 in the UK are expected to be greater than available carbon removal and storage capacity.”

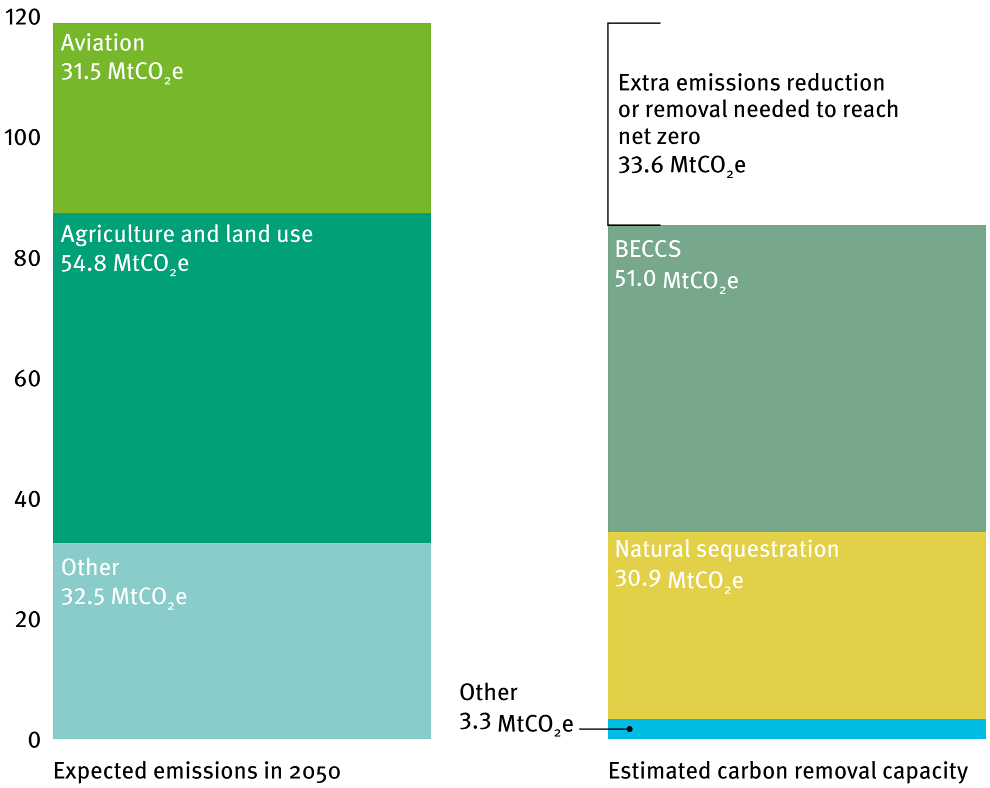
## 3. Unfair allocation of carbon credits

Natural sequestration is considerably cheaper than the technical alternatives being developed, like BECCS and DACCS, which are expected to be upwards of £76 per tonne of $CO_2$ even by 2050, compared to £2-23 per tonne for natural sequestration.[14] The amount of offsetting required by aviation could mean that, in an open, unconstrained market, it could buy up all the cheaper credits from natural carbon sinks.[15] This could be detrimental to other, less wealthy, UK sectors which will also need to rely on offsets to reach net zero, most notably agriculture.

Furthermore, to avoid ‘double counting’, a carbon credit sold to an airline through CORSIA must be removed from the emissions inventory of the country where it was produced. In other words, if a Woodland Carbon Code credit is sold to an airline under CORSIA, it cannot be counted towards the UK’s emissions targets. There is a risk that releasing a large number of credits would make it much more difficult for the UK to meet its domestic net zero target by 2050.

As things stand, emissions in 2050 in the UK are expected to be greater than available carbon removal and storage capacity (see below). Important decisions need to be made about how carbon removal capacity should be allocated and paid for, and which sectors should reduce their emissions further to make meeting the UK’s net zero obligation possible.

Expected emissions vs estimated carbon removal capacity in 2050, under the Committee on Climate Change’s ‘Further ambition’ scenario[16]



# How to make the most of aviation offsetting

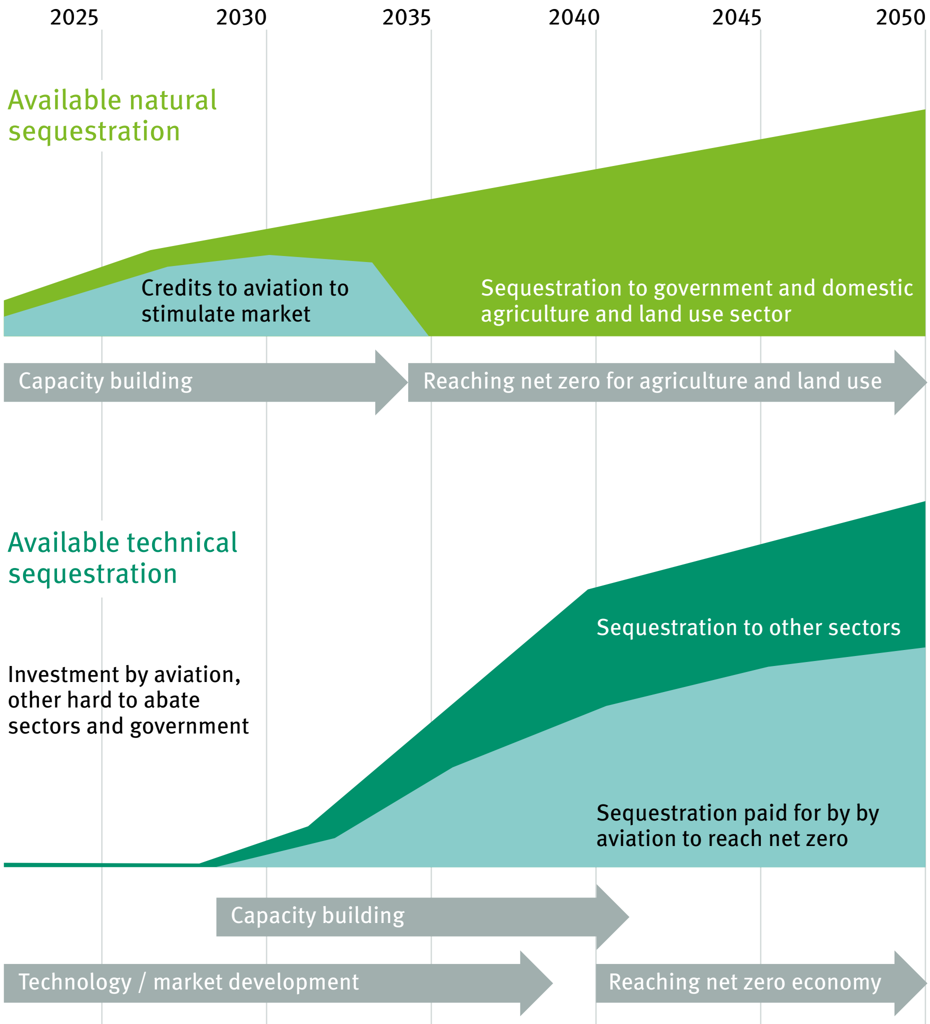
"The UK should enable a defined quantity of carbon credits from domestic nature-based projects to be sold to airlines."

To avoid these problems, new governance and policy is needed: to enable new technologies to be developed, to determine how much carbon removal is necessary, how it should be delivered and who should pay for it. Since market based offsetting schemes, such as CORSIA, exist, it makes sense to put new governance in place now to avoid the risks we have described. This would be the first step towards a coherent and robust system, to manage the transition to net zero across the whole UK economy.

The UK should enable a defined quantity of carbon credits from domestic nature-based projects to be sold to airlines over the next 15 years or so, to help boost delivery of natural sequestration. This could start with a large proportion of available credits going to aviation in the first instance, gradually reducing to zero around the year 2035 to allow subsequent natural sequestration to be used to help the agriculture and land use sector reach net zero.

Meanwhile an increasing proportion of aviation offsetting investment should be channelled towards the development of other carbon removal technologies, such as BECCS and DACCS, increasing to cover all remaining aviation emissions by 2050 at the latest. Significant reductions in aviation emissions will be needed and this is explored further below.

How aviation offsetting could be managed in the UK over time



"A new 'office for carbon removal' needs to be given the explicit purpose to manage the growth of UK carbon removal capacity."

The government departments for Environment, Food and Rural Affairs (Defra), Business, Energy and Industrial Strategy (BEIS) and Transport (DfT) should work together to prioritise the following actions:

## 1. Create a new 'office for carbon removal'

There are multiple ways that limited carbon removal capacity can be allocated and paid for.[17] At one end of the spectrum a market system would see carbon emitters buy carbon removal credits on the open market. This system could be unfair, where the cheapest carbon removal credits are not allocated equitably across all the sectors of the economy that need them. At the other end of the spectrum, the government could introduce some form of carbon tax or levy on polluting industries and use the revenue to pay directly for carbon removal. For example, the CCC has suggested a levy on polluting industries like aviation to fund tree planting. This would offer more public accountability and make it easier to ensure that a range of carbon removal technologies are developed and that these are deployed in an environmentally beneficial way. In between these two systems are endless possibilities to combine market mechanisms with public oversight and rule setting to motivate the strongest possible action.

To get the UK on track to meet the demand for carbon removal, a new 'office for carbon removal' needs to be given the explicit purpose to manage the growth of UK carbon removal capacity and put in place the policies, rules and frameworks needed. This body would implement policy to promote the development of multiple new and existing carbon removal technologies, oversee and set rules and standards for the creation and verification of carbon removal credits, and set the framework for allocating and paying for credits. This body would need sufficient resources to oversee the development of a whole new industry, and give confidence to businesses, government and the public that carbon removal solutions really work. Its functions could be funded by a levy on sectors and businesses which use carbon offsets.

## 2. Set separate targets for emissions and removals

To mitigate the risk that offsetting will slow down progress to reduce actual emissions, the government should set two separate targets: one for gross emissions and one for carbon removals. In the case of aviation, the targets should also take into account the non-$CO_2$ heating effects of aviation. Separate targets are the best way to ensure that maximum effort is put into reducing emissions first, with offsetting only serving to 'mop up' left over emissions.[18] As well as UK targets, the government should push for ICAO, the UN's international aviation body, to set a long term target to limit gross emissions from global aviation, and a separate target to reach net zero for global aviation by 2050 or earlier.

## 3. Include international aviation in UK climate legislation

The UK should continue to push for stronger global aviation targets. International solutions to aviation emissions are important to avoid leakage effects where constraining flying in one country simply leads to more flights to and from a neighbouring country. For example, emissions from flights within the EU are regulated under the EU Emissions Trading Scheme, providing a level playing field for reducing emissions across the continent. It is currently unclear whether the UK will continue to be part of the EU ETS, or how the ETS will interact with CORSIA.

However, the need for international solutions should not be used as an excuse not to act domestically. The UK cannot just wait and hope that global targets and action will be strengthened. In the meantime, the government should also follow the CCC's advice and include the country's share of international aviation in the UK's net zero law. Pursuing a strong domestic agenda should not mean the UK is any less committed to international efforts. Indeed, the UK can use strong domestic policy to show international leadership.

"A pathway should be established to move all CORSIA offsetting to carbon removals by 2035 at the latest."

A combination of domestic and international action to address aviation emissions will be most effective, as shown below.

Alternative scenarios for the UK in relation to CORSIA and the outcome for emissions

| Scenarios | Emissions from flights departing from the UK | Emissions from flights arriving in the UK |
|---|---|---|
| **UK in CORSIA**<br>No additional domestic action | Additional emissions above a 2020 baseline covered by policy and agreement. | Additional emissions above a 2020 baseline covered by policy and agreement. |
| **UK not in CORSIA**<br>Pursuing ambitious domestic targets | All emissions covered by policy, resulting in emissions reductions. | No emissions covered by policy and agreement. |
| **UK in CORSIA**<br>Pursuing ambitious domestic targets | All emissions covered by policy, resulting in emissions reductions. | Additional emissions above a 2020 baseline covered by policy and agreement. |
| **UK in a newly formulated CORSIA (with a long term net zero target)**<br>Pursuing ambitious domestic targets | All emissions covered by policy, resulting in emissions reductions. | All emissions covered by policy and agreement, resulting in emissions reductions. |

## 4. Focus offsetting on developing carbon removal capacity

As outlined above, offsetting schemes have so far included many carbon credits which do not represent real emissions reductions. Instead of investing in offset projects unlikely to reduce emissions, the aviation industry should focus only on those offsets that offer robust and measurable carbon removals.[19] A pathway should be established to move all CORSIA offsetting to carbon removals by 2035 at the latest.

In the first instance there is a need to continually review credits that are eligible for CORSIA offsetting to ensure the scheme is environmentally beneficial. Analysis carried out for the German Environment Agency suggests that all CORSIA demand from 2020 to 2035 could be met by existing Clean Development Mechanism (CDM) credits (ie those created before 2020) at less than €1 per unit.[20] Simply allowing airlines to buy credits from emissions reductions which already happened before CORSIA started could not lead to any net environmental benefit, and would be likely to lead to environmental harm by allowing aviation emissions to grow without being offset properly by robust carbon credits. CORSIA's Technical Advisory Board has recommended that only credits from activities that started from 2016 onwards should be eligible.[21] This advice should be followed and continually reviewed.

Significant investment in developing scalable technologies, like BECCS and DACCS, is needed as soon as possible, and aviation offsetting is a good opportunity to do this. While these technologies are in their infancy, natural climate solutions are a more immediately available source of carbon sequestration, but careful limits need to be placed around their use for aviation offsetting to avoid the risks we have outlined.

“There should be a cap on the number of UK nature-based carbon credits released to international airlines.”

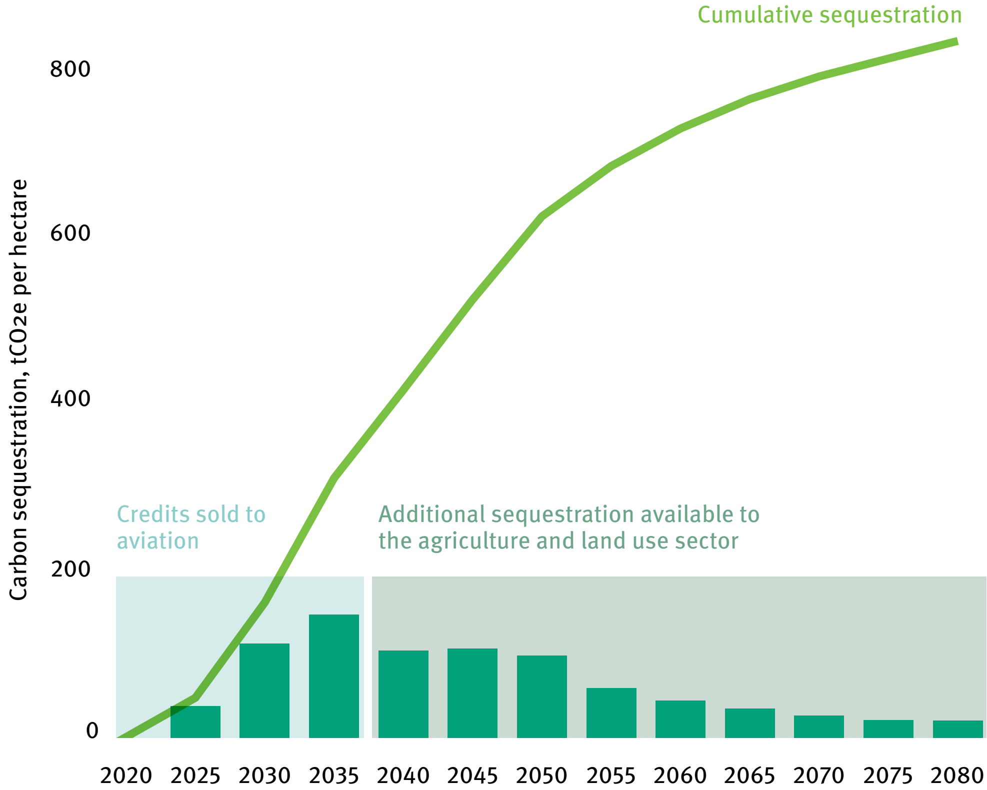
## 5. Release a limited number of UK credits to CORSIA

The government should enable the Woodland Carbon Code, initially, and then the Peatland Code and a new Farm and Soil Carbon Code (outlined on page 14), to become eligible to sell credits to airlines under CORSIA. To avoid the risk of unfair allocation of the cheapest credits, and lack of investment in developing the technological solutions to both reduce aviation emissions and capture and store carbon, there should be a cap on the number of UK nature-based carbon credits released to international airlines.

The cap should be set by the ‘office for carbon removal’, as we have described. The cap level set should balance the need for investment in natural carbon sequestration against potential negative impacts on the ability of domestic sectors, such as agriculture, to meet their own decarbonisation targets. The cap would probably represent a larger proportion of available sequestration capacity in the early years, reducing over time as technical removals come on line.

This approach would rely on assurance from the government that payments will be available for ongoing natural sequestration after 2035. The graph below shows how this might work for a woodland planted in 2020 under the Woodland Carbon Code. Any carbon credits created in the first fifteen years after trees are planted could be sold to airlines, while credits created from ongoing sequestration after this would be allocated to domestic sectors and paid for by those sectors or with public funding.

**Carbon sequestration in a woodland and how it could be allocated to different sectors over time**[22]



# High quality nature-based offsets in the UK

"The UK is well placed to deliver strong, reliable nature-based carbon credits."

Analysis of previous global offsetting schemes has shown that nature-based carbon sequestration projects, such as tree planting or improving agricultural soils, often perform poorly. This is because of concerns that carbon stored could be released again in future, also referred to as 'permanence', and the difficulty of showing that the carbon sequestration would not have happened anyway, regardless of creating and selling a carbon credit, known as 'additionality'.[23]

Permanence concerns arise because carbon sequestered in trees or soils could be released in future, for example due to fire or changes in management. There is scepticism about the additionality of some agricultural projects because of the relatively small role that carbon funding plays in decision making around agricultural management practices.

However, the UK is well placed to deliver strong, reliable nature-based carbon credits. It has a relatively robust regulatory baseline and good policy and legal frameworks, which will help to ensure that credits are real, properly verified and do not lead to extra emissions elsewhere.[24]

The government backed Woodland Carbon Code has given businesses confidence that carbon credits from tree planting accredited under the scheme are both permanent and additional. A Peatland Code has subsequently been developed by the IUCN Peatland Programme which follows the Woodland Carbon Code model. These are leading standards tailored to the UK context, adapted and improved over time.

## The case for a new Farm and Soil Carbon Code

Existing codes are not applicable for activities which could take place on farms alongside food production, such as agroforestry and growing hedgerows, or carbon sequestration from increasing organic matter in soils. This misses the opportunity of the carbon sequestration services that could be provided by farming. A new Farm and Soil Carbon Code would address this and support a whole new set of natural carbon sequestration projects in the UK.

While there is still uncertainty about the potential scale and measures that would be effective to deliver carbon sequestration on farms, especially with regard to soil carbon, this should not prevent action taking place where there are clear opportunities. There are already farmers in the UK experimenting with carbon farming, and there are existing schemes in other countries.

## Ballruddry catchment soil carbon project

This project will encourage 'regenerative farming' at a catchment scale through farm payments, facilitated and allocated through EnTrade's platform, developed and overseen by Agricarbon UK.

The project aims to cover 1,000 hectares of the total 3,500 hectare catchment. Farmers will introduce livestock into arable rotations, using 'mob-grazing' whereby cattle graze a small area of land for a short period (a day or less) before being moved to a new patch, leaving time for plants to recover fully. There is evidence that this can increase the amount of carbon stored in soil by allowing roots to grow deeper and by trampling plants into the soil.[25] Further trials are being carried out to test this approach.[26]

This method has significant biodiversity benefits, increasing soil health and providing a habitat for insects and other animals, letting pasture fully regrow rather than being constantly grazed. Greater plant cover and improved soil health also help water to soak into the soil, preventing run-off and water pollution.

The scale of this opportunity for grazing management is around 0.1 – 4.0 $tCO_2e$ per hectare per year for approximately five years, although particular sites could be higher depending on the condition of the soil at the start and local factors such as soil type and climate. This may seem small compared with around 10 - 20 $tCO_2e$ per hectare per year over 50 years which is provided by afforestation projects, but these interventions also have the advantage of allowing continued food production on the land, often with only minor management changes.

The extent of permanent and temporary pasture in the UK (7.3 million hectares or 30 per cent of the country) also means these interventions could be replicated at scale. [27] Further carbon credits could be generated by other activities on this land, such as agroforestry, not yet covered by existing carbon accreditation schemes.

Agricarbon UK plans to experiment with new technologies for measuring soil carbon in the field which will enable the accurate estimation of credits. This will be important to ensure the suitability of the credits, as each farm is likely to achieve different results depending on previous management, soil and climate conditions.

"The UK should aim to develop a Farm and Soil Carbon Code ready to sell credits to airlines in 2027."

The UK should aim to develop a Farm and Soil Carbon Code ready to sell credits to airlines in 2027, when CORSIA becomes compulsory. The code in the UK could be overseen by the new 'office for carbon removal' acting as the regulator, with expert input from bodies like the Environment Agency and Natural England, to ensure projects meet the highest standards and that there is confidence in the credits produced.

Features of an effective Farm and Soil Carbon Code would include:

**Credits and payments based on results**

It is difficult to model and predict how much carbon will be sequestered in soil because this is dependent on so many variables, including soil type, land management choices and the weather. Therefore, Farm Carbon Credits should be issued on the basis of measured increases in carbon stored in soil and vegetation. New technologies for in-field measurement being developed are expected to reduce the cost of measuring carbon stored dramatically.

**New solutions to permanence**

Permanence is a particular issue for farm carbon where losses can occur intentionally as well as unintentionally. The standard system for addressing permanence issues is to give a proportion of credits to a separate 'buffer' account, where they are held and can be used if carbon linked to credits already sold is lost, for example due to fire. However, this is challenging because it reduces the amount of funding farmers are able to get for their carbon sequestration activities, and it does not provide incentives to maintain carbon stores. Alternative options for assuring against losses that enable all credits to be monetised should be developed. These could include insurance products, assurance schemes, which involve farmers paying in and receiving dividends based on performance, or a government backed scheme where public money is used to pay for 'buffer' credits to stimulate the market.

**Stacking payments for multiple benefits**

Farm based carbon schemes often deliver lower levels of carbon sequestration than woodland, meaning carbon funding is not always sufficient to make them worthwhile. But they are nevertheless high value as they deliver other benefits, such as better water quality, flood mitigation or biodiversity improvements. As previously argued by Green Alliance and the National Trust, 'stacking' payments for these multiple benefits from multiple buyers, on top of carbon credit funding, could make more projects viable (see opposite).

**Solutions to leakage**

'Leakage' occurs where the activity that stores the carbon causes emissions elsewhere. For example, if livestock is introduced into an arable rotation to increase soil carbon, it is important that this does not lead to an increase in livestock numbers overall and cause additional methane emissions.

**Rules that account for fluctuations in carbon storage**

Carbon stored in soil could fluctuate over time, particularly if carbon is increased in one part of the rotation, and lost in another (for example due to ploughing). The Woodland Carbon Code deals with this in the context of commercial clearfell forestry by only allowing credits to be sold up to the average quantity of carbon stored over the full rotation period, as opposed to the maximum carbon stored. A similar approach could be introduced for farm carbon.

## Increasing the viability of carbon farming projects

In a previous study, Green Alliance and the National Trust showed that 'stacking' payments for the multiple environmental benefits of projects can change the choice of intervention made, as well as increase the number and size of projects considered viable.

For example, a particular species of tree might be the favourite from a carbon sequestration perspective but, if money is also available for improving biodiversity, water quality or flood mitigation, then another more diverse and environmentally beneficial woodland environment might be preferable.

In the case of soil carbon, carbon funding alone might not be enough to encourage farmers to change their land management practices. In this case, extra funding for water quality and biodiversity could guide action and make a project more viable.

We held a 'mock trade' simulation at the James Hutton Institute in Dundee, using the EnTrade trading platform, to explore how stacking payments might work in practice. It was clear that focusing on more than one environmental benefit could influence the choice of intervention. But more work needs to be done to develop a trading platform, in tandem with new standards such as a Farm and Soil Carbon Code, to make this viable in reality.

# Reducing UK aviation emissions

"There is a lot of interest in electric planes, but these are likely to be decades away from full commercial viability."

Despite opportunities to channel early funding into nature restoration, and the inevitable role which carbon removals can play in reaching net zero aviation by 2050 at the latest, offsetting will not be sufficient to solve the problem of aviation emissions on its own. Much more effort needs to go into reducing actual emissions, bringing the remainder down to a level that can be sustainably and equitably met by equivalent removals.

To be able to grow sustainably, the aviation sector, with the support of government, needs to invest heavily and immediately in genuine zero carbon flying technologies. Until these solutions are proven and commercialised, the only prudent course is to follow the advice of the CCC and manage demand to reduce emissions as much as possible.

International aviation and shipping were not included in the Paris climate agreement. And, although the UK has legislated to reduce its emissions to net zero by 2050, it has not formally included international aviation in its legally binding emissions reduction targets, despite the recommendation from the CCC that it should.

Total emissions from UK aviation were 36.5 $MtCO_2$ in 2017, of which 35 $MtCO_2$ were from international flights. Emissions from aviation have doubled since 1990.[28] Current government plans are to limit emissions to 37.5 $MtCO_2$ in 2050; this will require efficiency improvements, as well as limiting demand growth to 60 per cent from 2005 levels. But even this level of ambition will not be compatible with the UK's net zero obligation

In its 'Further ambition' scenario for reaching net zero, the CCC assumes that aviation emissions will be reduced to 31.5 $MtCO_2$ in 2050, which will be around a quarter of the whole economy's budget for remaining emissions.[29] This scenario still does not reach net zero across the economy, with a further 33.6 $MtCO_2e$ in emission reductions and carbon sinks needed. Subsequent CCC advice recommends limiting growth in demand for flying and suggests the government should revisit its airport capacity strategy in the context of its net zero obligation.[30]

## Ways to reduce aviation emissions

In the table opposite, we outline the most credible ways to reduce the carbon intensity of aviation. Of these, the biggest potential reductions come from fuel efficiency, cutting growth in the number of flights and the possible introduction of new carbon neutral 'electrofuels'. Electrofuels are made by combining hydrogen with captured $CO_2$, using renewable energy to create a fuel similar to kerosene but with near zero net emissions. With the right technology development and policy incentives, these fuels could have a big impact. However, the process is currently very expensive, and it is expected that it will be cheaper to capture and store carbon rather than capturing it and making it into fuel to burn in aircraft engines.

According to some estimations, new sustainable biofuels or fuels made from waste (sustainable aviation fuels) could play a greater role in lowering the carbon intensity of aviation, but there are questions about the availability of truly sustainable feedstocks to make the fuel, so we have used the CCC's estimation of ten per cent in the fuel mix by 2050.[31,32] There is also a lot of interest in electric planes, but these are likely to be decades away from full commercial viability and will not have the range for long haul flights which account for the majority of aviation emissions.

The government and aviation sector should prioritise investment in zero carbon flight solutions. But, in the meantime, emissions cannot be permitted to grow unchecked. When a truly sustainable solution, like electrofuels or electric planes, is commercialised and deployed at scale, then sustainable growth in the sector could be possible. Until then, we must take steps, as outlined by the CCC, to manage the growth in the number of flights to restrict emissions from aviation.

"Reducing the number of flights is the only way to address the significant non-$CO_2$ climate impacts of aviation."

Notably, reducing the number of flights is the only way to address the significant non-$CO_2$ climate impacts of aviation, such as contrail formation and $NO_x$ emissions. These are estimated to cause as much atmospheric heating as the $CO_2$ emissions, and are not currently accounted for.[33,34]

How to reduce international aviation emissions[35]

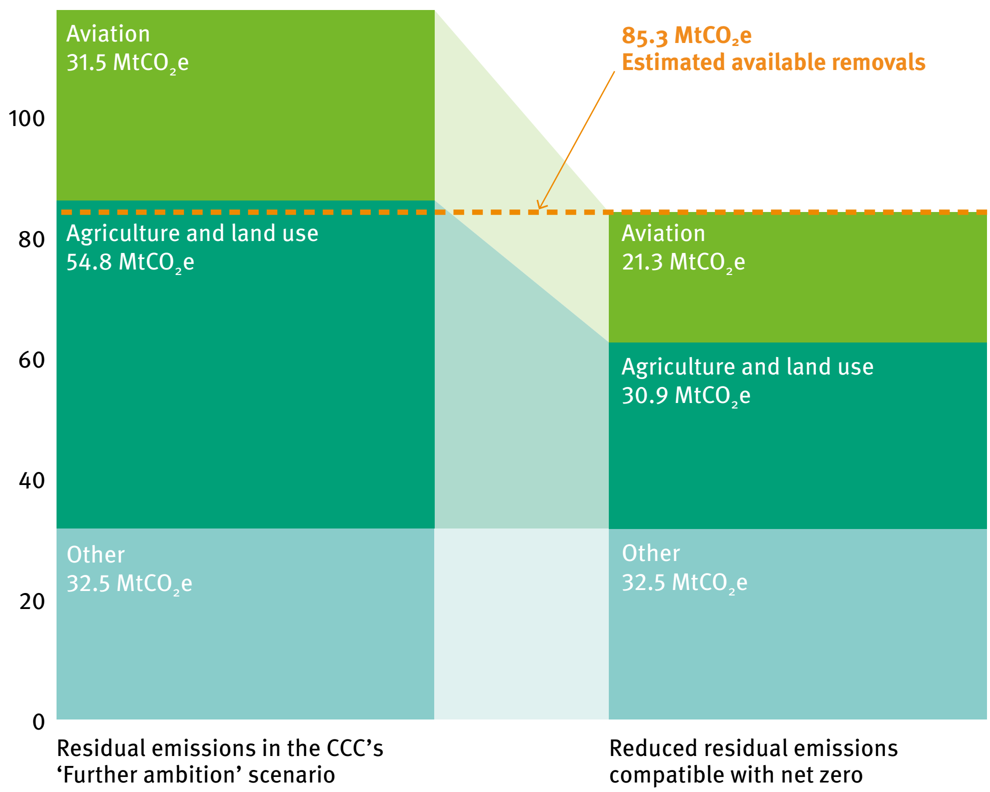
| Measure | Scale of $CO_2$ reduction by 2050 | Technical risk | Addresses non-$CO_2$ effects? | Other factors |
|---|---|---|---|---|
| Fuel efficiency improvements | 33% | Low | No | Most efficient designs will not be ready until the 2040s; there is potential for the 'rebound effect', ie lower fuel requirements could lead to lower ticket prices |
| Sustainable aviation fuels | c 5% | Medium | No | Market development will need support<br><br>This is in competition with other uses of biomass and waste management |
| Electrofuels | 0 – 100 % | High | No | High cost<br><br>Currently no market<br><br>Requires direct air carbon capture |
| Improved air traffic management | 0 – 8% | Low | No | Unlikely to be effective, unless demand for flights decreases |
| Demand reduction | 0 – 100 % | n/a | Yes | Reduces the need for airport expansion |

See the annex on page 24 for more details

## How to use these measures in the UK

Aviation emissions will need to be reduced to a level where they can be sustainably offset by removals, taking into account the needs of other sectors. The CCC estimates that there will be 85.3 $MtCO_2e$ carbon removal capacity per year in 2050, mostly consisting of BECCS and natural sequestration. As shown below, if BECCS can be developed at this scale, then the UK economy as a whole can reach net zero, if aviation emissions are reduced to 21 $MtCO_2$ per year or less. This is a maximum estimate which assumes agriculture and related land use emissions are reduced dramatically so they can be offset entirely by natural carbon sinks. Otherwise, even deeper emissions cuts across the economy, or further carbon removals, will be necessary.

Reducing emissions to a level which can be met by removals to reach net zero




We have looked at the emissions reductions possible for aviation in the UK between now and 2050 under four scenarios, using different combinations of measures. (We have excluded electrofuels from these scenarios due to high economic and technical uncertainty, but will discuss them separately).

Our scenarios are:

**1. Business as usual**
No constraints on airport capacity, one per cent a year of efficiency improvements and 60 per cent demand growth from 2005 levels.

**2. Technical improvements only**
No constraints on capacity, five per cent sustainable aviation fuel use by 2050, 1.2 per cent a year in efficiency improvements (consistent with 33 per cent improvement by 2050) and 60 per cent demand growth from 2005 levels.

**3. 40 per cent demand growth**
Technical improvements only as in scenario two but with demand growth at 40 per cent from 2005 levels.

**4. Zero demand growth**
Technical improvements as in scenario two but with zero demand growth from 2005 levels.

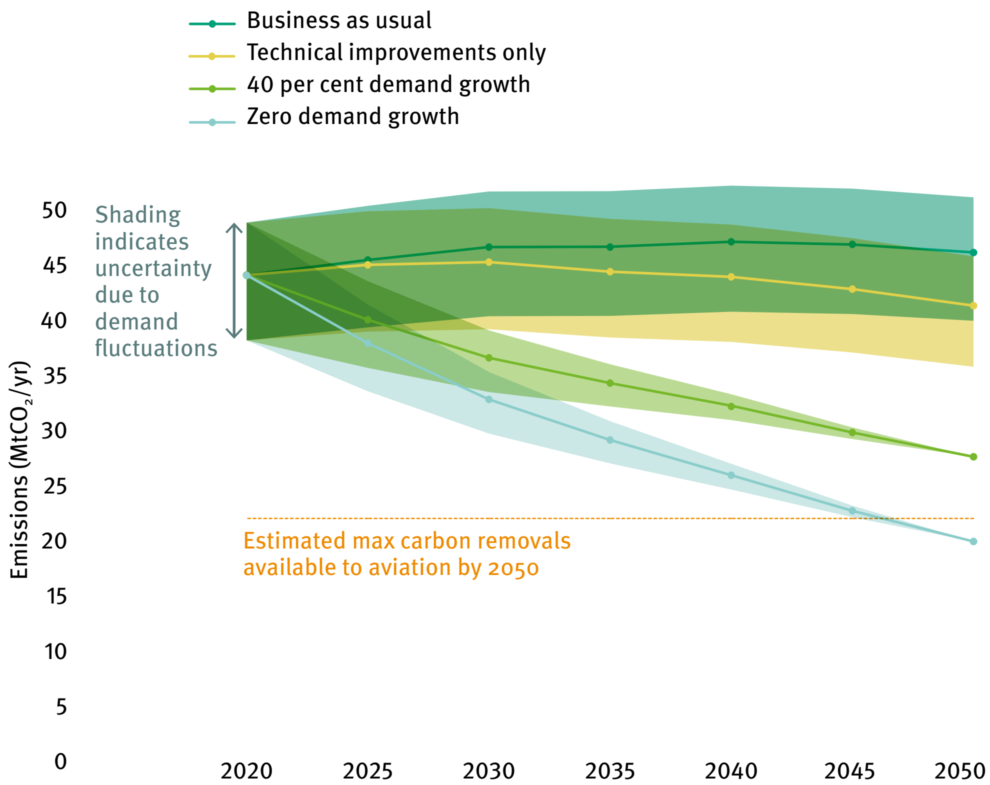
For a full methodology explaining how these scenarios were developed please see: green-alliance.org.uk/the_flight_path_to_net_zero_methodology

“Limiting the number of flights taken is the only way to reduce aviation emissions to a level where they could reasonably be met by carbon removals.”

We have modelled the emissions pathways for each of these scenarios for the period from now to 2050. This shows that limiting the number of flights taken is the only way to reduce aviation emissions to a level where they could reasonably be met by carbon removals, unless and until zero emission flight technologies are commercialised and widespread. Only in our ‘Zero demand growth’ scenario are emissions from aviation reduced below the 21 $MtCO_2$ threshold.

Moreover, relying on improving the emissions intensity of flying alone is risky since fluctuations in demand could have a much greater impact on emissions. Without carefully targeted policy, demand for aviation is difficult to manage as it is driven by a number of socioeconomic factors, such as oil and carbon prices, consumer spending power and market maturity. There is no guarantee that emissions intensity improvements will lead to overall emissions reductions unless there are also measures to control demand, as shown in the ‘Business as usual’ and ‘Technical improvements only’ scenarios below. Note that the starting emissions in 2020 are based on DfT emissions projections.[36] There is uncertainty around the starting point because actual emissions data is only available beyond 2017, so actual emissions in 2020 will depend on growth in demand and progress made to reduce emissions intensity between 2017 and 2020.

Emissions scenarios for the UK aviation sector to 2050




## Changing travelling behaviour

The number of flights taken can be reduced by constraining capacity, for example by ending airport expansion, or through internationally agreed taxation on aviation fuels, tickets or carbon emissions.[37,38] As outlined above, the government will need to take account of possible leakage effects, where a reduction in flights to and from the UK could lead to flights simply transferring to other countries.

"Many available measures to reduce emissions intensity would cost airlines nothing or would even save them money."

Demand management does not have to mean reduced mobility. One way of meeting demand more efficiently would be to increase the number of passengers per plane, rather than increasing the number of flights.

Policy makers also have substantial leeway to influence the behaviour of those who fly most: in the UK, 48 per cent of the population does not fly at all in any given year, while the top ten per cent of those who fly are responsible for half of all the flights taken.[39] A 'frequent flyer' levy, as proposed by the Free Ride campaign, or an air miles charge, would both be fair ways to limit growth in the demand for flights.[40,41]

## Improving passenger load and capacity

Modelling by the DfT assumes a load factor (how full each plane is) of 79 per cent and that a long haul international flight can seat 349 passengers. However, in the US, load factors vary seasonally between 80 and 90 per cent, suggesting policy targeting higher load factors should be possible.

Market drivers are pushing load factors down. The breakeven load factor, at which point it becomes profitable to operate a flight, has been decreasing due to low oil prices: for some carriers this has been below 60 per cent.[42] This is a market failure, as cheap oil is allowing airlines to operate inefficiently but profitably.

Schemes such as CORSIA and the EU's Emissions Trading System only target a plane's emissions rather than the per passenger carbon intensity, so the carbon cost to an airline does not change whether 400 or 800 people are on a flight.

In addition to the load factor (the seats occupied on a flight), the total seating available is dictated by the split between first, business and economy classes. For example, an Airbus A380 could seat 868 people if all were economy, however the space requirements for first and business classes mean that only 400 to 500 seats are typically available.

Our analysis suggests that airlines could reduce international aviation emissions by 17.5 per cent in 2030 if they met new demand by realistic increases in the number of seats available on each flight. Greater reductions could be achieved if load factors were also increased or if other changes were made. For example, if all the seats on an Airbus A380 were economy class, per passenger carbon intensity could be halved.

Targeting $CO_2$ per passenger kilometre, as the basis of taxation or slot allocation, rather than simply the amount of $CO_2$ generated per plane, would encourage carriers to increase passenger numbers per flight as well as fuel efficiency.

## Using policy to enable emissions cuts

Without further policy and action, emissions from aviation in the UK are projected to exceed 40Mt$CO_2$ by 2050.[43] Policy is needed to encourage take up of more sustainable fuels and constrain demand growth from 2005 levels to keep emissions below 21 Mt$CO_2$ by 2050, at which levels carbon sequestration and removal are possible.

Many available measures to reduce emissions intensity would cost airlines nothing or would even save them money, but are not being adopted quickly enough. This market failure alone justifies action by the government to stimulate action, ideally by targeting $CO_2$ emissions per passenger kilometre, to encourage reductions in emissions intensity and an increase in passengers on each flight. Other incentives can be provided by airports through slot allocations and landing fees.

Long haul flights, which represent 57 per cent of total UK air passenger miles, cannot be zero carbon without the use of a new fuel like electrofuel (see the annex on page 24 for more information).[44] However, these are not currently commercially available and are high cost. So, as well as constraining aviation growth in line with emissions targets, the government should consider a rising obligation to use zero carbon fuels like electrofuels to help build the supply chain to support cost reduction.

# Recommendations

## Manage carbon removals and offsets

Market based offsetting presents risks to achieving the UK's net zero obligation and limiting the damaging impacts of climate change. Relying on offsets could justify continued emissions, while climate physics requires both rapid reductions in emissions and rapid increases in carbon removals.

There is also a risk that the costs and benefits of carbon removal will not be shared sustainably or equitably if a pure market approach is taken, with early movers like aviation buying up the bulk of the cheap and readily available nature-based solutions. This would leave other sectors like agriculture, or the government, to pick up the bill for, and the risks of, developing more expensive BECCS and DACCS based carbon removal technologies.

To limit these problems, the government should create a new 'office for carbon removal' to manage and oversee the fair, sustainable allocation of carbon removal capacity across the economy. This body should:

- **Set the level of two different targets: emissions reductions and carbon removals.**
- **Set a cap on the number of nature-based credits that can be sold to international airlines.**

## Make the most of CORSIA

Offsetting schemes have a very poor track record at delivering the emissions reductions they claim. Furthermore, offsetting by paying to reduce or avoid emissions in another sector will not achieve the net zero goal. CORSIA and other offsetting initiatives in the aviation sector should focus on buying credits that result in carbon removals only.

While more scalable carbon removal technologies are being developed, natural sequestration is available now. There is potential to channel early funding to nature restoration and build capacity to deliver the large scale sequestration needed to achieve net zero.

The explicit purpose of this should be to develop natural climate solutions generally, rather than specifically as a solution to aviation emissions. The government should:

- **Develop a new Farm and Soil Carbon Code, and support UK carbon removal programmes to become eligible to sell credits through CORSIA.**
- **Commit to release a capped number of nature-based offset credits each year to international aviation up to 2035.**

## Get aviation emissions on track for net zero

International agreements to limit the growth of aviation emissions are incompatible with a 1.5°C target and the UK's net zero emissions target. Furthermore, as we have shown, traditional carbon offsets and carbon sequestration and removal cannot be a substitute for reducing actual emissions.

The global capacity to remove and store carbon from the atmosphere is limited, and aviation has significant other global heating effects, beyond $CO_2$. To ensure the UK continues to lead on tackling climate change and that maximum effort is made to reduce emissions from aviation the government should immediately:

- **Legislate to include the UK's share of international aviation emissions in the domestic legally binding net zero target.**
- **Push for an emissions plan, compatible with the Paris climate agreement, to be agreed at the 2022 ICAO general assembly.**

# Annex one

## Options for reducing aviation emissions

**Fuel efficiency improvements:** As the current fleet of planes ages, it will steadily be replaced with more fuel efficient models. Estimates of the scale of improvements vary but are in the range of 0.9 – 1.4 per cent a year which is likely to be cost saving to industry due to lower fuel costs. This process could be accelerated with incentives for carriers to retire their oldest planes early. However, in terms of global emissions, these would have to be genuinely retired rather than being sold to airlines in emerging markets. Greater efficiency, and thus lower fuel costs, has the potential for rebound effects whereby demand rises due to lower ticket prices. This would negate improvements in fuel efficiency.

**Electric aeroplanes:** Battery powered aeroplanes are a potential way to decarbonise aviation, assuming the batteries can be charged using zero carbon electricity. We have not covered this in detail in this report as it is unlikely that this technology will be able to meet the range requirements of long haul flights which are responsible for the majority of aviation emissions. However, electric aeroplanes have significant potential for shorter flights, and changes in behaviour and routing could enable them to play a role in longer journeys if passengers are willing to take multiple, shorter flights to travel long distances.

**Sustainable aviation fuel (SAF):** A number of technologies have been developed which can produce biofuels suitable to be used as a substitute for kerosene. Fuels derived from biomass have lifecycle emissions approximately 50 per cent lower than standard kerosene, although some SAF made from waste products can have higher savings of between 70 and 90 per cent.[45] However, due to the cost and availability of truly sustainable biomass that does not compete with food production, or cause further emissions due to land use change, market penetration of SAF is unlikely to be above ten per cent by 2050.[46] As SAF is also likely to be more expensive than kerosene, further policy interventions may be required to stimulate production and investment in the infrastructure needed to counter this. Airports could play their part, for instance, by giving landing slot allocation priority to airlines using SAF.

**Electrofuel:** It is possible to produce near carbon neutral aviation fuels by combining hydrogen, produced using renewable electricity, with captured $CO_2$. Although costs may come down as the technology matures, at current estimates it will be prohibitively expensive compared to kerosene. Electrofuels are, therefore, unlikely to be adopted without strong legislation on aviation emissions and a new industry would have to be developed rapidly to meet requirements, meaning there is a high technical risk in this option. It is worth noting that, at current cost estimates, the increased use of electrofuels would also greatly reduce demand for aviation.[47]

**Air traffic management (ATM):** developments in air traffic management could improve routing efficiency and decrease stacking time as planes wait for landing slots. However, the capability of ATM to deliver overall reduction is generally considered to be limited as it will probably only keep up with the projected increase in demand for aviation.[48] Consequently, reducing overall demand could make ATM efficiencies more effective, as well as reducing direct emissions by having fewer planes in the air.

**Demand management:** It is notable that a reduction in demand for aviation is the only option which carries no technical risk, as fewer planes flying will definitely lead to lower emissions. It is also the only option which addresses other causes of global heating from aviation, besides $CO_2$ emissions, such as contrail formation and $NO_x$ emissions. The combined heating effect of aviation is estimated to be nearly twice that of $CO_2$ emissions alone, meaning impacts are far greater than those suggested in most reports.[49] As the Paris climate agreement is a temperature target, and not just a target for $CO_2$ emissions, these sources should not be ignored and need to be addressed as a priority.

Projections of future demand vary based on market maturity, economic conditions and future oil and carbon prices, meaning that all projections on aviation emissions could vary by plus or minus ten per cent, if demand is not controlled.

# Endnotes

1 International Air Transport Association, press release, October 2018, 'IATA Forecast Predicts 8.2 billion Air Travelers in 2037'

2 International Civil Aviation Organisation (ICAO), 2016a, *What would be the impact of a global MBM scheme for international aviation?*, www.icao.int/Meetings/HLM-MBM/Pages/FAQ3.aspx; original figures in USD, converted to GBP using yearly average exchange rate to 31 March 2019. See: HM Revenue & Customs, December 2019, *Guidance: average for the year to 31 March 2019*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/810885/Average_for_the_year_to_31_March_2019.csv/preview

3 International Airlines Group, press release, October 2019, 'IAG backs net zero emissions by 2050'

4 easyJet, *Leading the industry on sustainable travel*, www.easyjet.com/en/sustainability

5 Since its introduction in 2011, only 5,267 hectares of woodland have been validated under the code, or about 750 hectares a year on average. For comparison, total planting rates in the UK were around 9,000 hectares in 2018 and, according to Green Alliance analysis, need to be at least 70,000 hectares a year to get the UK on track to meet net zero by 2040 in agriculture and related land use sectors. See: Forestry Commission, April 2018, *Woodland Carbon Code statistics: data to March 2018*; and Green Alliance, 2019a, *Cutting the climate impact of land use*

6 The CCC estimates 5.3 $MtCO_2e$ sequestration per year is possible in 2030 from trees planted after 2016, and Green Alliance analysis based on work by The Royal Society estimates that an additional 3.4 $MtCO_2e$ sequestration per year in soils is possible in 2030. Note there is some uncertainty about the effectiveness of soil carbon sequestration, with differing estimates of its potential. See: A Thomson et al, 2018, *Quantifying the impact of future land use scenarios to 2050 and beyond – final report for the Committee on Climate Change*, p 36; and Green Alliance, April 2019, *Cutting the climate impact of land use: methodology*

7 To date total lifetime sequestration of projects that were validated under the Woodland Carbon Code between 2012 and 2018 is 2.5 $MtCO_2e$, and projects can have timescales of up to 100 years. Assuming an average project lifetime of 25 years, this represents an average 0.1 $MtCO_2$ sequestered per year. This is likely to be an over estimate of the average yearly sequestration across the lifetime of projects, although sequestration rates vary greatly over time (see chart on page 13). See: Forestry Commission, April 2018, op cit

8 There is no publicly available data on the price of Woodland Carbon Code credits but, anecdotally, recent increases in demand are expected to push prices to around £10 per tonne.

9 Aviation emissions, see: ICAO, 2016b, *On board a sustainable future, ICAO environmental report 2016, aviation and climate change*, p 19. Carbon removal capacity, see: IPCC, 2018, 'Summary for policymakers' in *Global Warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, section C 3.2

10 Industry High Level Group (IHLG), 2019, *Aviation benefits report 2019*

11 ICAO, 2016b, op cit

12 M Cames et al, March 2016, *How additional is the Clean Development Mechanism? Analysis of the application of current tools and proposed alternatives*

13 D S Lee, December 2018, *The current state of scientific understanding of the non-$CO_2$ effects of aviation on climate*

14 Grantham Research Institute on Climate Change and the Environment, May 2019, *How to price carbon to reach net-zero emissions in the UK*; original figures in USD, converted to GBP using yearly average exchange rate to 31 March 2019. See: HM Revenue & Customs, December 2019, op cit

15 The Committee on Climate Change (CCC) estimates there is potential for 31 $MtCO_2e$ natural sequestration per year in the UK by 2050. See: CCC, April 2019, *Net-zero exhibits – agriculture & LULUCF*, figure 7.8.

Our modelling suggests that aviation's requirement for offsetting residual emissions to reach net zero in the UK ranges from 40.6 $MtCO_2$ a year via technical solutions only, to 19.2 $MtCO_2$ a year where demand is kept at 2005 levels.

[16] Further ambition scenario, nature-based removals, see: CCC, April 2019, op cit, figure 7.8. Tech based removals and residual emissions, see: CCC, May 2019a, *Net-zero exhibits – Chapter 6*, table 6.5

[17] Grantham Research Institute on Climate Change and the Environment, May 2019, op cit

[18] D P McLaren, et al, August 2019, 'Beyond "net-zero": a case for separate targets for emissions reduction and negative emissions', in *Frontiers in climate*

[19] J Larsson et al, January 2019, 'International and national climate policies for aviation: a review', in *Climate Policy*

[20] Umweltbundesamt, 2018, *Discussion paper: Marginal cost of CER supply and implications of demand sources*

[21] www.icao.int/environmental-protection/CORSIA/Documents/TAB/Excerpt_TAB_Report_Jan_2020_final.pdf

[22] Shows carbon sequestration for a typical sycamore, ash and birch woodland, yield class 8. See: Woodland Carbon Code, March 2018, *Woodland Carbon Code Lookup Tables V2.0*

[23] See for example: M Cames et al, March 2016, op cit; and Stockholm Environment Institute, June 2016, *Supply and sustainability of carbon offsets and alternative fuels for international aviation*

[24] Green Alliance and National Trust, 2019b, *New routes to decarbonise land use with Natural Infrastructure Schemes*

[25] K Zaralis and S Padel, 2017, 'The effects of "mob grazing" on soil organic matter and dairy cow performance – a case study' in *Proceedings of the 8th International Conference on Information and Communication Technologies in Agriculture, Food and Environment*; and www.soilassociation.org/our-work-in-scotland/farming-for-the-future/scotland-farming-news/2018/june/12/what-is-mob-grazing-anyway/, accessed 28 October 2019

[26] Soil Association, 'Pioneering mob grazing in Scotland', www.soilassociation.org/our-work-in-scotland/farming-for-the-future/field-labs/mob-grazing-scotland/

[27] UK Government, 2019, *Agriculture in the United Kingdom 2018*

[28] CCC, July 2019, *Reducing UK emissions: 2019 progress report to parliament*, p 25

[29] CCC, May 2019a, op cit, table 6.5

[30] CCC, September 2019, 'Net-zero and the approach to international aviation and shipping emissions', www.theccc.org.uk/wp-content/uploads/2019/09/Letter-from-Lord-Deben-to-Grant-Shapps-IAS.pdf

[31] Royal Academy of Engineering, July 2017, *Sustainability of liquid biofuels* and Energy Transitions Commission, November 2018, *Mission possible: reaching net-zero carbon emissions from harder-to-abate sectors by mid-century*

[32] CCC, May 2019b, *Net zero – technical report*, p 174

[33] D S Lee, December 2018, op cit

[34] The exact multiplier to use for the non-$CO_2$ emissions should be reviewed as the evidence base grows, as per the Scottish Climate Change Bill, however we cannot only consider $CO_2$ emissions, as is current practice.

[35] Our analysis of technical options available for emissions reductions in aviation to 2050 compared modelling assumptions provided by: CCC, May 2019b, op cit; Transport and Environment, October 2018, *Roadmap to decarbonising European aviation*; Sustainable Aviation, 2018, *Sustainable aviation $CO_2$ road-map*; Heathrow, 2019, *Preliminary environmental information report*; Department for Transport, October 2017, *UK aviation forecasts*; as well as consulting academic papers.

[36] Note on 2020 emissions estimate: the Department for Transport's central projections suggested total emissions from aviation to be 43.4 $MtCO_2$ in 2020. The last year with actual emissions data available is 2017 and this showed emissions of 36.5 $MtCO_2$. However, more recent data are available on aircraft kilometres flown in 2018. This suggests an increase in aircraft kilometres of seven

per cent on 2017. See: Department for Transport (DfT) and Civil Aviation Authority, 'Aviation statistics: data tables (AVI)', www.gov.uk/government/statistical-data-sets/aviation-statistics-data-tables-avi. Three years at this growth rate would give emissions of 44.7 $MtCO_2$ by 2020. Given that some fleet efficiency improvements are likely to occur in this period the DfT estimate seems a reasonable starting point. The biggest influencing factor on emissions growth over this period is changes in demand influenced by wider economic conditions.

[37] DfT, October 2017, *UK aviation forecasts 2017*

[38] J Larsson, et al, January 2019, op cit

[39] *The Guardian*, September 2019, '1% of English residents take one-fifth of overseas flights, survey shows'

[40] afreeride.org/

[41] R Carmichael, October 2019, *Behaviour change, public engagement and net zero. A report for the Committee on Climate Change*

[42] Oliver Wyman, 2017, *Airline economic analysis, 2016-2017 edition,* p 52 , table 73

[43] In our business as usual scenario we have removed the effect of carbon pricing on demand which is included in the DfT's figures (11 per cent reduction in demand by 2050), since this would require new policy to be implemented. We also removed the assumption that sustainable aviation fuels (SAF) would reach five per cent market penetration as this may not happen without government intervention in the market. We kept the assumption that the airline fleets would improve their fuel efficiency at a rate of one per cent per year as this is likely to happen due to market forces without any intervention. This gave our headline business as usual emissions figure of 45.40 $MtCO_2$ by 2050, with the caveat market sensitivities may increase or decrease this figure by around 15 per cent.

[44] DfT, October 2017, op cit

[45] A O'Connell, et al, 2019, 'Considerations on GHG emissions and energy balances of promising aviation biofuel pathways' in *Renewable and sustainable energy reviews*

[46] DfT, October 2017, op cit, p 53

[47] Transport and Environment, October 2018, *Roadmap to decarbonising European aviation*

[48] DfT, October 2017, op cit, p 53

[49] D S Lee, December 2018, op cit

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**The flight path to net zero**
Making the most of nature based carbon offsetting by airlines

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