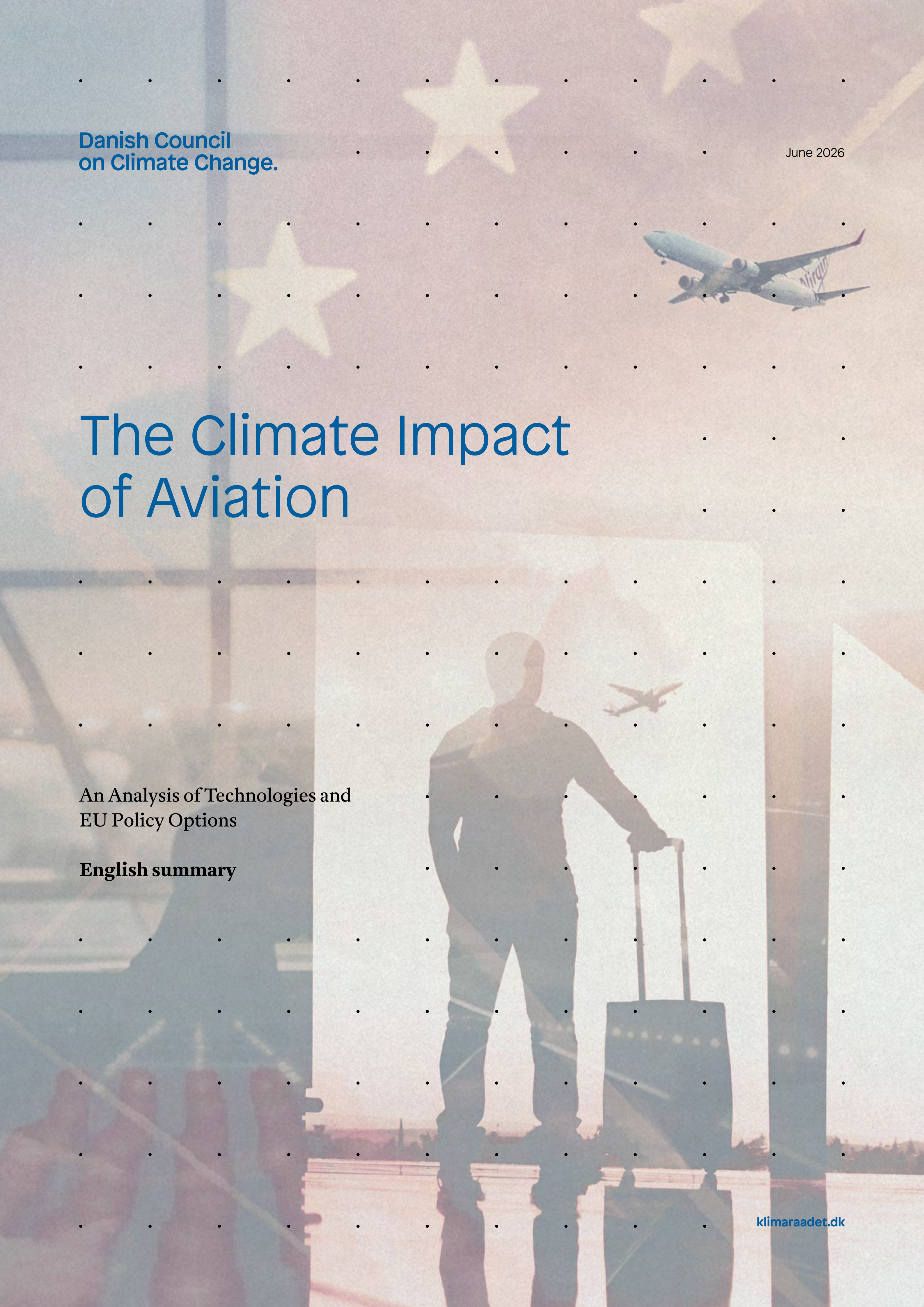
Danish Council on Climate Change.

June 2026



The Climate Impact of Aviation

An Analysis of Technologies and EU Policy Options

English summary

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Danish Council on Climate Change.

About the Danish Council on Climate Change

The Danish Council on Climate Change is the independent and statutory advisory body on climate change to the Danish Government. The Council is composed of experts with broad expertise and high level of climate-relevant academic knowledge. The Council provides impartial advice on Denmark's transition to a climate-neutral society by 2050.

The Climate Impact of Aviation
An Analysis of Technologies and EU Policy Options
(English summary)

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Luftfartens klimapåvirkning
En analyse af teknologier og EU's reguleringsgreb

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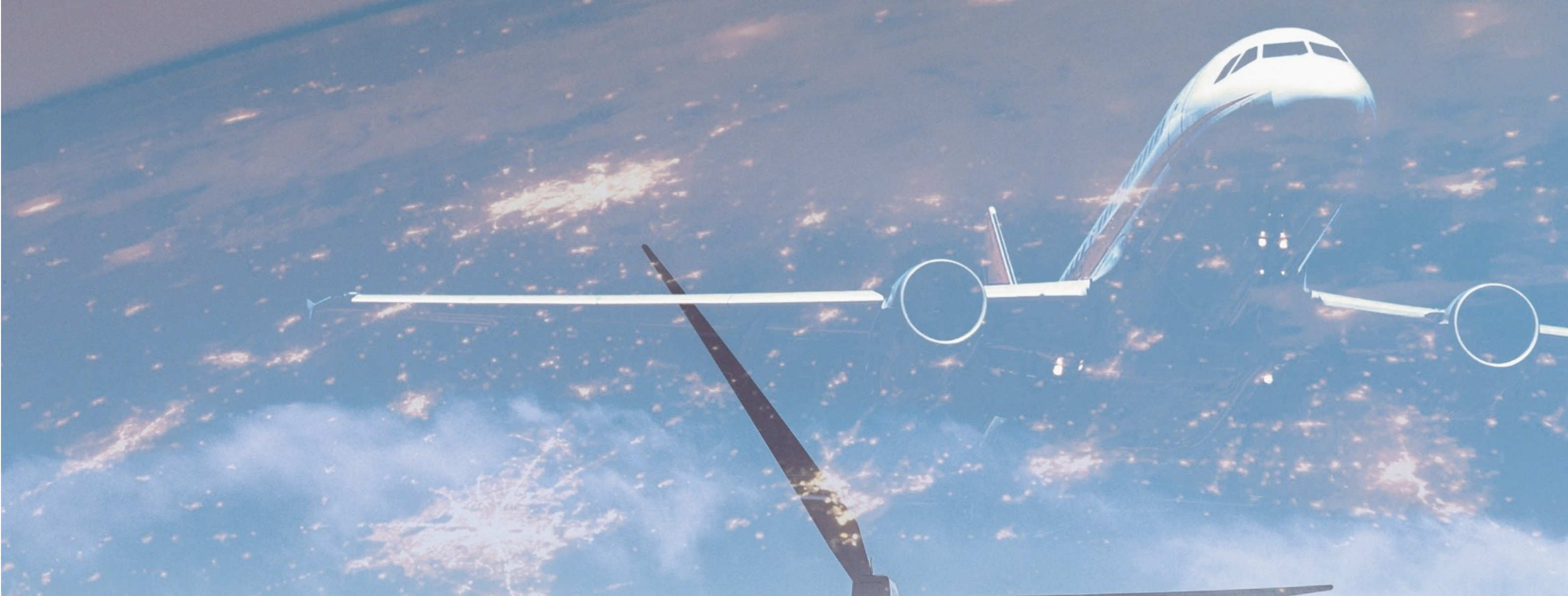
Nikolaj Plads 26, 2. sal
1067 København K
+45 22 68 85 88
Mail@klimaraadet.dk
Klimaraadet.dk

Front page design: B14

The Danish Council on Climate Change

Peter Møllgaard
Bente Halkier
Bo Jellesmark Thorsen
Brita Bye
Per Heiselberg
Marie Trydeman Knudsen
Marie Münster
Marit-Solveig Seidenkrantz
Christina D. Tvarnø



Demand for air travel continues to grow worldwide, increasing its impact on earth's climate. Yet global regulation of aviation emissions remains largely ineffective. In response, the EU has introduced carbon pricing, which currently cover flights within the EU and mandates for blending biofuels and synthetic fuels into aviation fuel. These regulatory measures are due to be reviewed in 2026 and 2027, providing an opportunity to review and improve the effectiveness of the regulations.

In this report the Danish Council on Climate Change explores how the climate impact of aviation can be reduced and examines implications of specific changes to the EU's key climate related aviation policies at a time when the political agenda is characterised by various crises and challenges. The Council also scrutinizes the EU compliance rules currently in place to ensure low carbon footprints from the technologies relevant to the aviation sector.

Contents

Main conclusions

Technology development is crucial for reducing the climate impact of aviation

The historical and continuous growth in international aviation activity is significant, and greenhouse gas emissions from aviation are not on track to reach net-zero. In addition, aviation affects the climate through the aircraft contrails often seen in the sky and through other so-called non-CO_2 effects. There are several ways to reduce the climate impact of aviation and the analysis of the Danish Council on Climate Change shows that early development and deployment of technologies is crucial.

Some technologies offer solutions that reduce aircraft emissions and other offset emissions from aviation through permanent negative emissions. Offsetting means that aviation industry actors continue to use fossil fuels but compensate for their emissions by purchasing carbon credits representing carbon capture and storage in another sector corresponding to emissions from fossil aviation fuels.

Most technologies with significant reduction potential are difficult to scale up quickly

Most of the technologies that could, in theory, enable aviation to reach net zero emissions are currently only on the verge of technological maturity, while also being costly and highly resource intensive. For biofuels, the use of bioresources is a particular drawback, while for synthetic fuels, the main challenge is the consumption of non-fossil electricity in a power system not yet fully transitioned.

The Danish Council on Climate Change examines two different ways of compensating for aviation emissions via deployment of permanent carbon removal technologies. One option is BECCS, which captures CO_2 from flue gas at bio-energy plants or other plants and stores it permanently underground. This solution involves significant consumption of scarce bioresources. Another option is DACCS, which captures CO_2 directly from the air and stores it permanently underground. Both technologies require underground CO_2 storage capacity. This capacity may be limited and is also expected to accommodate CO_2 from other sectors as well as CO_2 removed from the atmosphere. In addition, using BECCS and DACCS to offset emissions from aviation maintains the sector’s dependency on fossil energy sources and associated infrastructure.

Horizontal measures such as energy efficiency and contrail avoidance rerouting are useful solutions, but they are not sufficient on their own. Overall, significant challenges remain in relying on technologies to fully address climate impact of aviation.

Flying less will ease the challenge

Although there is no doubt that technology will be crucial to reducing aviation climate impact, the challenges described above also make it clear that reducing this impact will become significantly easier, if people fly less. EU legislation plays an important role both in promoting genuine low-carbon technologies and in incentivising people to fly less by affecting airline ticket prices.

EU compliance rules should ensure low climate impact from technologies

The EU regulates emissions from European aviation through the Emissions Trading System and through increasing blending requirements for biofuels and synthetic fuels in aviation jet fuel. Regarding the fuel blending mandate, it is crucial that the corresponding greenhouse gas inventory rules for compliance are robust if the mandate is to ensure a genuine reduction in climate impact. The Danish Council on Climate Change finds that not all emissions from biofuels and synthetic fuels are fully accounted for, and that the EU compliance rules can be strengthened further to reduce the carbon footprint.

EU policy should promote technology and the polluter pays principle

By expanding the scope of the Emissions Trading System to cover emissions from all flights departing from the EU, rather than only intra-European flights, the EU can extend the advantages of the current system. The carbon allowance price reduces greenhouse gas emissions cost-effectively, particularly through energy efficiency as it will reduce air travel due to the impact on airline ticket prices. However, the ETS is not sufficient in its own as the carbon allowance price is too low to drive technology development in the aviation sector. Thus, sector-specific regulation such as the fuel blending mandate for aviation is relevant.

However, as the analysis of the Danish Council on Climate Change shows there are currently considerable challenges related to upscaling biofuels and synthetic fuels. Consequently, it is relevant to increase technology neutrality in the regulation. This can be achieved by allowing DACCS as a compliance option under the fuel blending mandate, as an alternative to biofuels and synthetic fuels, provided that the overall level of ambition is maintained. Moreover, the Council finds that EU should regulate global warming impacts from non-CO_2 effects and the sector's consumption of land-use intensive bioresources.

Due to the high costs of available technologies in the aviation sector it should be considered whether the level of activity is proportionate to its climate impact. Today, neither airlines nor passengers are faced with the true costs for society of flying. By ensuring that polluters pay a higher share of the costs of emissions, the EU can effectively reduce aviation activity.

Recommendations

Ensure robust carbon footprint compliance rules for technologies

- **The EU should strengthen its existing accounting rules for biofuels and synthetic fuels.** The EU should make all biofuels and synthetic fuels subject to carbon footprint requirements and tighten the rules to ensure accurate inventory of emissions and to further reduce the climate impact of biofuels and synthetic fuels.
- **The EU should ensure accurate accounting of the climate benefit of carbon credits.** If aviation industry actors are to be allowed to fulfil their fuel blending obligations through the purchase of carbon credits from permanent negative removals of CO_2, those credits should only be allocated the share of the climate benefit that is in fact financed by the carbon credit. If the climate benefit of a project is co-financed through state aid or sales to the Emissions Trading System, carbon credit purchases should only be allocated a proportionate share of that climate benefit.

Strengthen the regulation of climate impacts

- **The Emissions Trading System should be expanded to include all departing flights.** The expansion should be designed to ensure appropriate interaction with other sectors covered by the Emissions Trading System, as well as with aviation-related regulation at both the EU and UN levels. An expansion would also help ensure that the EU's share of international aviation emissions is on track towards net-zero.

- **The EU should regulate non-CO_2 effects.** The EU should regulate aviation non-CO_2 gases and particles that affect the climate. In the short term, the EU could e.g. reward airlines actively avoiding contrails by rerouting or airlines using low-aromatic fossil jet fuel. In the 2026 revision, non-CO_2 effects should also be integrated into the Emissions Trading System, at least based on conservative assumptions about the climate impact. Once the evidence base is sufficiently robust, non-CO_2 effects should be fully integrated into an expanded Emissions Trading System equivalent to the CO_2 emissions.

- **The EU should reduce the consumption of bioresources.** The EU should introduce measures to limit the consumption of bioresources in the long term. Within the current regulatory framework, the EU has several options, including strengthening existing accounting rules for the use of biogenic CO_2 in the production of synthetic fuels.

Increase flexibility in the sector-specific regulation

- **Sector-specific regulation of aviation should be maintained.** The EU should maintain regulation of aviation emissions through the Emissions Trading System, complemented by a sector-specific regulation. The current fuel blending mandate and its level of ambition should be maintained and enforced to provide a stable and clear incentive across the aviation sector and the entire value chain of the fuel industry.

- **Offsetting emissions through DACCS should be allowed as a flexible compliance option under the blending mandate.** The EU should allow compensation of emissions through DACCS specifically as a flexible compliance option under the overall blending obligation in *ReFuelEU Aviation*. However, the DACCS option should be subject to periodic reviews and ongoing evaluation and be conditional to full compensation of the aggregated climate impacts across sectors. This is due to e.g. the drawback of continued fossil fuel consumption and the uncertainty associated with CO_2 storage capacity.

Make costs explicit and prioritise support for development over operating subsidies

- **The full costs should be reflected in ticket prices.** Currently, the EU subsidises the price gap between alternative fuels and fossil fuels, thereby lowering the costs of flying. These subsidies should be reduced or fully abolished so that passengers face the true costs of flying through the ticket prices.

- **Financial support should prioritise development support over operating subsidies.** The EU should aim to reduce investment risks in biofuel and synthetic fuel industries and other relevant technology areas, including DACCS, electric aircrafts and non-CO_2 mitigation technologies, through support for development and early-stage scale-up.

English summary

1.1 Introduction

Aviation relies heavily on fossil fuels, driving climate change

Air travel has historically relied on fossil jet fuel, an energy-dense fuel capable of powering an entire aircraft into the air. It is also easy to handle, and the current fleet and infrastructure are optimised for fossil aviation jet fuel.

The problem is that the climate and environmental costs of fossil jet fuel are not reflected in ticket prices. As a result, flying is too cheap from a societal perspective.

According to the European Commission's Joint Research Centre, international aviation emissions increased by 89 percent from 1990 to 2023.[1]

Demand for air travel continues to grow

Air travel has become a common means of transport, and an increasing number of people around the world can afford to fly. The COVID-19 pandemic led to a sharp decline in global air traffic in 2020 and 2021, but global demand for air travel is now back to pre-pandemic levels.[2]

Energy efficiency improved by more than 2.5 percent per passenger kilometre annually from 2010 to 2019. However, these efficiency gains were insufficient to outweigh the growth in emissions from increasing passenger numbers.[3]

Without existing international regulation, emissions from international aviation are projected to double – and potentially even triple – between 2019 and 2050 as air traffic continuous to grow.[4]

The UN recognises the negative climate impact of aviation and regulates emissions through ICAO

The Paris Agreement aims to keep increase in global average temperature below 2°C degrees and pursuing efforts to limit it to 1.5°C.

Under the Paris Agreement, parties are obliged to set national climate targets or so-called National Determined Contributions for their territorial emissions. These targets primarily include domestic aviation and generally exclude international aviation. In the case of the EU, however, emissions from flights between Member States are also included, because the EU has a single overall climate target covering all EU Member States.[5] The Paris Agreement therefore covers part of aviation emissions, but by no means all of them.

Under the Kyoto Protocol, which preceded the Paris Agreement, responsibility for addressing emissions from international aviation was assigned to the UN's International Civil Aviation Organization (ICAO).[6]

ICAO has 193 Member States and has adopted an aspirational goal of achieving net-zero emissions from international aviation by 2050. However, it has not adopted policy measures sufficiently to achieve this goal.

ICAO's policy framework covers around 85 percent of international aviation emissions

ICAO's main policy instrument for addressing international aviation emissions is CORSIA (the *Carbon Offsetting and Reduction Scheme for International Aviation*).[7] Under CORSIA airlines are required to meet emissions reduction obligations either by reducing their own CO_2 emissions or by purchasing eligible CORSIA carbon credits.

CORSIA will gradually expand to cover emissions from more countries. From 2027 onwards, the scheme will cover around 85 percent of CO_2 emissions from international aviation, with the remaining 15 percent originating from countries that are not covered by the scheme.[8] As international aviation accounts for around two-thirds of all aviation emissions,[9] CORSIA will cover approximately 60 percent of all aviation emissions.

Figure 1.1 illustrates how emissions from international aviation are projected to develop towards 2050 due to increased activity in a scenario without global regulation. The figure also shows the effect of the CORSIA's emissions reduction and offsetting requirements. Offsetting occurs outside the aviation sector and are therefore not part of aviation's own emissions.

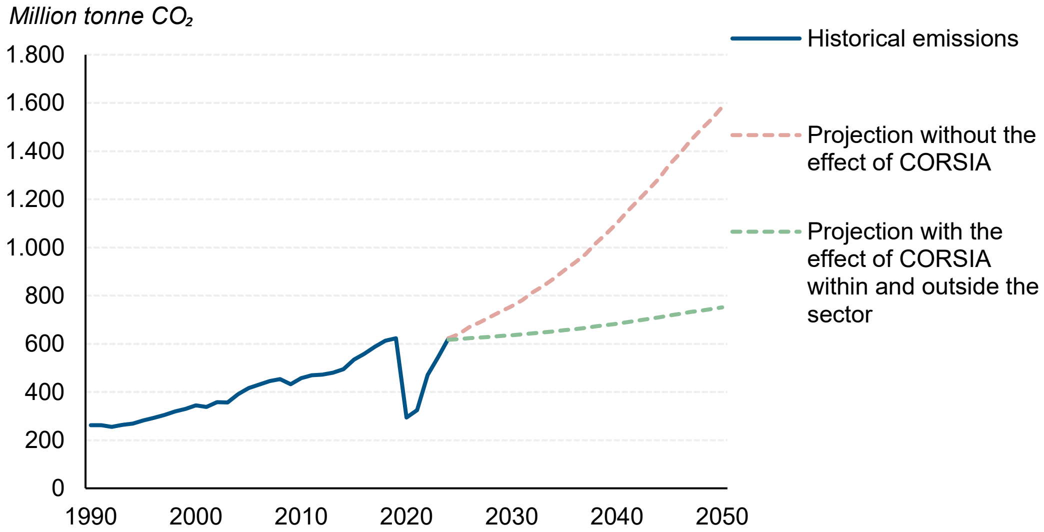


Figure 1.1 Emissions towards 2050 with and without the effects of CORSIA

Note 1: The emissions are from international aviation, corresponding to approximately two-thirds of total aviation emissions.

Note 2: The figure includes CORSIA covering 85 percent of international aviation emissions.

Note 3: The projection is shown as the average of a high and a low scenario. Several generalised assumptions mean that the figure should be interpreted with caution.

Sources: Climate Action Tracker 2025[10] and the Danish Council on Climate Change.

ICAO's current framework is insufficient to achieve net-zero emissions

Although ICAO has adopted an aspirational goal of achieving net-zero emissions from international aviation by 2050, it has not adopted policy measures sufficient to achieve this goal.

First, CORSIA currently requires emissions reductions or offsetting equivalent to only 15 percent of 2019 emissions. Second, as noted above, CORSIA's reduction and offsetting requirements are expected to cover only around 85 percent of emissions from international aviation from 2027 onwards. Figure 1.1 illustrates that emissions from international aviation remain far from net zero under the current framework.

Third, CORSIA's reliance on offsetting through carbon credits has been criticised for not representing fully and genuine climate benefits. The criticism concerns:

- whether the credits in fact reduce the claimed emissions reductions, and
- the lack of additionality – that is, whether the reductions would have been implemented by other actors anyway and therefore do not generate additional climate benefits.

Finally, CORSIA does not address non-CO_2 emissions from aircraft, as the aspirational goal of net-zero only concerns greenhouse gas emissions.

Air travel affects the climate through more than greenhouse gas emissions

The combustion of aviation jet fuel emits greenhouse gases, but it also releases other substances affecting the climate. These are referred to as non-CO_2 effects.

The most significant non-CO_2 effects, both today and historically, are associated with the formation of contrails and cirrus clouds as well as from nitrogen oxide emissions (NO_X). The climate impact from contrails and cirrus clouds is particularly pronounced in certain zones of the atmosphere, typically at altitudes of 8-18 kilometres under specific atmospheric conditions characterised by low temperatures and high relative humidity.[11] Box 1.1 explains non-CO_2 effects.

Box 1.1 Non-CO_2 effects from aviation

The following non-CO_2 effects from aviation have the largest impact on the climate:[12]

- **Water vapour.** Water vapour has a warming effect and thus affects the climate in the same way as a greenhouse gas.
- **Contrails.** Contrails are formed when water vapour condenses around emitted particles such as soot particles and freezes into ice crystals. Contrails can both reflect sunlight, which has a cooling effect, and retain outgoing heat radiation, which has a warming effect. Overall, they are assessed to have a net warming effect.
- **Cirrus clouds.** Under particular atmospheric conditions, contrails can develop into artificial cirrus clouds that may cover large areas. Like contrails, these clouds have both a warming and a cooling effect, as they both reflect sunlight and retain outgoing heat radiation. Similarly, the warming effect is overall assessed to be dominant.
- **NO_X.** NO_X emissions have several different effects. Most importantly, they contribute to the formation of ozone (O_3), which is a greenhouse gas with a warming effect. NO_X emissions also reduce the concentration of methane (CH_4) in the atmosphere, resulting in a cooling effect. Overall, the warming effect is assessed to be dominant.
- **Soot particles.** Soot particles both contribute to contrail formation and absorb solar radiation. The particles therefore contribute to warming in several ways.
- **SO_X.** SO_X forms sulphate particles that reflect sunlight and therefore have a cooling effect, in contrast to soot particles.
- **Other substances.** Several other substances also contribute to non-CO_2 effects, for example unburned hydrocarbons and carbon monoxide (CO).

The impact of non-CO_2 effects on global warming is significantly greater when assessed over a 20-year time horizon than over a 100-year time horizon. This is elaborated on in the Danish Council on Climate Change's *Status Outlook 2026*. The magnitude of non-CO_2 effects relative to CO_2 is estimated, with considerable uncertainty, to be a factor of 1.9 over a 20-year time horizon and a factor of 0.4 over a 100-year time horizon.[13] It is necessary to choose a time horizon in order to compare the effects. Non-CO_2 effects from contrails are largest over Europe, the United States, and the North Atlantic.[14]

The EU leads the way in global aviation regulation

The UN's global aviation regulation has proven ineffective in reducing emissions. The EU has as a result adopted its own regulation, which intends to reduce the climate impact of the EU's share of international aviation.

EU regulation currently consists of two key tools:

- **The Emissions Trading System (ETS1).** Airlines must purchase and surrender allowances corresponding to their CO_2 emissions from flights *within* the EU's borders. Airlines also must report on non-CO_2 effects.
- **The fuel blending mandate in *ReFuelEU Aviation*.** The mandate came into effect in 2025, when 2 percent biofuels, synthetic fuels etc. be blended into aviation jet fuel. The blending requirement increases gradually to 70 percent in 2050. There are also separate a sub-mandate specifying minimum shares of synthetic fuels. Finally, there are requirements for the carbon footprint of the blended fuels across their value chain. Biofuels are bio-based aviation fuels that can be produced using various bioresource inputs. Synthetic fuels are synthetic aviation fuels produced primarily by utilisation of electricity to generate hydrogen and captured CO_2. The blending mandate covers European airports and therefore emissions from flights *within* the EU and flights departing from EU airports.

Figure 1.2 shows emissions from European aviation and which of them are covered by EU regulation.

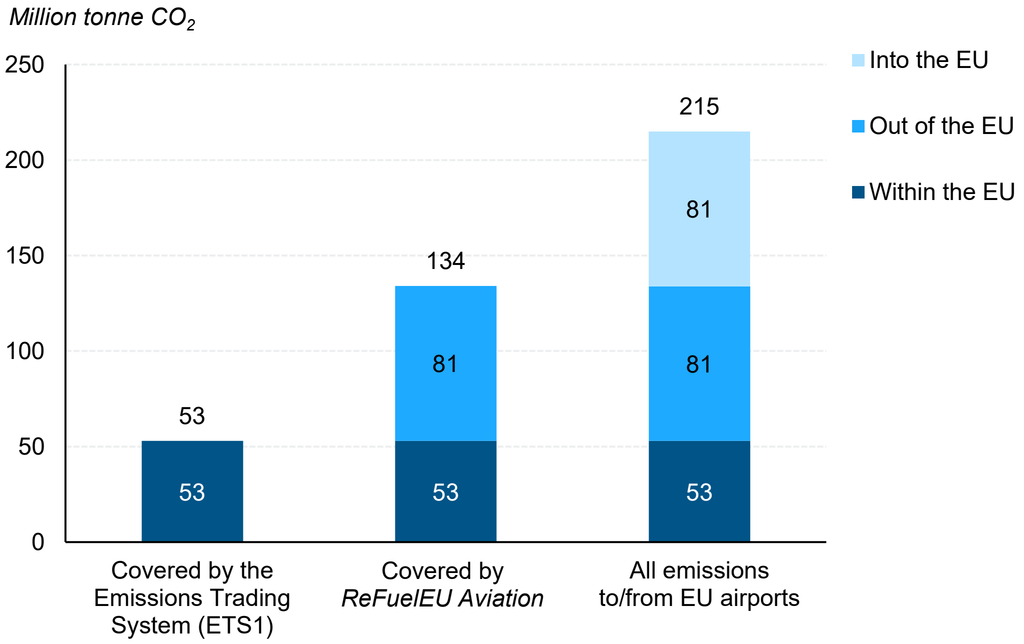


Figure 1.2 CO_2 emissions from aviation in 2023 and EU regulation

Note 1: The figures do not reflect non-CO_2 effects.

Note 2: CO_2 emissions from aviation within the EU increased to 63 million tonne in 2024[15], while CO_2 emissions from aviation to/from the EU and globally are expected to have increased since 2023[16].

Sources: European Environment Agency[17], EASA[18] and the Danish Council on Climate Change.

Emissions from flights within the EU are covered by the EU's climate targets and thus by obligations under the Paris Agreement. This is illustrated by the dark blue section of the figure. With *ReFuelEU Aviation*, the EU has ensured that half of the emissions from flights in and out of the EU are covered by EU regulation. This is shown by the medium blue section of the figure.

The EU's most important aviation regulations are to be reviewed in 2026 and 2027

The Emissions Trading System (ETS1) and the fuel blending mandate are to be reviewed in 2026 and 2027, respectively. Several key topics can be expected, including three examples of issues with the potential to increase and maintain climate ambition:

- **Expanded Emissions Trading System.** A potential expansion concerns covering emissions from flights out of the EU, whereas the current system only covers flights within the EU. As early as May, the European Commission announced that its proposal includes an expansion.[19] The emissions are shown in medium blue in Figure 1.2.
- **Non-CO_2.** EU may propose incentives to reduce non-CO_2 effects from aviation.
- **Blending mandate.** The *ReFuelEU Aviation* regulation must be reviewed with a focus on the requirements and field of application of the regulation, and on the implications for the EU's competitiveness and cost-effectiveness.

Negotiations are taking place against a backdrop of uncertainty and geopolitics

There are currently many political dynamics in the EU that may pull the upcoming negotiations on aviation in different directions.

The war in the Middle East in early March 2026 and other geopolitical developments are causing energy prices, including fuel prices, to fluctuate more than they have for many decades. This increases the political focus on both energy prices and short-term security of supply. It also gives rise to a deeper and more long-term political desire for strategic independence, and thus for the competitiveness of European businesses and for industrial policy.

The climate and competitiveness agendas are being linked in different ways

Some European Member States see major synergies between a green transition and increased competitiveness, security of supply, and strategic autonomy. By contrast, other Member States believe that the EU's climate efforts put unnecessarily heavy pressure and administrative burdens on European industry and citizens at a difficult place in time.

The imminent negotiations on the EU's climate regulation of aviation in 2026 and 2027 will take place during a period in which the European Commission has presented a number of different relaxations and options for flexibility in different climate policies at the request of some Member States. These include, for example, the EU's 2040 target, the postponement of the new Emissions Trading System for transport and heating etc. (ETS2), and relaxations in the climate regulation of the automotive industry.

1.2 The analysis of the Danish Council on Climate Change

The Danish Council on Climate Change examines technological and regulatory options

The Danish Council on Climate Change (DCCC) first examines how the climate impact of aviation can be reduced. It then examines whether the EU's accounting rules in fact ensure a low carbon footprint from aviation technologies and, finally, what the implications of changing different elements of the EU's climate regulation of aviation may be. The report concludes with brief perspectives on Denmark's opportunities to act as a frontrunner country.

Figure 1.3 illustrates the structure of the Danish report and the content of the chapters.

1. Chapter 1 introduces the context of the analysis and highlights the key results, conclusions and recommendations.
2. Chapter 2 outlines the Danish Council on Climate Change's analysis on how the climate change impact of aviation can be reduced.
3. Chapter 3 introduces the current EU legislation, and the Danish Council on Climate Change examines how effectively the EU compliance rules ensure a low greenhouse gas footprint of aviation technologies.
4. Chapter 4 discusses a range of policy options based on selected conclusions from chapters 2 and 3.
5. Chapter 5 briefly states possible ways for Denmark to act as a frontrunner considering the EU legislation.

Figure 1.3 Structure and content of the report

Source: The DCCC.

The report focuses on technological and regulatory options for the EU. As part of the analysis, reduced flying is considered as a mitigation measure, as are the effects of ticket prices on travel behaviour. However, the analysis does not examine other policy instruments to reduce flying, such as modal shifts to rail and the normalisation of low-carbon travel behaviour.

The Danish report contains conclusions in chapters 2, 3, and 4, but only recommendations for chapters 3 and 4, as these concern EU regulation.

The time perspective for the report's advice is primarily the next 10 to 15 years

The analyses in the report are intended to provide a basis for advice ahead of the imminent negotiations on the EU's key aviation policies, which are expected to have a major impact on the direction of aviation's climate-related development over the next decade. However, the analysis also relates to the development of aviation emissions towards 2050. Accordingly, when the report refers to the "short term", this means the next decade or so, while the "long term" refers to the period thereafter.

1.3 How can the climate impact of aviation be reduced?

The historical and continuing growth in international air travel is significant, and greenhouse gas emissions are not on track towards net zero emissions. In addition, aviation affects the climate through non-CO_2 effects. There are several ways to reduce the climate impact of aviation. Many of the technologies for reducing emissions are only on the verge of being mature, while also being expensive and highly resource intensive. There is no doubt that technology will be crucial to reducing the climate impact of aviation, but because of the challenges described above, it is clear that reducing this impact will become significantly easier, if people fly less.

There are different ways to reduce the climate impact of aviation

Figure 1.4 illustrates three overall ways to reduce the climate impact:

- Horizontal measures,
- technologies to reduce emissions
- technologies to offset emissions using permanent negative emissions.

Offsetting means that flights continue to burn fossil fuel, while an equivalent amount of CO_2, corresponding to the emissions from the fossil fuel, is captured and stored outside the sector. CO_2 can for example be captured from bio-energy plants (BECCS) or directly from the air (DACCS).

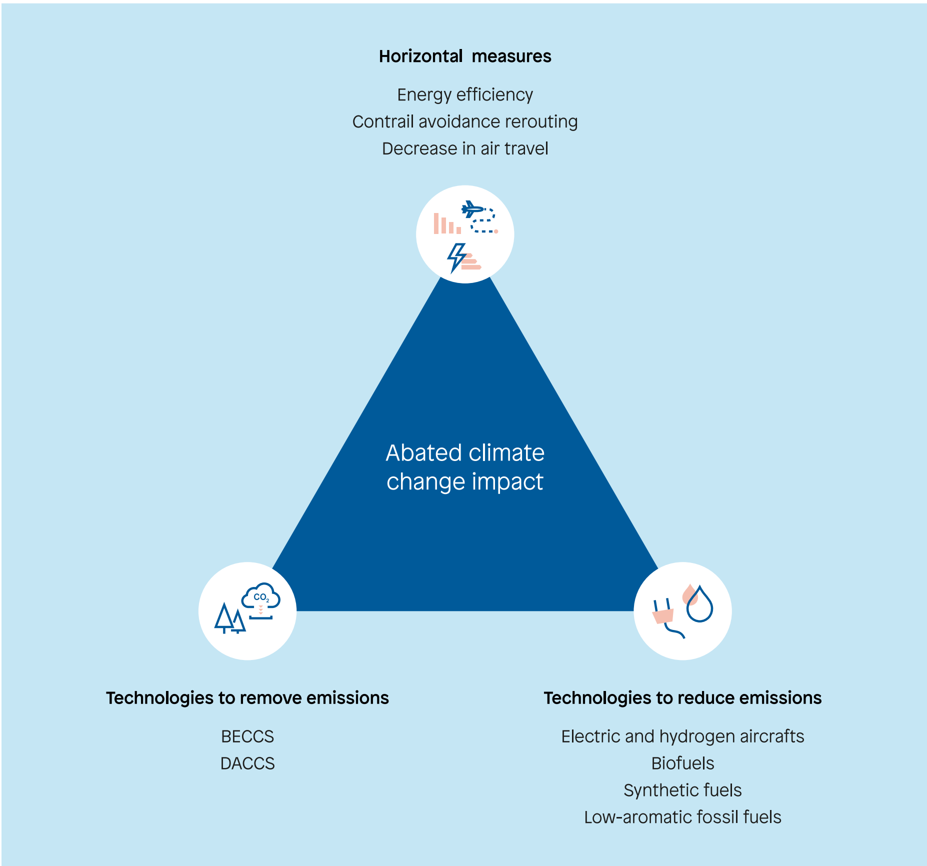


Figure 1.4 Horizontal measures, reduction and removal of CO_2e

Source: DCCC.

Since the aviation sector faces an enormous climate challenge, it is difficult to imagine a realistic pathway for bringing aviation to net-zero emissions without a combination of several solutions.

Energy efficiency, contrail avoidance rerouting, and decrease in air travel are horizontal measures that do not interfere with the choice between different technologies for reducing and for offsetting emissions. However, demand for air travel is expected to grow to such an extent that it will be relevant to deploy technologies that can both reduce the climate impact and also technologies that can offset it. The different technologies for reduction and offsetting are not mutually exclusive, but there may be different perspectives on whether specific technologies should be promoted.

The DCCC compares solutions in a systematic overview

The DCCC's analysis compares technologies for reducing the climate impact of aviation across a range of parameters covering climate, resources, maturity, and economics. In addition to the technologies, the analysis includes horizontal reduction measures: energy efficiency, contrail avoidance rerouting to reduce non-CO_2 effects, and decrease in air travel.

Figure 1.5 shows the results of the DCCC's comparison of technologies across the specific analytical parameters using a traffic light rating. The horizontal reduction measures are represented in a separate category alongside to provide a complete picture of the options for reducing the climate impact of aviation. The traffic light ratings are relative within each parameter and do not indicate whether a technology is good or bad in absolute terms.

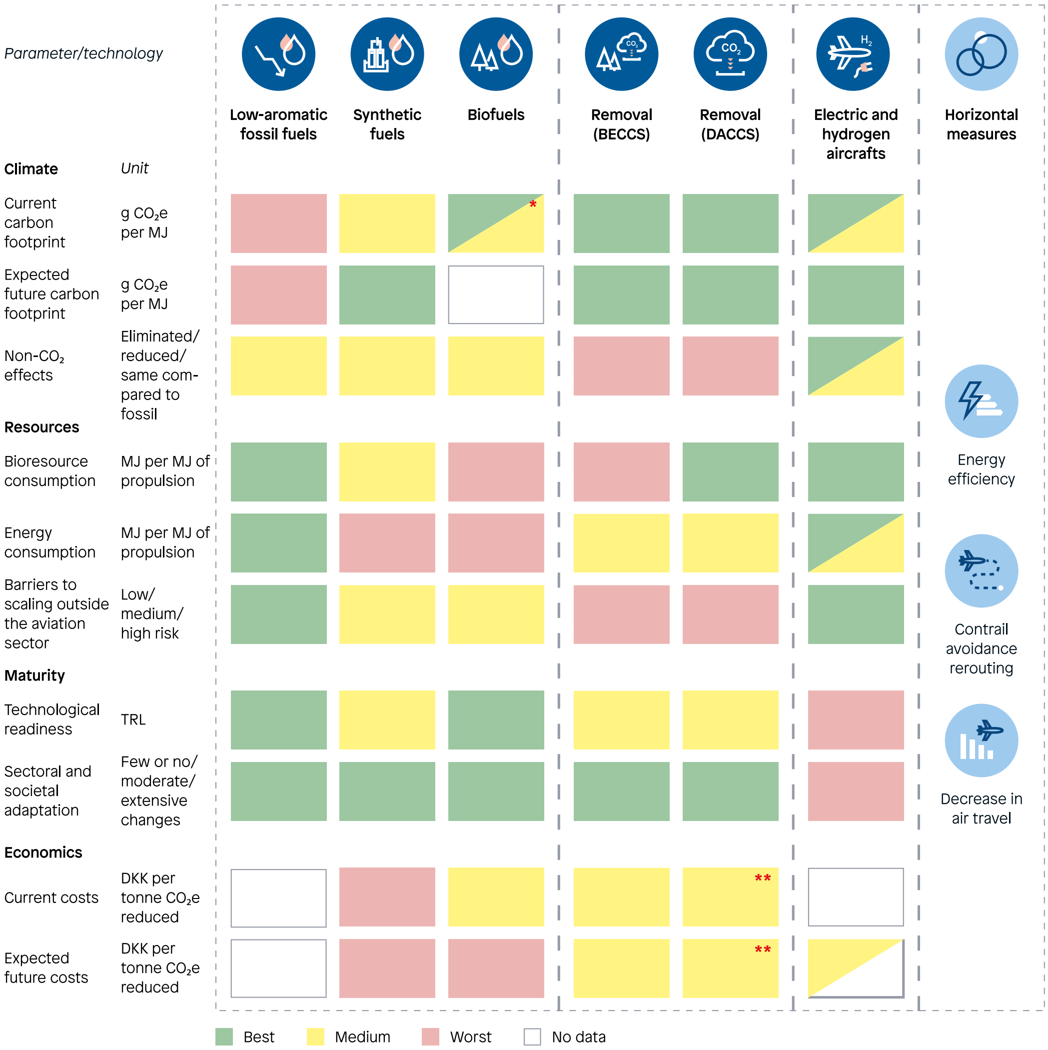


Figure 1.5 Analysis results for technologies

Note 1: Chapter 2 includes a version of the figure with average values, and the technical background report: *Teknologier til at reducere klimapåvirkning fra luftfart* includes a more detailed version showing the ranges behind those averages. The technical background report also covers the methodology and sensitivity analyses.

Note 2: * The red asterisk highlights that when substitution effects are taken into account, the carbon footprint of the biofuel HEFA is estimated at 135 g CO_2e per MJ, based on used cooking oil.[20] Furthermore, biomass is treated as carbon neutral in the figure, which should be qualitatively considered when interpreting the results. ** The two red asterisks highlight the considerable uncertainty associated with the costs of DACCS, including both capital and storage costs. In addition, any potential limitations in CO_2 storage capacity are not reflected in the cost estimates which is also true for BECCS.

Source: For sources see the technical background report: *Teknologier til at reducere klimapåvirkning fra luftfart*.

Each solution has its strengths and weaknesses

The DCCC's comparison shows that no single technology represents the optimal solution for the sector, as illustrated in Figure 1.5. Instead, each solution carries its own set of advantages and disadvantages. The key trade-offs are elaborated on below.

Carbon reduction technologies are important for the transition, but most are immature and expensive

Horizontal reduction measures such as energy efficiency, contrail avoidance rerouting and fewer flights can reduce the climate impact without requiring significant new technology development. While these measures are not sufficient on their own, they can complement other technological solutions and have an effect both in the short and long term.

Electric aircrafts are one of the most climate-friendly solutions, but the technology is still immature, requires major adjustments in sectoral and societal adaption, and is expected to be limited to shorter distances even in the future.

Biofuels and synthetic fuels offer relatively large technological potential. However, most of the production technologies are still only on the verge of being mature. They are also expensive - particularly synthetic fuels. Looking ahead, competition for the most climate-friendly residual and waste materials used in biofuel production will likely drive up costs over time, eventually making biofuels more expensive than electrofuels. However, there is significant uncertainty about the future price projections used in the analysis.

At the same time, scaling up these fuels requires access to large amounts of electricity and bioresources. For the technologies to have a low carbon footprint, the analysis shows, first, that the electricity must to a large extent be non-fossil, for example from renewables and nuclear power. Second, the bioresources must to a large extent be based on non-food crops, meaning bio-based wastes and residues. Biofuels and synthetic fuels therefore place significant demands on resources that are either limited in availability or will require a very high level of prioritisation to be made available in the required quantities.

It is relevant to take a closer look at removals technologies

It is also possible to reduce the climate impact of aviation in ways other than by reducing emissions from aircraft and fuel directly. This can be done by continuing to fly using conventional fossil fuels while offsetting emissions through permanent negative emissions. The DCCC considers only permanent negative emissions to be relevant, since it must be comparable to reduction technologies that are equally permanent in their effect. Two technologies are currently particularly relevant for this purpose:

- **BECCS.** Biogenic CO_2 is captured from the flue gas of bio-energy plants and stored permanently underground. BECCS stands for Bioenergy Carbon Capture and Storage. The climate benefit is attributed to the aviation sector through the purchase of carbon credits by the aviation industry actors.

- **DACCS.** CO_2 is captured directly from the atmosphere and stored permanently underground. DACCS stands for Direct Air Carbon Capture and Storage. The climate benefit is attributed to the aviation sector through the purchase of carbon credits by the aviation industry actors.

It is relevant to consider offsetting through permanent negative emissions for several reasons. First, based on the analysis, BECCS and DACCS do not appear to be more expensive than synthetic fuels, at least in the short term, while the price in the longer term is more uncertain.

Second, DACCS requires less use of bioresources, and non-fossil energy compared to biofuels and synthetic fuels. BECCS, on the other hand, involves a significant consumption of bioresources, at a level similar to the biofuels with the lowest consumption of bioresources among the biofuels included in this analysis.

Finally, BECCS and DACCS appear to be at the same technology readiness level as synthetic fuels. This is illustrated by all three being marked yellow in the analysis results in Figure 1.5 for the parameter on technological maturity.

There are also drawbacks to using permanent negative emissions

Although offsetting through BECCS and DACCS is considered worth exploring further, the analysis shows that these technologies also have drawbacks:

- Offsetting with BECCS and DACCS as solutions in aviation means that flights continue to use fossil aviation jet fuel.
- BECCS and DACCS use potentially limited geological CO_2 storage capacity.
- BECCS is associated with significant use of bioresources.

These drawbacks are briefly elaborated below.

Offsetting through BECCS and DACCS means flying on fossil aviation jet fuel

If offsetting with BECCS and DACCS is used as a solution in aviation, this will mean that flights continue to use fossil fuels and that the emissions from these fuels are neutralised elsewhere through offsetting with permanent negative emissions. The solutions will therefore not reduce dependence on fossil fuels, and fossil by-products will continue to enter the market. In addition, offsetting maintains a fossil industry for which infrastructure and value chains have been designed and subsidised. This may constitute a structural barrier that worsens the relative competitive position of new solutions.

BECCS and DACCS use potentially limited CO_2 storage capacity

There is currently uncertainty about the techno-economic scale of geological CO_2 storage capacity, both globally and across Europe. Scalability and cost levels for geological storage in Europe will remain uncertain until more detailed site-specific assessments have been carried out, and CO_2 has been stored continuously at large scale over several years.

A limitation in CO_2 storage capacity may consist both of a limitation in the total, time-independent capacity for geological storage of CO_2 and of a limitation in the scaling up of storage capacity in the coming decades.

If storage capacity proves to be limited relative to demand, political prioritisation of the use of the limited storage capacity will be needed. In that case, any offsetting of emissions in aviation may risk limiting offsetting of emissions in other sectors that may be vital to society and where emissions are also difficult to reduce. If so, the overall climate benefit across sectors would be smaller than the emissions from the aviation sector that it is intended to offset.

BECCS is associated with significant consumption of bioresources

The DCCC’s technology analysis shows that BECCS is associated with significant consumption of bioresources, whereas DACCS does not rely on the use of bioresources. The analysis also shows that there are probably not enough sustainable bioresources in the EU to meet aviation demand while also meeting competing demands from other sectors and material uses. The use of woody biomass for BECCS has a carbon footprint that is not included in the assessment of the technology. This should be taken into account when assessing how advantageous the technology is.

With offsetting, the reductions do not take place in the aviation sector

Technologies for offsetting aviation emissions do not generate reductions within the aviation sector itself. From a climate perspective, where the effort takes place is less important. However, it may be a focus and a political question whether each sector has a responsibility to reduce its own emissions. The DCCC has not based this analysis on the argument of sectoral distribution, nor on any derived implications for the development of the sector as a result.

Flying less will ease the challenge

Overall, reducing the climate impact of aviation is challenged by the fact that different technology choices each involve major challenges. First and foremost, the technologies are difficult to deploy quickly at large scale because they are not yet mature enough, because they cannot compete on market terms and because they draw on bioresources, non-fossil energy and CO_2 storage capacity.

The many challenges do not mean that technology can be dispensed with. Technology will be crucial to bringing aviation's climate impact towards net zero. But as many technologies are expensive and relatively immature, it is also clear that reducing the climate impact will become significantly easier, if people fly less.

Moreover, the major technological challenges will be easier to overcome if the horizontal reduction measures in the analysis are used by improving energy efficiency, contrail avoidance rerouting to reduce non-CO_2 effects and providing incentives to decrease air travel activity.

1.4 Does EU regulation ensure a low carbon footprint from aviation technologies?

If the blending mandate is to ensure a genuine reduction in climate impact, the underlying compliance rules must be robust. The EU has already taken significant steps to ensure a low life-cycle carbon footprint from biofuels and synthetic fuels. However, the DCCC finds it necessary to strengthen these rules and cautions against weakening them in future political negotiations. Otherwise, there is a risk that society will invest in solutions that are only marginally better than, or, in some cases, even worse than, conventional fossil fuels. Conversely, stronger rules have the potential to provide an effective and much-needed safeguard for the climate performance of biofuels and synthetic fuels. It is also important that inventory rules for offsetting emissions with BECCS and DACCS accurately account for the true climate benefits. This is particularly relevant if future negotiations open the possibility of permitting permanent carbon removals to compete with the blending of biofuels and synthetic fuels in meeting blending obligations.

The blending mandate is supplemented by compliance rules regarding the carbon footprint

Under the EU's blending mandate, requirements are set for the carbon footprint of biofuels and synthetic fuels. For the mandate to function effectively and deliver genuine climate benefits, these rules must be robust. The technology analysis by the DCCC shows that technologies may, in some cases, have a worse carbon footprint than fossil fuels if input resources are not accounted for properly. The DCCC therefore examines whether EU compliance rules for the inventory of carbon footprint ensure a low carbon footprint from biofuels and synthetic fuels.

The EU has also adopted rules for accounting for permanent carbon removals from BECCS and DACCS. Although these technologies cannot currently be used to comply with the blending mandate, they could become relevant for meeting aviation compliance obligations, should the EU decide to allow this. It is therefore also important to examine EU rules governing the climate impact of BECCS and DACCS.

Biofuels

EU compliance rules for biofuels should be strengthened

The EU has taken several steps to ensure a low carbon footprint for biofuels. For example, most eligible biofuel feedstocks must consist of waste and residues. This is a positive development. However, the DCCC finds that the rules on the carbon footprint of biofuels should be tightened by:

- making all biofuels subject to carbon footprint requirements, rather than only a subset of them;
- avoiding, as far as possible, the use of land-intensive primary bioresources, such as energy crops;
- requiring new biofuels to achieve a 70 percent reduction in carbon footprint relative to fossil fuels, in line with requirements of synthetic fuels; and
- including emissions associated with alternative uses of the resources used to produce aviation fuel, for example when used cooking oil is diverted from other applications to aviation fuel production.

Synthetic fuels

There is also scope to strengthen the rules on the carbon footprint of synthetic fuels

The EU's rules on the carbon footprint of synthetic fuels are designed, for example, to limit the share of fossil fuel in the electricity grid mix that is used in the production of synthetic fuels and other eligible fuels.

Although the DCCC considers the rules to be a reasonable and pragmatic attempt to achieve this objective, the Council also finds that the rules do not fully ensure that low-carbon electricity is not simply diverted from other uses and replaced by fossil-based electricity. It should, however, also be noted that only relatively small volumes of synthetic fuels are expected to be required before 2035.

The DCCC finds that the EU should:

- strengthen, and at least maintain, the rules on additionality for non-fossil electricity through temporal and geographical correlation, as the carbon footprint of synthetic fuels could otherwise increase quickly;

- bring forward the phase-out date for allowing fossil CO_2 to be treated as zero-emission in the carbon footprint calculation for synthetic fuel production, as the plants from which the CO_2 is sourced should also transition away from fossil energy.

BECCS and DACCS

Rules must be strengthened if offsetting is to be permitted as part of aviation's climate obligations

The EU may potentially allow the use of technologies that permanently offset emissions when the aviation climate obligations are reviewed. If so, it would be natural for the EU Carbon Removal Certification Framework (CRCF) Regulation,[21] to serve as the standard for certifying negative emissions projects. Regardless of where the compliance rules are placed within the regulation, it will be crucial that the EU:

- ensures that carbon credits are only allocated the share of the climate benefit that is financed by the carbon credit purchase, and that any co-financed climate benefits (e.g. through state aid or sales to the EU Emissions Trading System) are not attributed to the credit
- accurately measures the climate benefits of bio-based credits. In this analysis, the DCCC sets out key factors relevant for determining the climate impact of biomass consumption.

1.5 What are the implications of changing key elements of the EU's climate regulation of aviation?

Major changes may be on the way when the EU's Emissions Trading System (ETS) and the aviation fuel sector's blending mandate are reviewed in 2026 and 2027. The DCCC finds that the EU can achieve more comprehensive regulation by expanding the scope of the ETS to all flights departing from EU, regulating non-CO_2 and reducing the sector's consumption of land-use intensive bioresources. Continuing the approach of having sector-specific regulation in the EU has several advantages, even if this may be at the expense of cost-effectiveness in the short term. However, it is possible to increase technology flexibility even with sector-specific regulation. Allowing removals with DACCS as an alternative to blending biofuels and synthetic fuels is one option. However, several conditions must be met before the climate benefits add up. Finally, by letting consumers pay the actual costs the EU can dampen air travel.

The DCCC analyses EU regulation of aviation's climate impact

The key aviation policies in the EU are to be reviewed in 2026 and 2027. This applies to the ETS and the fuel blending mandate. The reviews provide an opportunity to increase climate ambitions, but they also risk weakening current policies. The DCCC discusses the implications of six potential policy options arising from the analysis of technologies and the mapping of the current legislation. The policy options are not recommendations from the DCCC. Rather, the DCCC's discussion of these options forms the basis for its recommendations. The policy options are:

- Policy option 1: Expanded scope of the Emissions Trading System
- Policy option 2: Regulation of non-CO_2 effects
- Policy option 3: Limiting the consumption of bioresources
- Policy option 4: Emissions Trading System without a blending mandate
- Policy option 5: Removals as a possible alternative to fuel blending
- Policy option 6: No future support for price gaps and fuel production

Policy option 1: The scope of the Emissions Trading System should be expanded to cover all flights departing from the EU

With policy option 1, the DCCC examines a situation in which the scope of the ETS is expanded to cover all flights departing from the EU.

The DCCC's calculations show that emissions from aviation can be reduced by around 5 percent in 2030 and around 10 percent in 2050 if the scope of the ETS is expanded to cover emissions from all flights departing from the EU. This is illustrated in Figure 1.6.

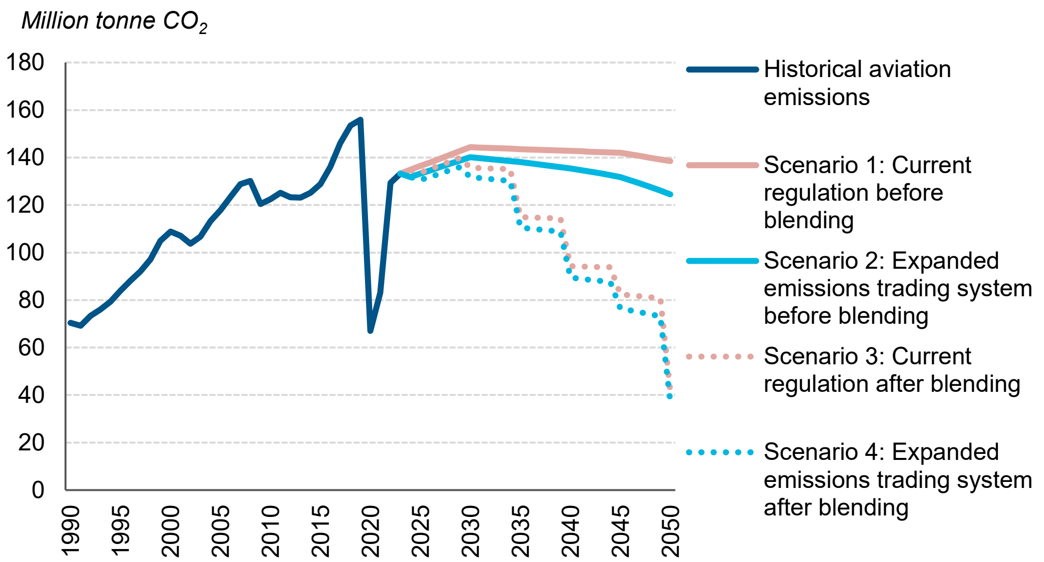


Figure 1.6 Development in greenhouse gas emissions from European aviation under different scenarios

Sources: EASA[22] and the DCCC.

The figure shows emissions from flights between EU airports, including domestic flights, as well as flights departing for destinations outside the EU. Four situations are illustrated in the figure. Situations 1 and 2 illustrate the effect of an expanded scope of the ETS without taking the current blending mandate into consideration. Situations 3 and 4 show the effect of an expanded scope of the ETS on top of the effects of the current blending mandate.

An expanded scope of the ETS would require additional allowances to be issued, thereby increasing the number of allowances in circulation and generating significant additional revenue for the EU. The revenue could help support the transition of the aviation sector or other sectors.

The size of the increase in allowances in circulation should reflect the expected future demand from the aviation sector as objectively as possible. There exists a risk that too many or too few allowances will be allocated politically, which would affect the carbon allowance price and the effectiveness of the system.

The DCCC recommends that the scope of the ETS is expanded to include all flights departing from the EU. The Council recommended this in *Status Outlook 2026*, and this sector analysis supports the recommendation.

Policy option 2: The non-CO_2 effects of aircraft should be regulated

With policy option 2, the DCCC examines how the non-CO_2 effects of aircraft can be regulated.

If non-CO_2 effects are included in the EU's ETS on the same basis as the climate impact of greenhouse gases, the market could potentially ensure the most cost-effective reductions of non-CO_2.

The DCCC recommends that non-CO_2 effects are regulated. In the short term, this could, for example, be done by rewarding airlines that actively avoid flying through atmospheric layers with a high risk of contrail formation or by introducing requirements for the aromatic content of aviation jet fuels.

In addition, the DCCC supports the intention of the current regulation to integrate non-CO_2 effects into the ETS. Non-CO_2 effects should, as a minimum, be integrated into the ETS as part of the planned review based on conservative assumptions about their climate impact, so that obvious reductions are not simply postponed while waiting for more developed accounting methods.

The DCCC recommended this in *Status Outlook 2026*, and this sector analysis supports the recommendation.

The DCCC also recommends that the European Commission examine models for requiring all remaining fossil aviation jet fuel to be gradually replaced with low-aromatic fossil jet fuel, as this would reduce non-CO_2 effects.

Policy option 3: The consumption of bioresources should be reduced

With policy option 3, the DCCC examines different ways within the current regulation in which the EU can reduce the consumption of bioresources. It is clear from the technology analysis that there is a limited availability of bioresources within the EU in the form of wastes and residues for aviation jet fuel.

In principle, to meet the EU's fuel blending mandate bioresources can be imported. However, as biomass is a scarce resource globally, this should be taken into consideration when relying on imports. Biomass is also becoming increasingly important for all countries, as the world moves towards net-zero emissions.

In addition to strengthening the EU's rules on the carbon footprint of biofuels, the EU can apply policy options that directly reduce the use of bioresources for aviation jet fuel. This can be done without changing the design of the current legislation fundamentally.

The DCCC recommends that the European Commission examine the implications of requiring hydrogen to be added to biofuels to increase carbon efficiency. The benefit of enhancing the carbon efficiency of biofuels must, among other things, be weighed against the fact that it would require additional consumption of non-fossil energy for hydrogen production.

In addition, the DCCC recommends that the EU strengthens the rules for the use of biogenic CO_2 for synthetic fuels. This is because wood accounts for around 80 percent of the EU's consumption of solid biomass for energy, and most biogenic CO_2 therefore comes from the burning of wood.[23]

Policy option 4: The Emissions Trading System should not be the only policy measure

With policy option 4, the DCCC examines a situation in which emissions from aviation are regulated solely through the ETS, and thus implicitly in which the fuel blending mandate in *ReFuelEU Aviation* is removed.

The DCCC's analysis shows that the carbon allowance price does not create sufficient incentive for investments in new technology to reduce emissions from the aviation sector, particularly in the short term. This is shown in Figure 1.7.

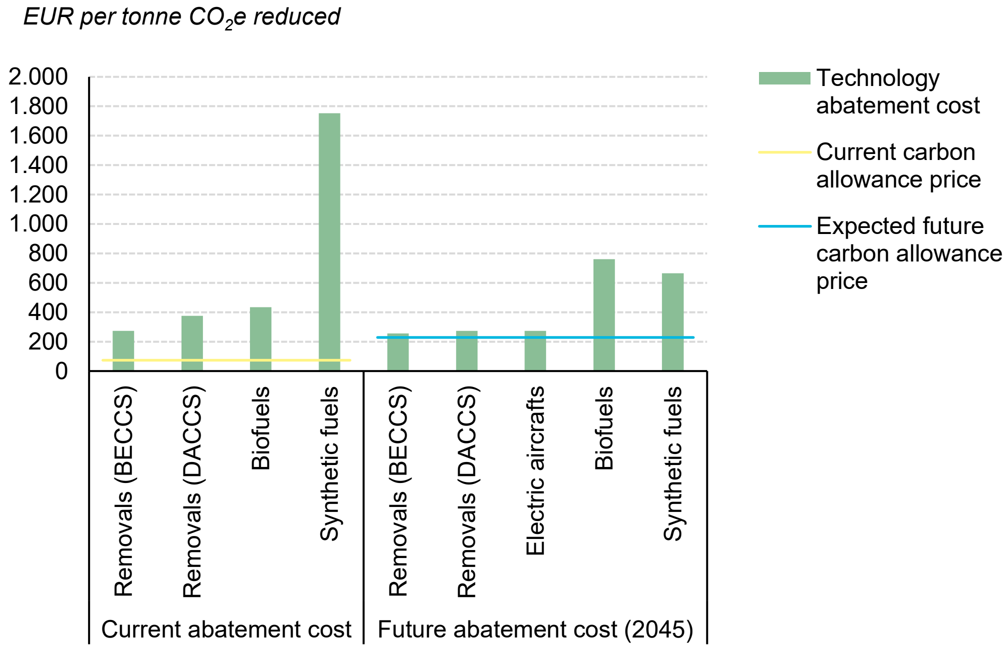


Figure 1.7 Additional cost of alternative technologies compared with fossil aviation fuel relative to the allowance price

Source: See the technical background report: *Teknologier til at reducere klimapåvirkning fra luftfart* for sources.

The figure shows that biofuels and synthetic fuels will not come into play, particularly in the short term, if the fuel blending mandate is removed and the ETS is the only regulation of the emissions from aviation, based on the price assumptions used in the analysis. This is shown by the fact that the columns for these fuels are above the carbon allowance price, particularly in the short term. The analysis assumes significant cost reductions in the future. For biofuels, an increasing biomass price is assumed.

In addition, this may have significant implications for the competitiveness of the other sectors covered by the ETS, as aviation will purchase allowances since this is the cheapest option for the sector. This is also shown in the figure. This would result in a higher carbon allowance price for the other sectors covered by the ETS.

Overall, the DCCC finds that there are several advantages to continuing the approach of having sector-specific regulation in the EU, even though this may be at the expense of cost-effectiveness in the short term.

Furthermore, removing or changing the fuel blending mandate and the associated sanction mechanisms that help ensure clear political signals would constitute a major change. This is particularly the case for the regulatory and political signal against a backdrop of recent calls to weaken the level of ambition in other EU climate policies. Overall, the DCCC therefore assesses that there are pragmatic and reasonable arguments for maintaining and enforcing the fuel blending mandate as the sector-specific regulation for aviation.

The DCCC recommends that the ETS should not be the only policy measure and that it should continue to be supported by sector-specific regulation such as the fuel blending mandate.

Policy option 5: The EU should allow DACCS as a solution for aviation to meet its climate obligations subject to several conditions

With policy option 5, the DCCC examines a situation in which offsetting with permanent negative emissions is allowed as a flexible option for meeting the fuel blending mandate, that is, as an alternative to blending biofuels and synthetic fuels.

In the DCCC's technology analysis, DACCS is cheaper than the average costs of biofuels and synthetic fuels and is at a similar maturity level to several of them. However, offsetting CO_2 emissions via DACCS maintains dependency of fossil fuels and continues to result in climate impacts from non-CO_2 effects and fossil by-products.

The DCCC assesses that BECCS should not be permitted as an offsetting option for aviation, due to its consumption of bioresources and because, as noted above, the climate impact of using biomass, – particularly wood – is not currently accounted for in the crediting framework under the EU Carbon Removal Certification Framework (CRCF) Regulation.

The DCCC recommends that offsetting with DACCS is allowed as an option for meeting the fuel blending mandate, on the condition that it does not dilute the overall effect on the climate. This should be ensured, among other things, by:

- Ensuring that carbon credits are only allocated the share of the climate benefit that is financed by the carbon credit purchase.
- Requiring the EU to also compensate for the climate impact from non-CO_2 effects and fossil by-products, if these are not adequately regulated elsewhere.

Policy option 6: The EU should ensure that passengers are exposed to the actual price and target financial support towards technology development

With policy option 6, the DCCC examines a situation in which the aviation sector, first, does not receive financial support from the EU to cover the price gap between fossil aviation jet fuels and biofuels and synthetic fuels and, second, does not receive financial support for fuel production.

The DCCC's calculations indicate that greenhouse gas emissions from aviation would overall be reduced by around 8 percent in 2035 and 18 percent in 2045 if no support is provided to cover the price gaps.

The DCCC recommends that the EU should allow the high costs of the aviation sector to be reflected to a greater extent in ticket prices, making flying more expensive and decreasing air travel activity. The EU should therefore remove financial support to minimise airlines' costs of purchasing alternative fuels.

However, the DCCC does not recommend stopping financial support for investments in technology development. Instead, the EU should work to ensure that financial support is provided for development and early scaling of the production of biofuels and synthetic fuels, as well as other relevant areas of technology development such as DACCS, electric aircraft, and technologies to reduce non-CO_2 effects.

The DCCC's recommendations to the EU to increase climate ambitions and flexibility

Overall, the EU can apply several policy options to reduce the climate impact of aviation. It is important to expand the scope of the ETS, as this would price the emissions from a larger share of European flights and incentivise further energy efficiency and a reduction in flying. It is also important to regulate emissions of non-CO_2 from flights, for which there is currently no incentive. In addition, the DCCC recommends that the EU should further limit the consumption of land-use intensive bioresources and strengthen the inventory rules to ensure low carbon footprints from the new climate technologies.

The ETS should not be the only policy measure, as the carbon allowance price is too low to drive technology development for aviation. Sector-specific regulation, such as the fuel blending mandate for aviation, is therefore relevant. And since there are substantial challenges to scaling up production of biofuels and synthetic fuels, it is relevant to increase technology neutrality without removing the sector-specific regulation or changing the design of the current regulation fundamentally. Major changes would increase investment uncertainty in the sector and weaken confidence in the long-term transition. Finally, flexibility prevents the risk of a negative impact on the climate if the development of one or more technologies do not meet expectations.

The DCCC therefore recommends allowing offsetting with DACCS as an alternative to biofuels and synthetic fuels in meeting the fuel blending mandate, while maintaining the level of ambition.

When technologies are expensive, there is reason to reconsider whether the level of aviation activity is in balance with the sector's climate challenge. The DCCC assesses that the EU should, to a greater extent, place the cost of the sector's transition on airlines and passengers, so that higher ticket prices provide a clearer and more appropriate signal to end users.

1.6 How can Denmark be a frontrunner country considering EU regulation?

In a brief final discussion, the DCCC considers measures through which Denmark can be a frontrunner country in the transition of the aviation sector. This applies to both national measures and cooperation with other countries.

Denmark can meaningfully make an additional effort

As a member of the EU, Denmark faces the same challenge as the union in relation to aviation. In Denmark too, the desire to fly is increasing, both for domestic and international flights.[24]

The DCCC lists several steps that Denmark could potentially take beyond its EU obligations, and which would be beneficial to strengthen, given the recommendations made at EU level in this report. These steps could be taken as a frontrunner country and help to address the challenges of the EU. The DCCC has not examined these in further detail or analysed their implications in this analysis. Denmark could, for example:

- Introduce requirements for low-aromatic fossil jet fuel in Danish airports, thereby helping to reduce non-CO_2 effects.
- Support the development of alternative fuel production in Denmark.
- Lead and participate in increased international cooperation on new technologies and infrastructure, for example in projects on electric aircraft routes in the Nordic region.
- Dampen demand for air travel by evaluating the level of the national passenger tax with a view to ensuring sufficient coverage of, for example, the climate impact and structural distortions relative to other modes of transport.
- Promote alternatives to air travel and thereby reduce demand for air travel.

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