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Department for Transport

Sustainable Aviation Fuel Mandate

Final stage Cost Benefit Analysis

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Contents

Glossary

ASTM American Society for Testing and Materials

AtJ Alcohol to Jet

BAU Business as usual

BECCS Bioenergy with Carbon Capture and Storage

BtL Biomass to Liquid

CBA Cost benefit analysis

CC(U)S Carbon capture, (utilisation) and storage

CORSIA Carbon Offsetting and Reduction Scheme for International Aviation

DAC Direct Air Capture

DACCS Direct air Carbon Capture and Storage

DESNZ Department for Energy Security and Net Zero (formerly part of the Department for Business Energy and Industrial Strategy, BEIS)

DfT Department for Transport

UK ETS Emissions Trading Scheme

FAME Fatty Acid Methyl Ester

FOAK First-of-a-kind

GHG Greenhouse gas

HEFA Hydroprocessed Esters and Fatty Acids

HVO Hydrotreated Vegetable Oil

IAS International Aviation and Shipping

ICAO International Civil Aviation Organization

IEA International Energy Agency

LCF Low Carbon Fuel

MSW Municipal solid waste

NPV Net Present Value

PtL Power to Liquid

RTFO Renewable Transport Fuel Obligation

SAF Sustainable Aviation Fuel

TAG Transport Appraisal Guidance

TRL Technology Readiness Level

UCO Used Cooking Oil

WtL Waste to Liquid

Executive summary

Background

1. In July 2021, the UK government published a consultation on introducing a sustainable aviation fuel (SAF) blending Mandate[1], which would place an obligation on fuel suppliers to supply a certain percentage of sustainable low-carbon aviation fuels from 2025. The Jet Zero Strategy[2], published in July 2022, set out the government's wider strategy for decarbonising the UK aviation sector, and identified SAF as one of six key measures with an important role to play in this transition.

2. The government's vision is for the UK to be a global leader in the development, production and use of SAF. The second consultation on the SAF Mandate published in March 2023 set out three pillars of the UK's SAF programme: 1) drive demand for SAF in the UK; 2) kickstart a UK SAF industry; and 3) work in partnership with industry and investors to build long term supply[3]. The Mandate is expected to help realise this vision and support the UK's SAF programme by supporting the expansion of supply by providing investors more certainty about the future level of SAF demand. The second consultation also considered in greater depth the options relating to the Mandate trajectory, buy-out prices, HEFA cap level and ambitions for the power-to-liquid (PtL) obligation.

3. This cost benefit analysis (CBA) accompanies the final government position on the SAF Mandate and sets out our analysis of the potential costs and benefits of the policy. The analysis uses a range of assumptions throughout in order to illustrate the potential economic outcomes associated with the final Mandate design. The results of a range of sensitivity tests are also presented to illustrate the sensitivity of the results when key assumptions are varied within reasonable bounds. Therefore, the scenarios provide an indication of possible outcomes, risks and benefits associated with SAF under alternative scenarios but are not predictions of what will happen under the Mandate.

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[1] https://assets.publishing.service.gov.uk/media/6305fca9e90e0729d7707973/sustainable-aviation-fuels-mandate-summary-of-consultation-responses-and-government-response.pdf

[2] https://www.gov.uk/government/publications/jet-zero-strategy-delivering-net-zero-aviation-by-2050

[3] https://assets.publishing.service.gov.uk/media/6424782560a35e00120cb13f/pathway-to-net-zero-aviation-developing-the-uk-sustainable-aviation-fuel-mandate.pdf

Final Mandate design

4. The Mandate sets a SAF uptake trajectory starting at 2% in 2025, reaching 10% in 2030 and 22% in 2040. These targets are aligned with the trajectory for SAF assumed in the emissions reduction trajectory set out in the Jet Zero Strategy.

5. The Mandate includes a buy-out mechanism which allows suppliers to meet the Mandate in the absence of sufficient SAF supply. The buy-out price is set at a level that balances the need to attract UK SAF supply from domestic and global markets, whilst also preventing any undue burden on industry or consumers in the event of higher-than-expected costs. Using updated evidence on production costs and greenhouse gas emission savings for various SAF pathways, a buy-out price equivalent to £4.70/litre is proposed.

6. A HEFA cap has been included in the Mandate to create space for more advanced fuels, which will be crucial for the Mandate to be met in the longer term. There is no cap on the level of HEFA during the first two years of the Mandate. From 2027 a HEFA cap will be in place, reducing the maximum share HEFA can contribute to SAF demand to 71% in 2030 and 35% in 2040.

7. A PtL obligation will be introduced from 2028 at 0.2% of total jet fuel demand, reaching 0.5% in 2030 and 3.5% in 2040. This will accelerate the development of this type of fuel which has reduced risk of feedstock competition and other negative environmental impacts. Based on updated data, the buy-out price for PtL is set at £5/litre.

Evidence and methodology

8. This CBA reflects significant enhancements to the methodology and assumptions used to assess the impacts of a SAF Mandate. This is informed by work commissioned from the Aviation Impact Accelerator (AIA), led by Cambridge University's Whittle Laboratory and the Cambridge Institute for Sustainability Leadership. This provided updated evidence on the expected costs, greenhouse gas savings and feedstock and energy demands associated with SAF production. We have independently validated this evidence against a range of other available literature.

9. The mandated level of SAF under the policy is defined as a percentage of aviation fuel used on UK departing flights. Expected aviation fuel demand is sourced from internal modelling using the DfT's Aviation Model. The DfT Aviation model has undergone significant development and key assumptions have been updated since the CBA which accompanied the second consultation was published. Full details of the model can be found in the DfT modelling suite document that is being published by the DfT separately.

10. DfT internal modelling has, as in the second consultation stage CBA, drawn on assumptions about the relative cost-effectiveness of each SAF in delivering GHG emission reductions, feedstock availability, SAF technology deployment and policy

design (e.g. HEFA cap and PtL obligation) to calculate the least cost fuel mix to meet the mandate in each year. The additional costs and benefits of the Mandate are then calculated, relative to a Business-as-Usual (BAU) scenario.

11. The modelling also considers the potential effect of the Mandate on biofuel availability for road transport. Biofuels used in biodiesel compete for the same feedstocks as HEFA SAF. Our analysis assumes that in the scenarios where demand for aviation and road transport biofuels exceeds the supply of biofuels, road transport will have reduced access to biofuels, reducing the carbon savings projected for the RTFO. It also leads to a benefit of lower road fuel costs in the CBA, as the reduced biofuels are replaced with cheaper diesel fuel instead. It should be noted that overall the value of any reduction in carbon savings in road transport are valued more highly than the fuel saving, when using central carbon values.

12. Finally, in line with the commitment made in the second consultation stage CBA, the results of analysis considering the implications of the SAF Mandate for decarbonisation across the rest of the economy is presented.

13. There is significant uncertainty related to the availability of feedstocks for UK SAF production and the level of SAF fuel imports accessible to the UK. To reflect this significant uncertainty, all results are presented for three UK SAF production and import scenarios, defined as follows:

    Scenario A – high biomass feedstock and 50% of planned SAF plants under the DfT funded Advanced Fuel Fund (AFF) projects are delivered, and UK maintains import share of UCO to 2029 and this then declines to GDP share in 2050.

    Scenario B – high biomass feedstock and 50% of AFF SAF projects are delivered, and a linear decline in UK import share of UCO fuels to UK share of global GDP in 2050.

    Scenario C – assumes low biomass feedstock available, 25% of AFF SAF projects are delivered, and a fast decline in the UK import share of global UCO fuels (UK imports ~11% of global UCO fuels currently, and this falls to UK share of global GDP in 2030, ~3%).

14. The assumptions made regarding feedstock and import availability are based on the outputs of the Biomass Strategy and analysis undertaken for the upcoming Low Carbon Fuel Strategy due to be published later in Spring 2024.

Potential Impacts

15. As shown in Table 1, the monetised costs and benefits of the Mandate vary under the three UK SAF production and import scenarios. Under scenarios A and B the NPVs are positive (around £1.9bn in Scenario A and around £1.2bn in Scenario B), while under Scenario C the NPV is significantly negative (-£1.7bn).

16. The main differences between the scenarios are that under Scenario C, the low availability of SAF feedstocks causes the model to select more expensive SAF

production routes, and results in higher levels of buyout. This results in carbon savings being significantly lower, and fuel costs also being lower but to a much lesser extent. In addition, there are much higher buyout costs to business, but these are offset by an equal benefit to government.

Table 1 – High level economic cost and benefit results

£ millions over baseline (2010 prices)	Scenario A	Scenario B	Scenario C
Fuel costs	-11,434	-11,434	-6,639
ETS/CORSIA costs	2,250	2,250	658
Buyout costs to business	0	0	-60,465
Total costs (undiscounted)	-9,184	-9,184	-66,445
Monetised carbon savings	11,668	9,190	2,291
Monetised road fuel benefit	1	1,674	1,225
Buyout benefit to government	0	0	60,465
Total benefits (undiscounted)	11,669	10,865	63,980
Discounted social costs	-6,442	-6,442	-47,237
Discounted social benefits	8,325	7,653	45,608
Net Present Value	**1,884**	**1,212**	**-1,629**

17. There is significant uncertainty associated with other key assumptions used in the analysis, including carbon, kerosene and SAF prices. These are considered in the CBA via sensitivity tests.

18. The analysis suggests the SAF Mandate will directly deliver 54 MtCO2e in emission reductions under Scenario A, 43 MtCO2e in Scenario B and 11 MtCO2e savings in Scenario C between 2025 and 2040.

19. Whole system energy modelling undertaken since the second consultation indicates that SAF is important for reducing the costs of transitioning to net zero across the energy system, over a broad range of scenarios including high and low biomass availability. This holds provided UK production is focused on SAF pathways that can be coupled with Carbon Capture and Storage (CCS). This is because SAF produced in this way is expected to be a relatively cost-effective way of generating negative emissions, and alternative options for decarbonisation of aviation before 2040 are limited.

The potential energy demands of the Mandate have also been estimated. Demand for low-carbon electricity for domestic SAF production could be between 6 TWh and 11.2 TWh in 2040, while low-carbon hydrogen demand could be between 3.9 TWh and 7.4 TWh by 2040.

1. Policy rationale

Policy background

1.1 The UK is committed to delivering our legal obligations to achieve net zero by 2050 and deliver on upcoming carbon budgets as laid out in the Net Zero Strategy.[4] These will require the rapid decarbonisation of the UK economy, requiring a 68% reduction in Greenhouse Gas (GHG) emissions by 2030 and a 78% reduction by 2035 (including international aviation and shipping emissions) from 1990 levels.

1.2 The Jet Zero Strategy, published in July 2022, committed the UK aviation sector to reaching net zero emissions by 2050, and to UK domestic flights reaching net zero by 2040. This strategy is aligned with the Transport Decarbonisation Plan (TDP)[5], Flightpath to the Future[6], and the Net Zero Strategy, though the Net Zero Strategy pathways suggest that the UK can reach net zero without fully decarbonising the international aviation and shipping sectors.

1.3 Sustainable aviation fuel (SAF) is one of the key levers available to accelerate the transition to net zero aviation. These are advanced fuels obtained from sustainable feedstocks, which can be blended into conventional jet fuel without requiring significant aircraft or engine modifications. When fully replacing fossil kerosene, they can achieve lifecycle emissions reductions of around 70% typically, and when produced with low-carbon electricity and carbon captured from the air potential savings can reach 100% compared to conventional jet fuel[7]. When carbon capture and storage (CCS) technology is deployed alongside gasification and Fischer-Tropsch (FT) pathways these lifecycle emission reductions can surpass 100%[8]. Using SAF also reduces sulphur

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[4] BEIS (October 2021) *Net Zero Strategy: Build Back Greener* net-zero-strategy-beis.pdf (publishing.service.gov.uk)

[5] DfT (July 2021) *Decarbonising Transport* Transport decarbonisation plan - GOV.UK (www.gov.uk)

[6] DfT (May 2022) *Flightpath to the future* Flightpath to the future: a strategic framework for the aviation sector - GOV.UK (www.gov.uk)

[7] Aviation Impact Accelerator, *Resource to Climate Comparison Evaluator* RECCE: Resource to Climate Comparison Evaluator (aiatools.org)

[8] Bioenergy with carbon capture and storage (BECCS) potential in jet fuel production from forestry residues (sciencedirect.com)

dioxide and particulate matter emissions, and potentially other non-CO_2 impacts, including contrails.

1.4 An initial SAF Mandate consultation, between July and September 2021, set out the government's intention to introduce a UK SAF blending Mandate, a requirement for a certain percentage of aviation fuel supplied to be sustainable, low carbon fuel. This was first announced in the Prime Minister's Ten Point Plan in November 2020. In July 2022, the government response to the first consultation confirmed that the UK government would introduce a SAF Mandate to take effect on 1 January 2025. The response also confirmed the headline ambition of the SAF Mandate: by 2030, fuel suppliers will be obligated to ensure that SAF comprises at least 10% of the UK aviation fuel mix.

1.5 The second consultation on the SAF Mandate ran between 30 March and 22 June 2023, seeking views on the detailed design of the SAF Mandate.

1.6 A long-term obligation can generate demand for SAF, thereby reducing carbon emissions, provide an incentive to SAF producers (in the form of a tradable credit) and signal to investors the vital role the government believes the technology will play in the UK.

Problem under consideration

1.7 The UK aviation sector produced 38.1 million tonnes of GHG emissions ($MtCO_2e$) in 2019.[9] The continued growth in passenger demand has meant that UK aviation fuel use has more than doubled from 5.4 Mt in 1990 to 12.2 Mt in 2019, despite significant aircraft efficiency improvements. Although aviation emissions fell to 15.4 and 14.7 $MtCO_2e$ in 2020 and 2021 respectively, as a result of the COVID-19 pandemic, they have since risen to 29.6 MtCO2e in 2022 as the sector recovers. Aviation is currently forecast to be one of the largest emitters by 2050.[10] Reaching net zero aviation emissions by 2050, as committed to in the Jet Zero Strategy, will therefore require significant emissions reductions, whilst also balancing the need not to negatively impact efforts to decarbonise the wider system.

1.8 The Jet Zero Strategy identified SAF as one of the key technologies for delivering GHG emissions reductions in the UK aviation sector, especially in the medium-term. SAF production and use is currently limited in the UK. Certain SAF production routes rely on technology that is yet to be proven at scale, have high initial capital and operating costs and uncertainty on return on investment. Without a long-term regulatory and policy framework in place to support industry and provide certainty, these factors act as barriers to an investable proposition for SAF technology developers and investors. Consequently, production capacity will continue to be limited in the UK. A SAF blending Mandate will guarantee a level of SAF demand that provides more certainty to investors.

[9] *Final UK greenhouse gas emissions national statistics* Final UK greenhouse gas emissions national statistics: 1990 to 2021 - GOV.UK (www.gov.uk)

[10] BEIS (October 2021) *Net Zero Strategy: Build Back Greener* net-zero-strategy-beis.pdf (publishing.service.gov.uk)

1.9 The UK government is already addressing some of the supply-side barriers through a series of grant funding competitions, such as the Advanced Fuels Fund (AFF) grants[11], which aim to take UK SAF production plants through to commercialisation. In parallel, the government is working in partnership with industry and investors to build the long-term conditions for SAF supply in the UK. This includes engaging through the Jet Zero Council SAF Delivery Group (SAF DG) and committing to introduce a revenue certainty mechanism by the end of 2026.

Rationale for intervention

1.10 There are a range of market failures and wider strategic factors which justify government intervention to promote the supply of SAF in the UK.

Negative externalities

1.11 Externalities are costs and/or benefits associated with the production or consumption of a good, which are not directly experienced by the agents taking part in a transaction. These external costs and benefits lead to allocations of resources and consumption of goods which differ from the socially optimal level. Where this occurs, government intervention is justified to bring the consumption of goods into line with the optimal level.

1.12 The use of fossil-based kerosene in aviation imposes a negative externality on society. Greenhouse gases emitted from the production and combustion of kerosene contribute to climate change and a range of associated impacts including rising sea levels and increased risk of extreme weather events. These impacts will lead to severe and long-lasting environmental and economic damage, which will be experienced, in large part, by those not involved in the original consumption of flights.

1.13 In recognition of the negative externalities associated with GHG emissions, the UK was the first major economy to legislate the requirement to reach net zero emissions by 2050. The UK has set legally binding carbon budgets which set the economy-wide course for decarbonisation and will include emissions from International Aviation and Shipping (IAS) from the 6th Carbon Budget.[12] The Jet Zero Strategy, published in 2022, also set out an ambitious emissions-reduction trajectory for the aviation sector.

1.14 There are existing mechanisms in place to attempt to internalise the negative externalities associated with aviation, namely the UK Emissions Trading

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[11] *Advanced Fuels Fund competition winners* Advanced Fuels Fund competition winners - GOV.UK (www.gov.uk)

[12] Carbon budgets place a restriction on the total amount of greenhouse gases the UK can emit over a 5-year period. IAS emissions have not been formally included in carbon budgets up to and including the fifth carbon budget. Instead, these have been set using a 'headroom approach' (excluding IAS emissions, but with lower emissions allowed for other sectors). Following the recommendation of the Climate Change Committee, the Sixth Carbon budget (covering 2033-2037) legally includes IAS emissions within the target for the first time.

Scheme (ETS)[13] and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)[14]. Trading schemes such as the UK ETS put a cap on total emissions in the sectors they cover and provide tradable certificates which allow business to emit carbon, up to the capped amount. Over time, the total cap on emissions in these sectors is reduced. Businesses need to purchase allowances to cover the GHG emissions produced, in the case of aviation CO_2e emissions from fuel consumed during flights. CORSIA is a global carbon offsetting scheme. It does not cap the total aviation emissions in its scope, instead it requires qualifying airlines to offset the growth in CO_2e emissions on routes in scope above a baseline level (equal to 85% of the level of international aviation CO_2e emissions in 2019 from 2024 onwards) by purchasing credits generated by projects that reduce emissions from other sectors.

1.15 Market-based mechanisms, such as the UK ETS and CORSIA, encourage GHG emissions reduction at cheapest cost, as industries that face the cheapest decarbonisation options are expected to be the first to act to abate, whilst industries that face more expensive options to reduce emissions continue to purchase credits. They establish a market price for carbon, which encourages emissions innovation to reduce GHG emissions in future and avoid paying the carbon price. Investment in SAF allows airlines to reduce the number of allowances or credits they need to purchase. However, not all flights are currently within the scope of these schemes. Also, carbon prices, under both the ETS and CORSIA, are currently low when compared to the estimated social cost of carbon and remain lower than the cost of investment in solutions like SAF. This means that ticket prices do not reflect the full social cost of flying and are not sufficiently incentivising the uptake of decarbonisation solutions such as SAF, hence the need for further intervention to decarbonise the sector. The mandate will drive demand for SAF, securing growth in the sustainable aviation fuel sector that ETS and CORSIA will not deliver alone.

Imperfect information and investor uncertainty

1.16 In the early years of deployment, high SAF production costs will result in initially high market prices, and low demand. Cumulative deployment is expected to

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[13] The UK Emissions Trading Scheme (UK ETS) replaced the UK's participation in the EU ETS on 1 January 2021. The UK ETS applies to energy intensive industries, the power generation sector and parts of the aviation sector. Within the aviation sector, the routes covered by the UK ETS include UK domestic flights, flights between the UK and Gibraltar, and flights departing the UK to European Economic Area states and Switzerland conducted by all included aircraft operators, regardless of nationality. For more information, see: https://www.gov.uk/government/publications/participating-in-the-uk-ets

[14] In 2016, the International Civil Aviation Organization (ICAO) adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to address CO_2 emissions from international aviation. International aviation emissions are capped at 85% of 2019 levels, and any emissions above this level must be offset. CORSIA is implemented in three phases: a pilot phase (2021-2023), a first phase (2024-2026), and a second phase (2027-2035). For the first two phases (2021-2026), participation is voluntary. For more information, see: https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

bring this cost down significantly, driven by economies of scale and technology learning effects, such as those seen in the offshore wind power sector[15].

1.17 Without certainty surrounding the future demand for SAF and long-term information on cost reductions combined with uncertainty on future carbon pricing, investors will be wary of investing in SAF production. This is especially the case for more advanced fuel production pathways, given the very high capital costs associated with SAF production and the high levels of technology risk associated with first-of-a-kind (FOAK) plants. There may be sufficient market signals for investors to support the development of cheaper HEFA plants but feedstock availability for this pathway is likely to become scarcer as global demand for SAF increases. In the absence of mandated demand for SAF, this uncertainty and imperfect information is likely to discourage investment in advanced SAF production and may lead to a scenario where production is unable to meet the growing demand.

1.18 The SAF mandate, by way of a long-term demand signal for SAF, can therefore provide certainty to the market and encourage investment into the production of advanced fuel pathways.

Industrial benefits

1.19 As laid out in the Net Zero Strategy[16] the global shift towards net zero offers an opportunity for the UK to create new green jobs and put the UK at the forefront of growing global markets. The air transport and aerospace sectors contribute significantly to the UK economy, directly employing around 230,000 people[17] and contributing around £20 billion to GDP[18]. Failing to invest in decarbonising aviation may harm the competitiveness of the UK aviation sector, as other nations decarbonise their own aviation sectors, causing negative impacts to UK employment and growth.

1.20 Many SAF projects are also developing within existing industrial clusters, working in synergy with other industries such as low carbon hydrogen, to deliver wider net zero objectives and provide regeneration opportunities and clean growth. Research by Sustainable Aviation suggests domestic SAF production could contribute £10 billion per year to the UK economy in 2050, supporting around 60,000 jobs[19]. The recently announced winners of the Advanced Fuels Fund competition funding will collectively produce, if all projects reach full

[15] Carbon Brief (September 2019) Analysis: Record-low price for UK offshore wind cheaper than existing gas plants by 2023 (carbonbrief.org)

[16] BEIS (October 2021) *Net Zero Strategy: Build Back Greener* net-zero-strategy-beis.pdf (publishing.service.gov.uk)

[17] DfT analysis of Office for National Statistics (ONS) Business Register and Employment Survey data

[18] DfT analysis of ONS low-level aggregates of UK output gross value added (GVA)

[19] Sustainable Aviation (2023) *Sustainable Aviation Net Zero Carbon Road-Map* https://www.sustainableaviation.co.uk/wp-content/uploads/2023/04/SA9572_2023CO2RoadMap_Brochure_v4.pdf

operational scale, over 700,000 tonnes of SAF and reduce CO2 emissions by 2.7m tonnes each year whilst adding new jobs to the economy.

1.21 A domestic SAF industry can also support UK fuel security while fostering industrial development across the whole country. Not only can SAF use result in new domestic plants being developed in the UK, but it also gives a route for existing oil refineries to transition towards more sustainable products, strengthening existing supply chains, building new ones and retaining the UK industry's expertise and skills.

1.22 Beyond the estimates provided by Sustainable Aviation mentioned above, jobs and growth benefits are not monetised further in this CBA. This is partly because it is not certain how much SAF would be produced in the UK or in other countries. There is also considerable uncertainty as to the additionality of any jobs associated with SAF produced in the UK. Given these uncertainties and the additional information and modelling complexity needed to quantify this impact, it is considered disproportionate to include this within the CBA.

1.23 The ONS has recently turned attention to define the taxonomy and experimentally quantify green jobs within the economy in September 2023.[20][21] However, given the nascency of estimates, it's not yet clear on the best and agreed way to disaggregate and account for green jobs associated with fuel production which overlaps across other modes of transportation.

Policy objectives

1.24 The following critical success factors of the policy have been defined:

- Reduce greenhouse gas emissions associated with aviation and contribute to lower emissions across the UK as a whole.
- Encourage investment in the nascent UK SAF industry by providing a long-term demand signal, sending a clear signal to investors to develop SAF production facilities.
- Incentivise innovation in less-commercially developed fuel pathways, which have the potential to provide the greatest GHG reductions, driving down costs and encouraging learning spillovers.

1.25 The remainder of the document is structured as follows: Section 2 presents the final Mandate design; Section 3 presents the methodology and assumptions used in the CBA; Section 4 presents the costs and benefits of the Mandate; Section 5 presents the results of whole system modelling of the implications of

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20 https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/developingestimatesofgreenjobsintheuk#jobs-in-green-industries

21 https://www.ons.gov.uk/economy/environmentalaccounts/datasets/experimentalestimatesofgreenjobsuk2015to2020

the Mandate for decarbonisation across the economy and Section 6 highlights key uncertainties and risks and presents the results of a range of sensitivity tests.

2. Final Mandate design

2.1 This section sets out the final Mandate design and describes the 'Business As Usual' (BAU) counterfactual.

Background

2.2 The SAF Mandate will place an obligation on suppliers of aviation fuel to demonstrate that a given proportion of fuel supplied is SAF, in line with trajectories presented in Section 2. Suppliers will receive certificates for each tonne of SAF supplied. The certificates received per tonne will vary based on the GHG abatement each fuel provides relative to a baseline abatement of 70% on a lifecycle basis compared to standard jet kerosene. Suppliers can meet their obligation in three ways:

- Obligation can be met entirely through the supply of SAF.
- Fuel suppliers who exceed their obligation can sell excess certificates to those suppliers who do not meet their obligation.
- Suppliers can buy out of their obligation by paying a fixed sum per credit of fuel not supplied.

2.3 The Mandate will set increasing targets out to 2040 and then remain at the 2040 level until they are reviewed. Formal review will take place at least every 5 years. An illustrative example of how these trajectories could continue out to 2050 is included in Table 2 (though the increasing trajectory beyond 2040 is not being committed to at this stage).

Option 0 - Business As Usual

2.4 The 'Business As Usual' scenario assumes that no Mandate is introduced, and there is no additional intervention in the UK SAF sector beyond what has already been announced. As is currently the case, there is no obligation on SAF supply under the RTFO. However, suppliers can choose to claim under the scheme and be awarded certificates for the volumes of SAF supplied into the UK, where they meet the eligibility criteria. The UK ETS and CORSIA provide some incentive for airlines to use SAF, though, especially in the case of CORSIA, this incentive is currently limited given the current relatively low carbon prices under the scheme. Around 15% of emissions from UK departing flights are not currently covered by either the UK ETS or CORSIA. This is because some states are not participating in the voluntary period of CORSIA and others are exempt from CORSIA obligations. This is expected to fall to below 10% from 2027 when the mandatory phase of CORSIA begins.

2.5 In the absence of an obligation on SAF, supply in the UK is assumed to be low. Uptake is assumed to reach 2% of UK jet fuel demand by 2030, and 10% by 2050. This is in line with the assumed SAF uptake in the Jet Zero Strategy's Continuation of Current Trends scenario. It also aligns with emerging evidence from the RTFO, where limited but increasing SAF has been claimed. Industry stakeholders have suggested that the RTFO in its current form does not provide sufficient contribution towards the cost of producing SAF, especially for less commercially developed pathways such as PtL.

Mandate Trajectory

2.6 The second consultation set out three options for Mandate trajectories, split into pre- and post-2030. All options centred on a 10% uptake in 2030, as committed to in the Jet Zero Strategy.

2.7 The Mandate trajectory is the medium option consulted on, which starts at 2% in 2025, reaches 10% in 2030 and reaches 22% in 2040. This trajectory would put us on track to meet a 2050 ambition of 50%, in line with the High Ambition scenario from the Jet Zero Strategy, should a future review conclude such a target would be appropriate.

2.8 We do not expect all SAF claimed under the Mandate to be produced domestically. Further discussion on the expected levels of domestic production and imports for SAF can be found in section 3.

Table 2. SAF Mandate trajectory options - Mandated SAF level as a % of total aviation fuel

Option	***2025***	***2030***	***2040***
BAU	0.5%	2%	4%
Policy option	2%	10%	22%

Figure 1. SAF Mandate trajectory options (2025-2040)[22]

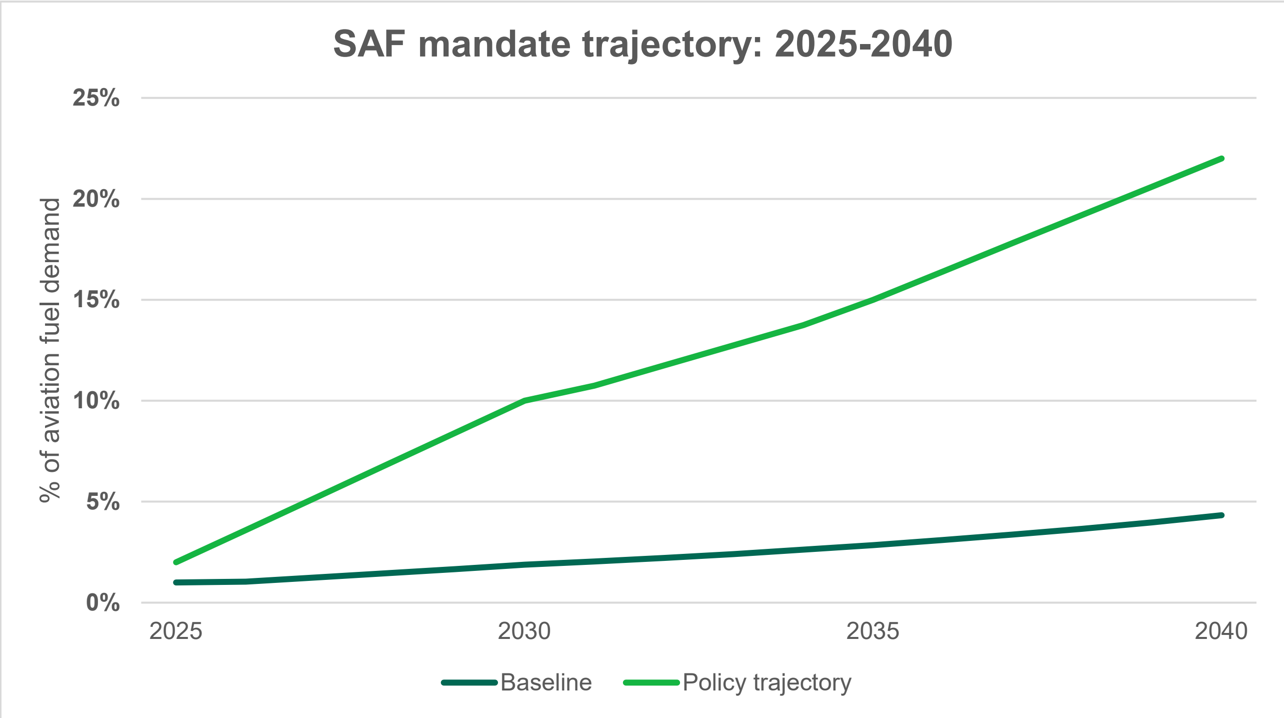
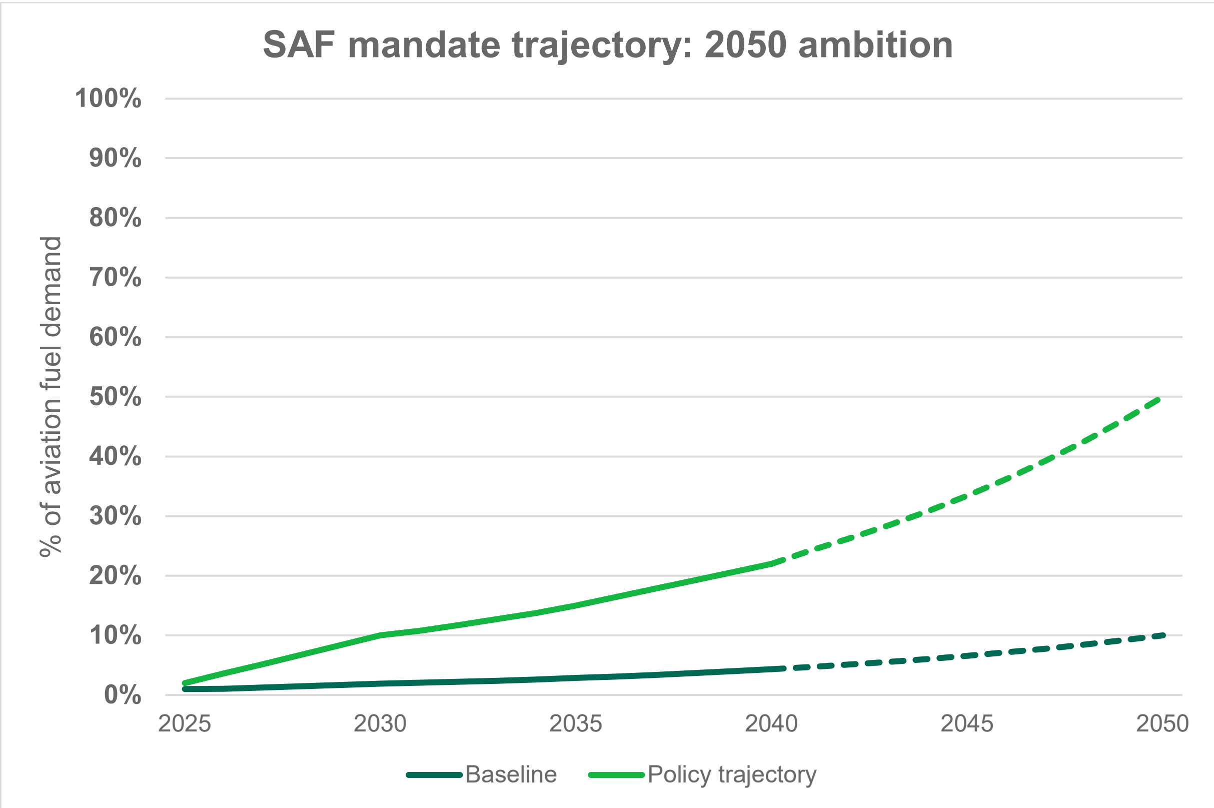


Figure 2. Illustrative continuation of SAF Mandate trajectories out to 2050



[22] Note that legislation will flatline targets beyond 2040, they will not end at that point.

Buy-out price

Principles

2.9 The purpose of the buy-out is to provide a mechanism to allow suppliers to fulfil their Mandate obligation in a scenario where they are unable to do so through the supply of SAF or purchase of certificates. Setting the buy-out price at the correct level is critical to ensure compliance with the Mandate. If the buy-out is set too low, then suppliers may choose to buy-out instead of supplying SAF, reducing emissions savings and compromising the policy aims. If the buy-out is set too high, any supplier unable to meet their obligation through the supply of SAF will face a consequently high-cost burden, which could in turn place an undue financial strain on industry and by extension consumers.

2.10 There are three key principles which should drive the setting of a SAF buy-out price:

- Setting a buy-out price which ensures carbon abatement, incentivising compliance with the Mandate and ensuring UK SAF supply from domestic and global SAF markets.
- Ensuring no undue burden on industry, and by extension consumers, because of a buy-out price being set too high and avoiding a suboptimal allocation of feedstock.
- Encouraging research and development in fuel pathways not yet benefitting from economies of scale or learning rates, helping bring through new technologies which may provide greater GHG savings in the long run.

2.11 Given the number of potential SAF fuel pathways and the significant cost variation across pathways, the buy-out price has been set at a level which is high enough to incentivise a range of novel SAF pathways.

2.12 The buy-out price has been set at £4.70/litre or £5,880 per tonne. This figure is higher than any of the options presented in the consultation, reflecting updated evidence on the costs associated with different SAF pathways discussed in Section 3. This price represents mid-range estimates of SAF cost from the Aviation Impact Accelerator dataset for different types of SAF pathway, with a 50% margin applied to account for price volatility, uncertainty surrounding the cost estimates, and to ensure the scheme incentive is competitive with other similar international schemes. Analysis of price volatility data from Argus Media for jet kerosene and SAF fuels, indicates a margin of 40%-50%. Including a margin at this level should help ensure that the buy-out price remains an effective incentive even where standard market price fluctuations occur.

Comparison with the Social value of carbon

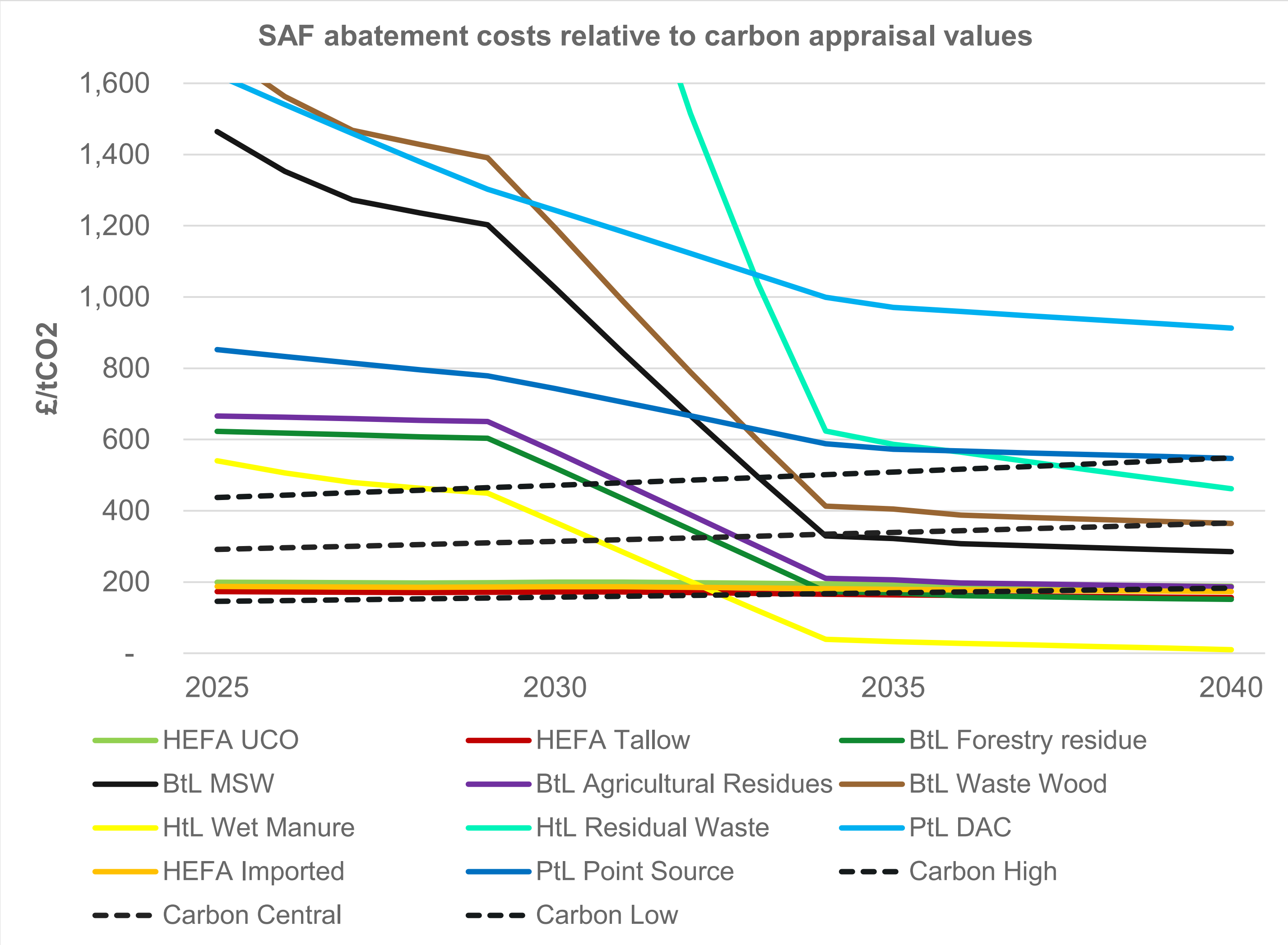
2.13 The carbon appraisal values included within government's Green Book supplementary guidance[23] attempt to quantify the social value of carbon abatement. These values reflect an attempt to estimate the abatement cost of the most expensive measure/technology required to meet the government's climate change targets in any given year. In theory, if the cost of GHG abatement (£/tCO2e abated) is in line with/less than these social values of carbon then the technology should be adopted. If it is higher, it means the technology does not provide efficient abatement compared to other economy-wide options, although it is not always possible to include all costs and benefits in appraisal and wider strategic considerations should be taken into account.

2.14 SAF, as noted previously, does not currently benefit from economies of scale and as such has high production costs. This means that the cost of abatement currently associated with many of the SAF pathways is greater than the DESNZ central carbon appraisal value. Over time, as production costs fall, most SAF pathways are expected to become cost-effective in terms of the abatement they provide, as demonstrated in Figure 3. The diagram shows a range of costs for pathways selected in the modelling.

2.15 The central estimates of future production costs used in Figure 3 suggest that some more novel SAF pathways may not become cost effective before 2040. As shown in Figure 6 (see Section 3) there is a particularly high level of uncertainty surrounding the future production costs of these pathways and lower bound estimates of the costs suggest they could be cost effective significantly before 2040. It is only by incentivising some production of these fuels in the earlier years of the scheme, that it will be possible for the market to reveal which fuels will ultimately be most cost-effective. The design of the SAF Mandate should ensure that the most cost-effective mix pathways will be incentivised. Although the SAF industry does not currently offer cost-effective carbon abatement, buy-out prices must be set using current production costs in order to operate as an effective incentive for compliance in the early years.

Figure 3. SAF abatement costs relative to DESNZ carbon appraisal values (2025-2040)

[23] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK (www.gov.uk)



HEFA cap

Principles

2.16 HEFA is currently the cheapest and most developed SAF fuel pathway (see Figure 6). As such, it is expected that a large percentage of SAF supplied to meet the Mandate in the early years will be HEFA. However, the feedstocks used to create HEFA (primarily UCO and tallow) can also be used to produce biodiesel and HVO, a key fuel type for difficult-to-decarbonise road transport modes under the RTFO. In 2020 UCO made up 50.5% of all fuel supplied under the RTFO[24] in the form of biodiesel.

2.17 A cap on the amount of HEFA that can be supplied under the Mandate has been included as a key policy design element to encourage investment and innovation in production of later non-HEFA SAF types, including Biomass to Liquid and PtL, which will be crucial to meeting the Mandate in the longer term.

[24] *Renewable Transport Fuel Obligation Annual Report 2020* Renewable Transport Fuel Obligation Annual Report 2020 - GOV.UK (www.gov.uk)

The HEFA cap will also reduce the risk of diversion of feedstocks away from road uses to aviation fuel production.

Options considered

2.18 As part of the consultation, we considered an upper and lower bound HEFA cap which ranged from allowing no HEFA into the fuel mix, and allowing the highest level suggested by our modelling of the expected fuel mix. Since the consultation analysis, we have updated our evidence on feedstock and fuel availability and therefore our analysis of the expected fuel mix has evolved.

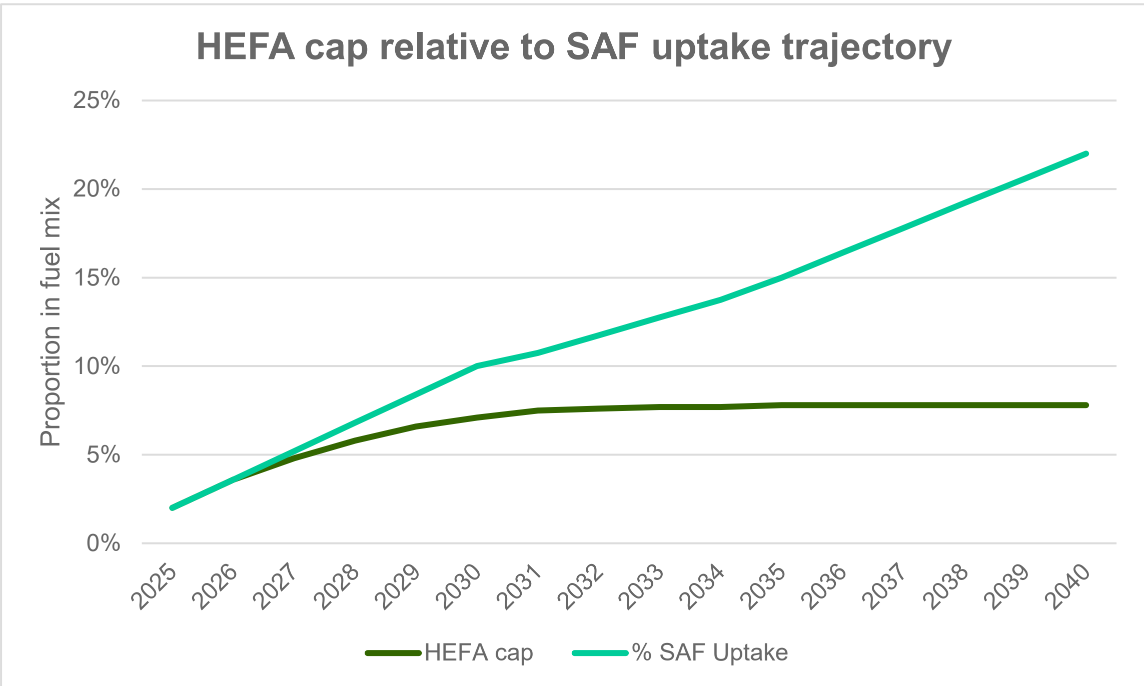
2.19 Our updated evidence suggests that more HEFA will be available than previously estimated which means that the level of the proposed HEFA cap is higher than the upper bound included in the previous consultation.

Setting the HEFA cap

2.20 A key objective of including a HEFA cap in the design of the Mandate is allowing space for more advanced non-HEFA and PtL SAF to be developed. Based on the analysis outlined in Section 2 an assessment has been made about the volume of SAF that should be protected to ensure a market for them. The HEFA cap has been set at a level which allows sufficient space while also aiming to ensure that the Mandate can be met in all years.

2.21 For the first two years of the SAF Mandate, there will be no cap on the level of HEFA that can be supplied, and the cap then comes in from 2027 allowing a lower proportion of SAF into the mix each year. Figure 4 below shows the proposed HEFA cap against the proposed SAF trajectory.

Figure 4. HEFA cap relative to total SAF in the fuel mix (2025-2040)



Power to Liquid Obligation

Principles

2.22 Given the decarbonisation potential of PtL pathways, the Department wants to ensure suppliers are incentivised towards their further development. A Power to Liquid obligation will therefore require jet fuel suppliers to ensure a proportion of the SAF supplied under the main Mandate meets the definition of the fuels that can be supplied under this obligation. This obligation has a higher buy-out price.

2.23 PtL is currently one of the most expensive SAF pathways and therefore it is unlikely suppliers would supply this fuel without a specific obligation to do so.

2.24 The PtL obligation can only be met through supply of SAF for which the energy content is derived from renewable or nuclear energy sources, and not biomass. This analysis therefore focuses on this pathway.

Options considered

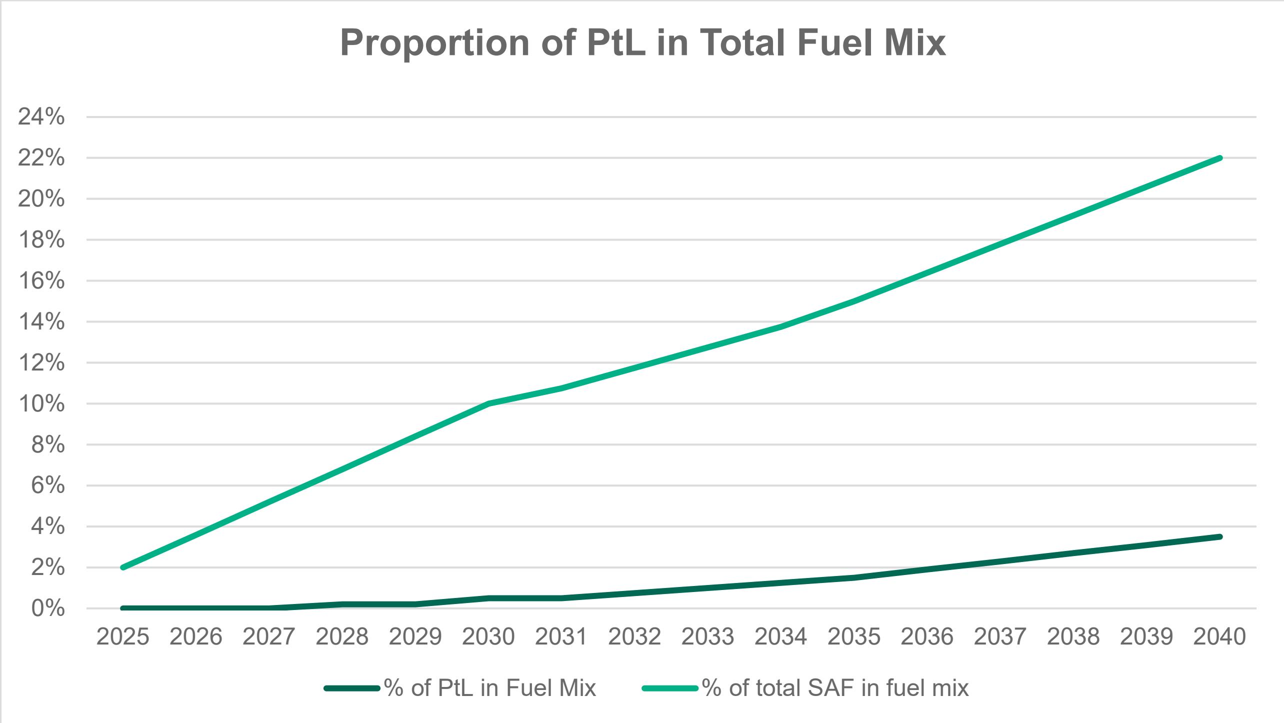
2.25 As part of the consultation, we considered an upper and lower bound PtL obligation. This ranged from a low level, reaching 1.5% of total jet fuel supplied in the UK in 2040 and a very high level reaching 8% of total jet fuel supplied in 2040.

Setting the PtL trajectory

2.26 Between 2030 and 2040, the PtL obligation trajectory broadly aligns with the medium option we consulted on. During this timeframe there is less certainty regarding international production capacity as well as the availability of CCUS, low carbon energy and low carbon hydrogen that these plants rely on. However, by showing ambition and establishing a market, we will encourage investment to accelerate the development of PtL and capitalise on the environmental benefits it offers. This will also allow space for other SAF pathways that are likely to develop earlier and are expected to be more cost effective in the short-medium term.

2.27 The Mandate begins in 2025 at 0% of total jet fuel supplied in the UK and begins to ramp up from 2028, reaching 0.5% in 2030 and 3.5% in 2040. Figure 14 below shows this level of obligation against the main Mandate trajectory.

Figure 5. Proportion of PtL relative to total SAF in the fuel mix (2025-2040)



Power to Liquid obligation buy-out price

2.28 The PtL obligation requires a separate, higher buy-out price in order to provide sufficient incentive to supply the more expensive PtL fuels. Several buy-out price options were included in the previous consultation. These ranged from £2/l, in line with the main Mandate consultation buy-out price to £4.15/l based on estimated production costs plus a 50% margin.

2.29 The PtL buy-out price has been set at £5/litre or £6,250 per tonne. This figure is higher than any of the options presented in the consultation, reflecting updated evidence on the costs associated with different SAF pathways discussed in Section 3. This price represents mid-range estimates of SAF cost from the Aviation Impact Accelerator dataset for PtL fuel utilising Direct Air Capture carbon, with a 50% margin applied to account for price volatility, uncertainty surrounding the cost estimates, and to ensure the scheme incentive is competitive with other similar international schemes. Analysis of price volatility data from Argus Media for jet kerosene and SAF fuels, indicates a margin of 40%-50% would help to account for standard market price fluctuations and ensure that the buy-out price remained an effective incentive.

3. Methodology

Assumptions and methodology

Scope

3.1 The scope of the analysis covers impacts delivered by a SAF Mandate starting in 2025, through to 2040. The analysis considers several scenarios, but these should not be interpreted as predictions of what will happen under the Mandate. The following impacts are included:

Monetised costs:

- Additional fuel costs associated with using SAF in place of kerosene, taking account of reduced cost of UK ETS allowances and CORSIA credits, where applicable.
- Buy-out cost to business, where a proportion of the Mandate is not met through supplying fuel (this is a transfer, as there is a matching benefit to government)
- Resulting impact on ticket prices and passenger demand[25].
- Reduction in GHG savings under the RTFO if there is displacement of feedstock used to produce road fuels to SAF.

Non-monetised costs:

- Other additional costs as a result of complying with the Mandate (e.g., administration costs and admin costs, etc.).
- Buy-out cost to businesses supplying road transport fuels under the RTFO, if there is displacement of feedstock used to produce road fuels to SAF (this is a transfer, as there is a matching benefit to government)

Monetised benefits:

- GHG emissions reductions from replacing kerosene with use of SAF.
- Buy-out revenue to government, where a proportion of the Mandate is not met through supplying fuel. (this is a transfer, as there is a matching cost to business)

[25] To avoid double counting ticket price impacts are not included as an additional cost within the appraisal, instead they have been modelled to illustrate how costs to businesses may be passed onto consumers and to enable us to model the secondary impact on demand as a result of increased ticket prices.

- Reduction in fuel costs for participants of the RTFO if there is displacement of feedstock used to produce road fuels to SAF.

Non-monetised benefits:

- Growth impacts on GVA and employment.
- Change in other environmental impacts, including non-CO_2 emissions and contrails.
- Buy-out benefit to the government under the RTFO, if there is displacement of feedstock used to produce road fuels to SAF (this is a transfer, as there is a matching cost to business)

Other indirect non-monetised impacts:

- Social impacts of SAF Mandate via its impact on ticket prices and demand.
- Impact on availability of feedstocks, and energy demands.
- Social impacts of SAF on road transport via its impact on fuel prices and demand if there is buy-out under the RTFO.

Evidence and assumptions

3.2 Since the publication of the second consultation on the SAF Mandate, we have significantly enhanced our evidence base on the costs, GHG savings, and feedstock and energy implications of SAF, and the likely availability of SAF domestically and overseas.

3.3 This is informed by work commissioned from the Aviation Impact Accelerator (AIA), led by Cambridge University's Whittle Laboratory and the Cambridge Institute for Sustainability Leadership. DfT commissioned the AIA team to provide updated evidence on the costs, GHG savings, and feedstock and energy implications of different SAF pathways. This builds on the work they produced ahead of the second consultation, including building a bespoke modelling tool, drawing on their publicly available Resource to Climate Comparison Evaluator tool (RECCE)[26], to determine the most cost-effective fuel mix under a SAF Mandate, and to calculate the associated costs, greenhouse gas and feedstock and energy implications.

Jet fuel demand

3.4 The Mandated level of SAF under the policy is presented as a percentage of aviation fuel used on UK-departing flights (represented by bunker fuel sales). The assumptions on projected fuel demand are sourced from internal modelling using the DfT's Aviation Model.

3.5 The DfT Aviation model has undergone significant updates since the previous cost benefit analysis for the second consultation was published. More detail on these updates can be found in the DfT Aviation Modelling Suite document being published by the DfT separately.

[26] https://recce.aiatools.org/

3.6 For the central case, projected fuel demand is based on updated aviation demand forecasts from the Department's aviation model. These are based on the same policy assumptions underpinning the Jet Zero Strategy Continuation of Current Trends Scenario, but also include the impact of the SAF mandate final design. The updated forecasts suggest that around 11.5 million tonnes of jet fuel will be used in 2025, reaching 13.3 million tonnes in 2040.

3.7 In practice, there is significant inherent uncertainty associated with forecasting future jet fuel demand levels, due to uncertainty relating to the drivers of aviation activity, and uncertainty in the rate of improvement in fuel efficiency of aircraft over this period. A limitation of the analysis is that we have not been able to test the sensitivity of the CBA results to alternative potential future jet fuel demand levels.

Kerosene prices and carbon prices

3.8 Forecasts of kerosene prices used within the analysis come from internal DfT analysis of historic crude oil and jet fuel price data, and DESNZ forecasts of oil prices.[27] Given the historic volatility of kerosene prices, a range of price series is tested in the analysis.

3.9 It is assumed that, in the counterfactual case, airlines face the cost of kerosene plus a carbon price, where that fuel is used within scope of either the UK ETS or CORSIA schemes. Around 30% of emissions from UK departing flights are currently covered by the UK ETS, while around 70% are covered by CORSIA, although there is significant overlap between the two schemes.[28] Overall, it is estimated that around 15% of emissions from UK departing flights are not currently covered by either the UK ETS or CORSIA. This is driven by some states not participating in the voluntary period of CORSIA or by states being exempt from CORSIA obligations. This is projected to fall to below 10% from 2027 when the mandatory phase of CORSIA begins. The CORSIA Emissions Unit prices included in this analysis are in line with the illustrative price series published by DfT as part of the Jet Zero consultation.[29] The UK ETS allowance prices are in line with the latest series published by DESNZ[30]. Further details of the methodology for these are included in Annex 7.1.

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[27] Oil price forecasts are based on November 2023 version released by the Department for Energy Security and Net Zero.

[28] Flights from the UK to the EEA and Switzerland are in scope of both the UK ETS and CORSIA. We are carefully considering the approach to CORSIA implementation and interaction with the UK ETS, and we will consult further in due course.

[29] See Annex B for details of illustrative ETS and CORSIA prices Jet zero: further technical consultation (publishing.service.gov.uk). The continuation of current trends scenario uses the Central ETS price series and the Low CORSIA price series. These assumptions are designed to illustrate the potential range of carbon prices faced by airline operators in future for analysis purposes. The assumptions do not represent the UK Government’s view on the most likely evolution of market prices under any carbon pricing mechanism.

[30] DESNZ (2023) https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2023/traded-carbon-values-used-for-modelling-purposes-2023

Social value of Carbon

3.10 Changes in GHG emissions are valued using the values set out in supplementary guidance to Treasury's Green Book.[31] The central values are used for the core CBA results presented in section 4, and section 6 presents the results of a sensitivity test which shows how the results vary when the low and high values presented in the guidance are used instead.

SAF production costs

3.11 The SAF production costs in the CBA analysis are sourced from the AIA's own bottom-up techno-economic modelling, which considers the capital and operating expenditure of the different technologies, alongside the amount and price of feedstock required for each production route. The AIA produced a modelling tool which has been updated and integrated into our CBA analysis, since the previous consultation. Costs are expected to fall over time, based on learning curves and predictions of future technology costs. Overall, the central values suggest that SAF will be around 2-7 times the cost of kerosene (without carbon pricing impacts) in 2025, falling to 1-3 times the cost by 2040. The AIA inputs draw on a wide range of data sources, including peer-reviewed academic journals, technical literature and industry-wide questionnaires. The assumptions made are based on expert judgement.

3.12 The assumptions informing the AIA's SAF costs have been independently reviewed against a range of other available literature, including from the International Council on Clean Transportation[32] (ICCT), the World Economic Forum (WEF)[33], PwC[34], independent analysis for DfT by E4Tech, and against market SAF production prices provided by Argus media. It is understood that spot market for SAF is currently trading at a higher cost than those used in this analysis. For example, in the latter stages of 2023, Argus Media reported spot SAF prices of around £2,600/tonne.[35] Stakeholders have informed the Department that these prices are based on small numbers of trades (as most SAF is provided through direct contracts), hence a preference to use the SAF price projections from the AIA modelling.

3.13 There is significant uncertainty surrounding SAF production costs, due to the early stage of technology development. In the long run, costs of advanced fuels such as PtL will be heavily dependent on the cost of low-carbon electricity. To reflect this and the significant volatility in aviation fuel prices in general, a range of optimistic and pessimistic estimates of SAF costs have been tested in the analysis, as illustrated in Figure 6, with further details in Annex 7.2. The central

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[31] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK (www.gov.uk)

[32] ICCT (2019) *The cost of supporting alternative jet fuels in the European Union*. https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_20190320_1.pdf

[33] WEF (2020) *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathways to Net-Zero Aviation*. https://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf#:~:text=The World Economic Forum’s Clean Skies for Tomorrow,the transition to net- zero flying by mid-century

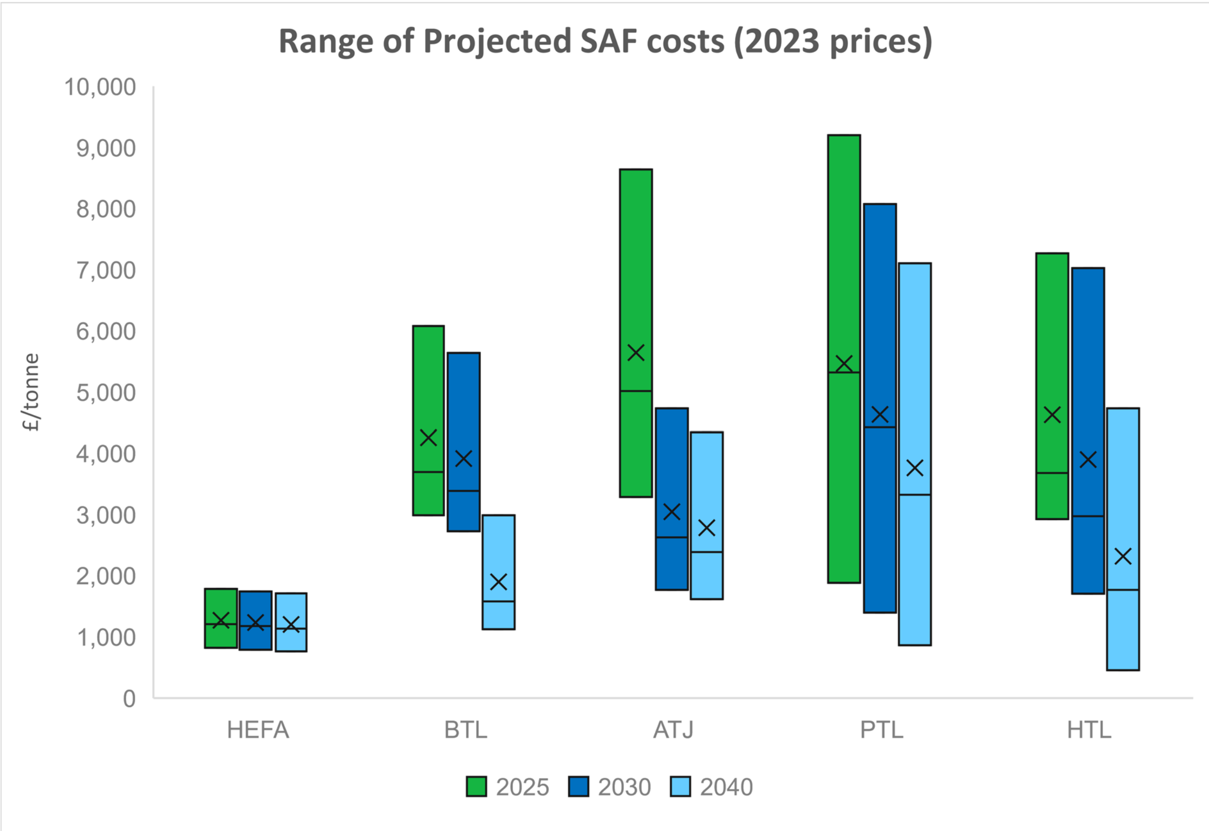
[34] PwC (2022) *The real cost of green aviation* https://www.strategyand.pwc.com/de/en/industries/aerospace-defense/real-cost-of-green-aviation.html

[35] Argus Media average daily reported SAF price between Jan 2023-Jan2024 (Accessed January 2024)

values used in the analysis are indicated by the markers in the middle of the bars.

3.14 The scenarios and cost estimates provided here do not include modelling of the integration of CCUS technology into SAF production. This would increase the costs of SAF production. However, it would also result in much higher emission reductions, significantly reducing the abatement cost of Biomass to Liquid SAF pathways, and so overall would reduce the cost of meeting the SAF mandate. This scenario is explored further as a sensitivity in Section 6.

Figure 6. Range of SAF production costs used in analysis



3.15 The results of a sensitivity test considering a scenario in which SAF prices are significantly greater than production costs are presented in section 6.

SAF GHG savings

3.16 The GHG emissions estimated in the AIA modelling have been compared against the range of external evidence discussed above, and other sources such as the ICAO lifecycle assessments, and information provided by industry under the government's Advanced Fuel Fund competition.

3.17 It should be noted that, while the use of SAF reduces the lifecycle emissions associated with aviation, interactions with carbon cap and trade schemes mean that emissions reductions may be offset elsewhere in the traded sector. This is discussed in further detail in section 6. In addition, increased use of SAF in aviation may have implications for the amount of feedstock available to decarbonise other sectors, and for CCUS availability to produce electricity or hydrogen, both of which generate negative emissions. These issues are discussed further in sections 4 and 6.

SAF technology deployment in the UK

3.18 The production of SAF in the UK is determined and constrained by two factors within this analysis: technology deployment and feedstock availability. The Department has gathered evidence on both of these constraints. These constraints are reflected within the cost-benefit modelling impacting the fuel mix, overall costs and emission reductions.

3.19 The following section sets out the approach taken regarding technology deployment of SAF production facilities in the UK across the three broad types of SAF.

HEFA technology deployment

3.20 HEFA is a type of SAF that can be produced from oils. HEFA is currently the only commercially mature SAF pathway and is likely to be the predominant SAF pathway in the short term. For the purposes of this analysis, it is assumed that HEFA will be predominately derived from Used Cooking Oil (UCO).

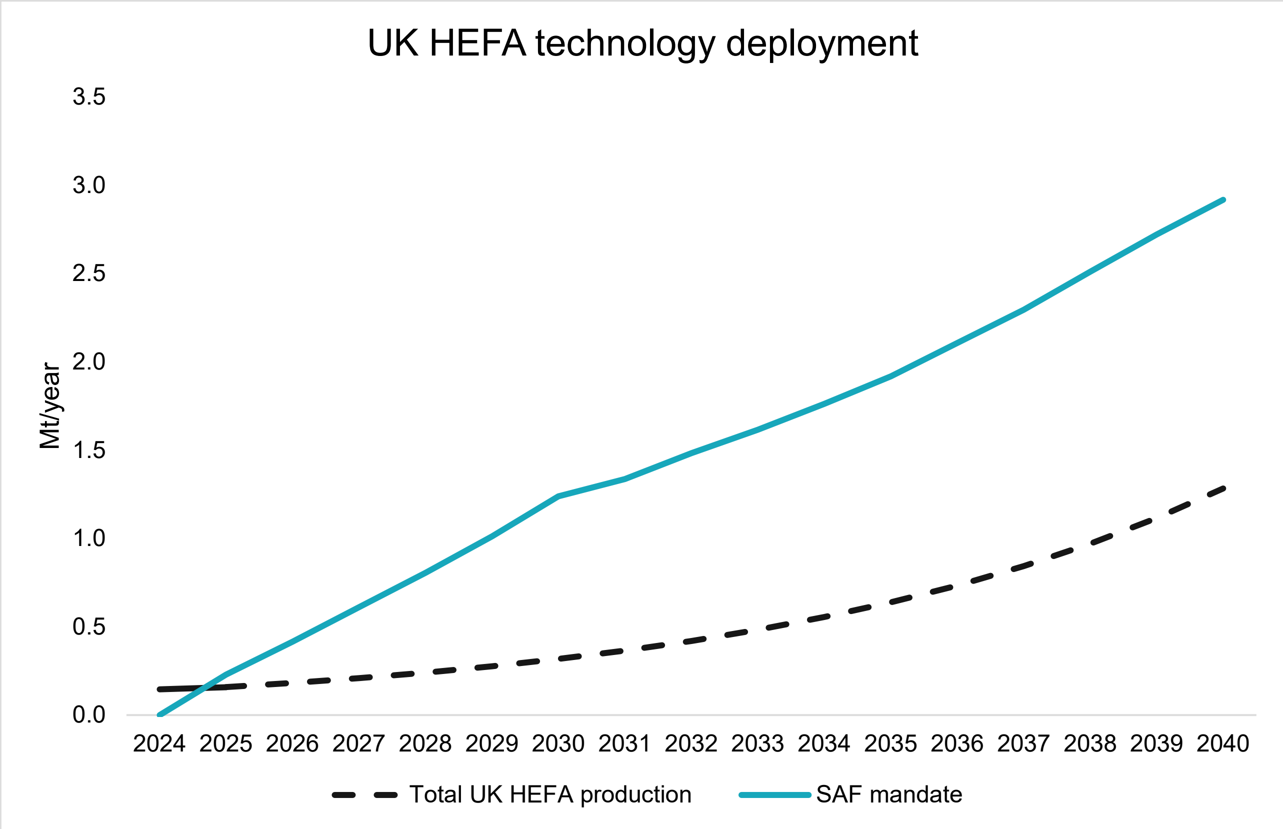
3.21 UCO based fuels are already heavily relied upon across the world and constitute a large proportion of bio-diesel on the UK market.

3.22 However, currently, the UK production capacity of HEFA is limited. HEFA production capacity has been estimated based on Hydrotreated Vegetable Oil (HVO) refinery capacity in the UK provided by Argus Media.[36] The modelling assumes a co-processing split of 54% HEFA and 46% HVO.[37] This suggests that the UK has the potential to produce 145kt (6.7PJ) of HEFA a year from 2025.

3.23 From 2025, we assume that HEFA production in the UK could grow by a compound annual growth rate (CAGR) of 15%. This is based on the DfT Ricardo/E4Tech feedstock model and regional historical growth rates in biofuel production - see Annex 7.5 for further detail regarding production CAGR.

[36] Argus Media HVO refinery capacity data (Accessed September 2023)
[37] Renewable jet fuel supply scenarios in the European Union in 2021–2030 in the context of proposed biofuel policy and competing biomass demand - Jong - 2018 - GCB Bioenergy - Wiley Online Library

Figure 7. Development of UK HEFA technology deployment over time (2024-2040)



3.24 Figure 7 presents the maximum UK HEFA technology deployment based on the assumption that 0.16Mt of HEFA is produced in 2025 and production capacity grows 15% year-on-year thereafter.

3.25 The graph shows the importance of UK produced HEFA to meeting the SAF mandate, and also that it is not expected to be able to meet all SAF demand alone.

Advanced Fuels Fund and non-HEFA fuel technology deployment

3.26 The AFF is a DfT grant funding competition which is supporting the development of 13 UK SAF projects[38]. The AFF provides capital funding to FOAK SAF plants to support them through the project pipeline, to the point of final investment decision and construction. The AFF aims to address technology and construction risks by facilitating the detailed feasibility study stages of projects, thus providing confidence to investors on the feasibility of projects.

3.27 AFF support will help kick-start a UK SAF industry and, along with the introduction of the Mandate, help us to achieve our commitment with industry of having at least five commercial-scale SAF plants under construction in the UK by 2025.

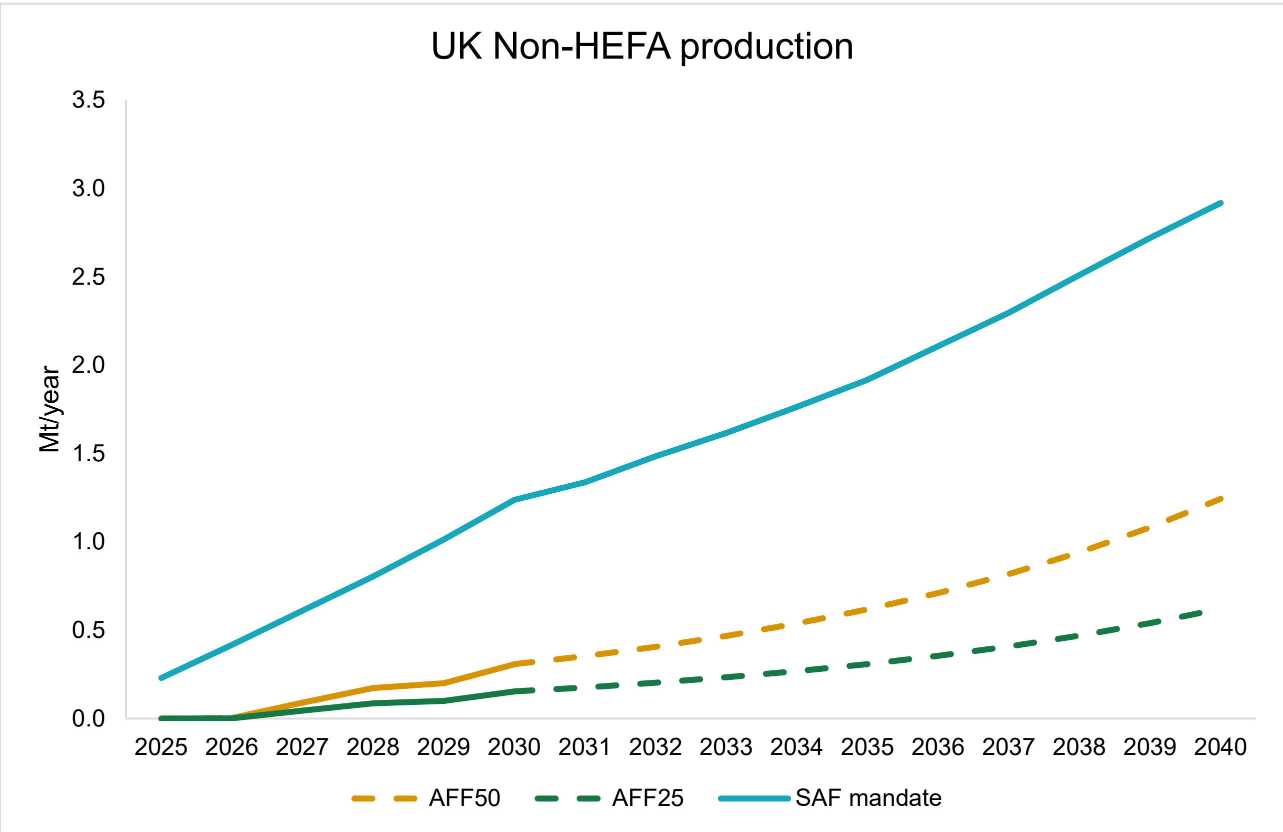
[38] Advanced Fuels Fund competition winners announcement (gov.uk)

3.28 The AFF specifically funded non-HEFA and PtL SAF plants. In this CBA, non-HEFA SAF refers to pathways using non-oily feedstocks such as: forest residues, agricultural residues and municipal solid waste (MSW). PtL fuels, however, utilise hydrogen and carbon as the primary feedstocks to create kerosene.

3.29 The AFF provides the clearest line of sight of UK SAF projects that are likely to become operational. The total expected capacity of projects which have been funded under the AFF has been used to estimate the domestic non-HEFA SAF technology deployment until the year 2030. After this point, a 15% CAGR is applied to forecast future technological deployment.

3.30 Given the inherent uncertainty in FOAK projects such as these, two domestic technology deployment scenarios have been modelled. (AFF25 and AFF50). In these scenarios AFF production is assumed to reach 25% and 50% respectively of total AFF plant capacity, therefore, reducing the overall level of non-HEFA technology deployment in the modelled scenario. It should be recognised that actual success rates may be higher than this, and new projects incentivised by the SAF Mandate could come forwards.

Figure 8. Development of UK Non-HEFA SAF technology deployment over time (2025-2040)



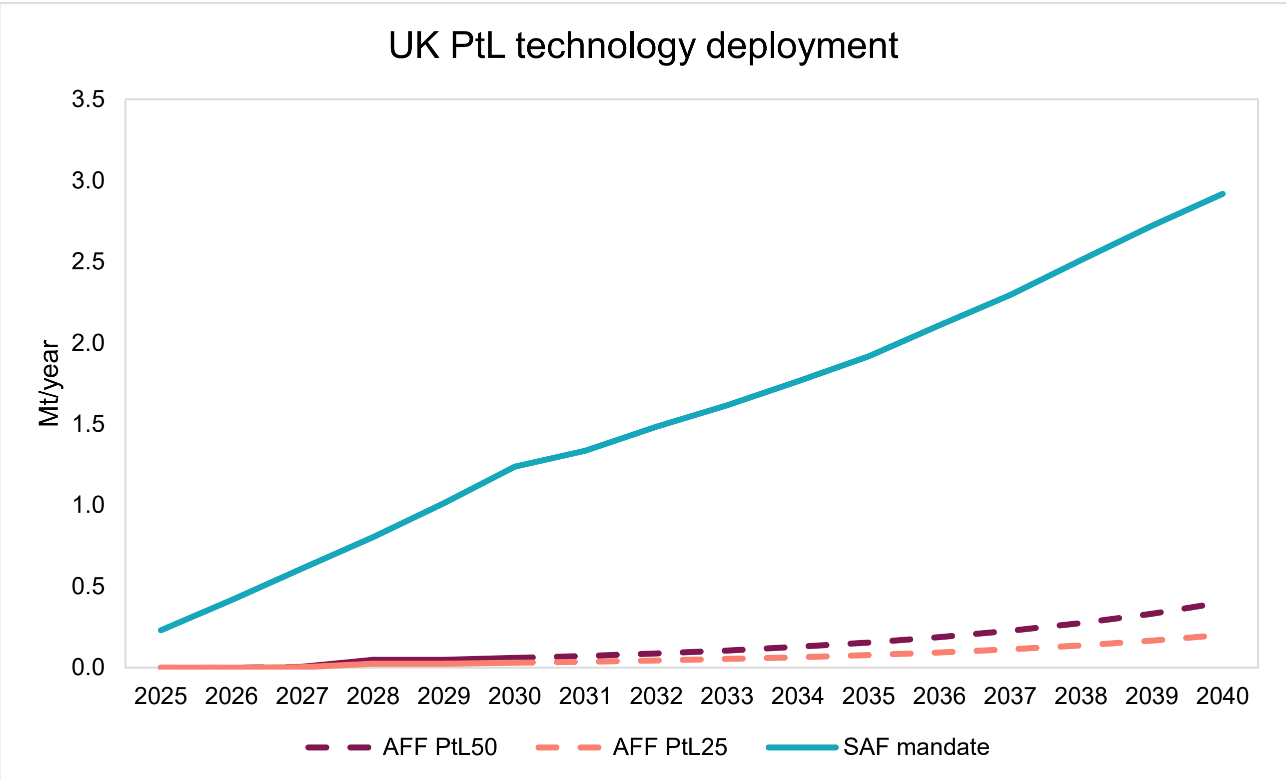
Power to Liquid (PtL) fuel technology deployment

3.31 PtL fuel is not commercially available yet. The resources required for PtL are potentially abundant and the lifecycle emissions of the fuel are typically low making it one of the most promising technologies to decarbonise aviation. This is because it uses only electricity and captured CO2 as inputs. However, in order to deliver PtL at scale, production facilities must be built and significant amounts of renewable electricity, green hydrogen, and captured carbon must be available. It is also expected to be one of the most expensive SAF pathways over the period to 2040 (see Figure 6). Therefore, over the period to 2040 PtL is projected to be relatively constrained.

3.32 Currently, there are six PtL plants in development in the UK, which have been funded under the AFF. These are due to come online between 2026 and 2030. After 2030, a CAGR of 21% is used to forecast future technology deployment. This higher CAGR is based on an E4tech report[39] and historic yearly growth in solar PV installations and reflects that the relatively low starting point for PtL opens up the potential for relatively high growth rates over the period.

3.33 As per the non-HEFA AFF analysis, two domestic PtL deployment scenarios have been modelled (PtL25 and PtL50). In these scenarios AFF production is assumed to reach 25% and 50% respectively of total AFF plant capacity. This reflects inherent uncertainty for projects such as these to deliver at full capacity from their projected start dates. It should be recognised that actual success rates may be higher than this, and new projects incentivised by the SAF Mandate could come forwards.

Figure 9. Development of UK Power to Liquid technology deployment over time (2025-2040)

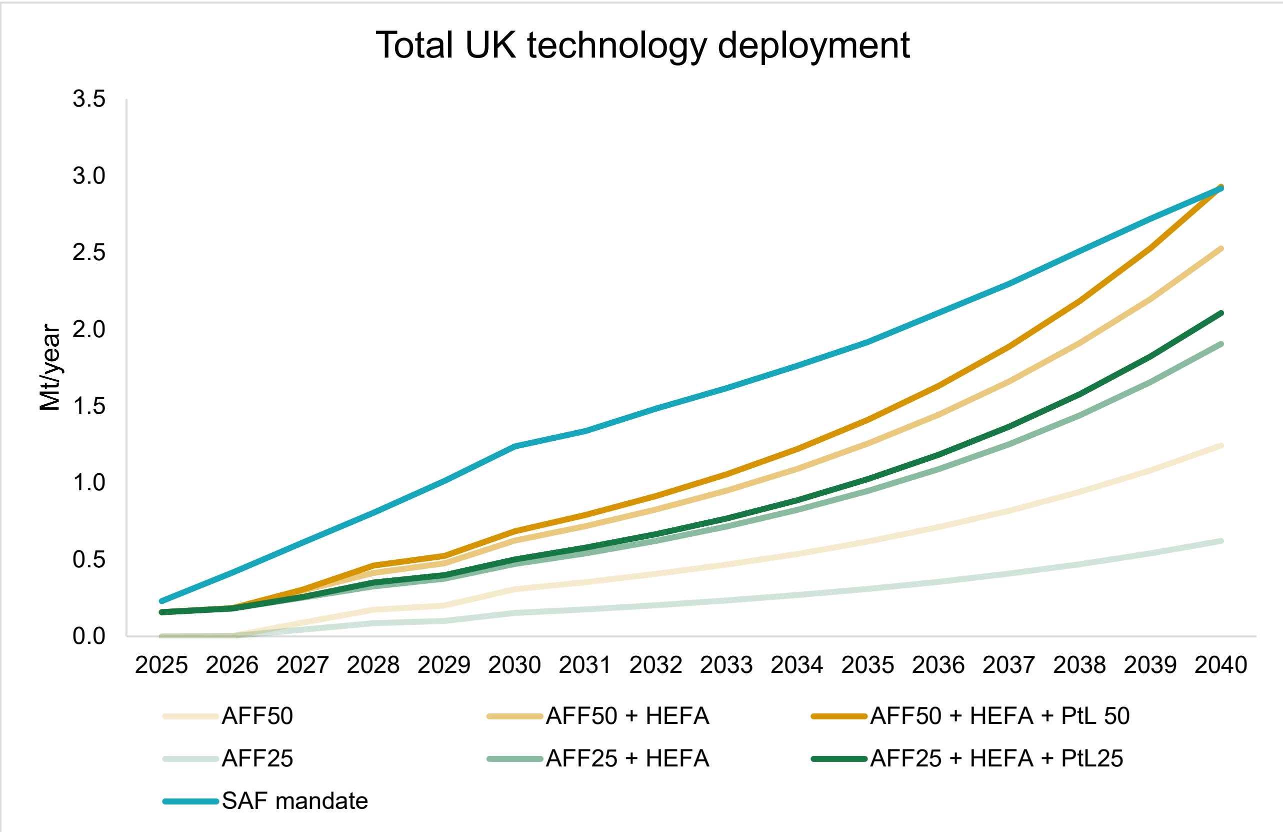


[39] Independent external analysis undertaken by E4tech in 2021. Specifically, the 21% CAGR is based on IEA reports related to growth in solar PV installations between 2015 and 2019.

3.34 As PtL SAF has the lowest level of technology readiness, the model results indicate a relatively small role for it in the SAF Mandate fuel mix to 2040. This is reflected in the scenarios produced for this CBA. However, beyond 2040 the potential for PtL SAF is could be much larger.

Combined SAF technology deployment

Figure 10. Total UK SAF technology deployment over time (2025-2040)



3.35 The chart above shows the combined UK SAF production of HEFA, Non-HEFA and PtL fuels assuming that AFF production meets 25% and 50% of total plant capacity. The UK can import SAF where it cannot be produced domestically, as it does currently under the RTFO.

Feedstock Availability and SAF Imports

3.36 As noted above, the amount of SAF that can be supplied in the UK will primarily be constrained by the global SAF production capacity and by feedstock availability.

3.37 Feedstock availability assumptions have been informed by the work underpinning the Biomass Strategy[40] and the forthcoming Low Carbon Fuel Strategy. The model also accounts for feedstock imports used in domestic

[40] Biomass Strategy 2023 - GOV.UK (www.gov.uk)

production. To estimate feedstock imports, a high and low scenario have been considered.

3.38 The bounds of global SAF production estimates are based on estimates of global production of feedstocks. These estimates have also been informed by the Biomass strategy, forthcoming Low Carbon Fuels strategy and internal DfT analysis. Generally, the UK's share of global GDP is used as a proxy for purchasing power in a global fuel and feedstock commodity market, this proxy is also used in this work to estimate the potential levels of imports the UK might be able to access.

3.39 Further discussions on these import assumptions, rationale, and sources can be found in the Biomass Strategy 2023 Technical Annex.[41]

3.40 These import scenarios are used throughout this analysis when referring to non-HEFA and PtL SAF.

3.41 For HEFA fuels, a variation of these import scenarios is used to reflect the fact that the UK is already a disproportionately large importer of UCO and UCO-derived fuels today above and beyond its global GDP share.

3.42 The following section assesses the feedstock availability across each SAF pathway.

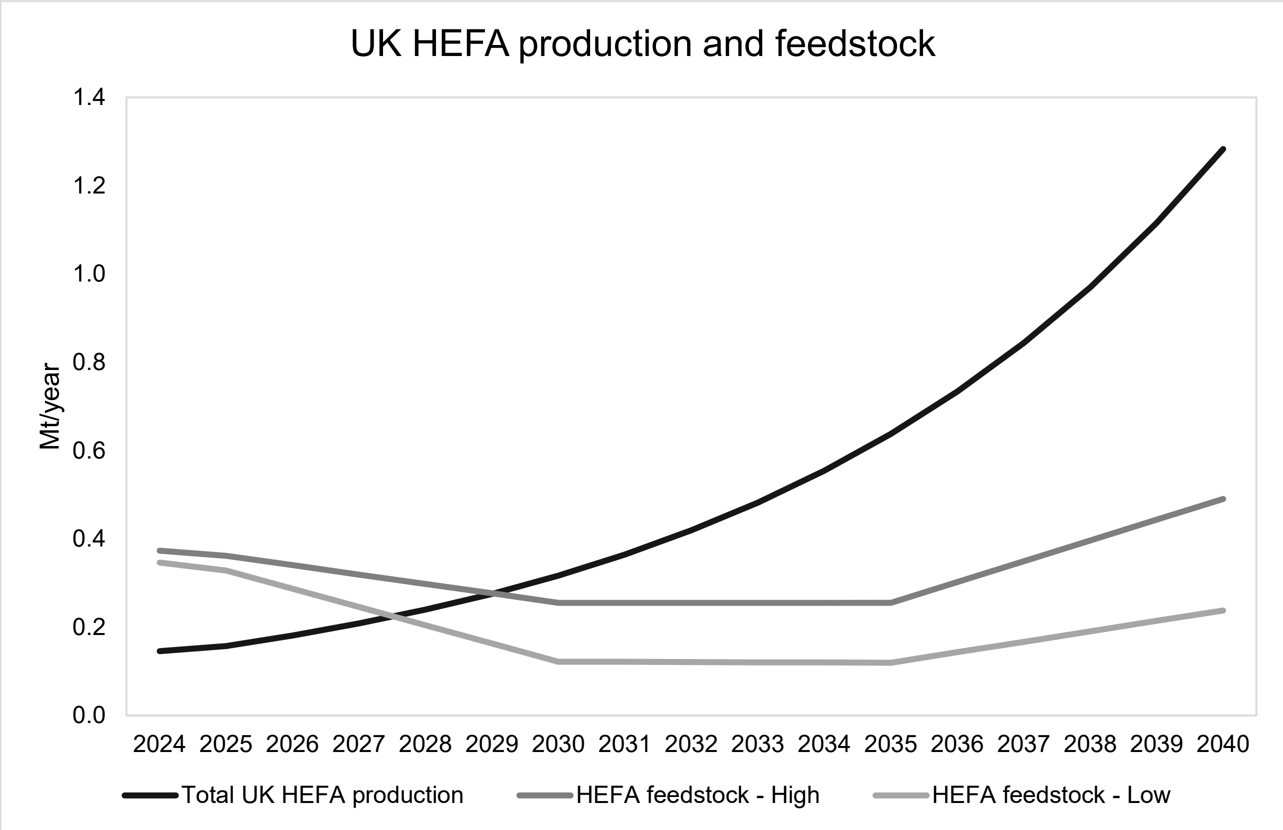
HEFA Feedstocks and Imports

3.43 HEFA uses waste-oil feedstocks which can be used for both road and aviation fuel. These feedstocks, in particular UCO, are used in current biodiesel production. This means there may be trade-offs in feedstock use between the RTFO and the SAF Mandate. HEFA feedstock availability will therefore be dependent on whether the RTFO or SAF Mandate will be prioritised by fuel suppliers in the market. In addition, HEFA feedstocks are likely to face increased demand across global markets due to government initiatives to decarbonise other economies.

3.44 The amount of feedstock available to UK HEFA producers has been estimated based on analysis underpinning the upcoming Low Carbon Fuel Strategy and includes both domestically arising feedstock and imports. This analysis considers a low and high scenario. HEFA feedstock availability in Figure 11 accounts for both domestic and imported feedstocks. The Department's modelling uses current production facilities and assumes a co-processing split of 54% for HEFA and 46% for HVO. Our modelling suggests that UK HEFA production is likely to be constrained by HEFA feedstock availability from 2029 onwards.

[41] Ibid.

Figure 11. UK HEFA production and feedstock availability (2024-2040)



3.45 By the year 2028, HEFA production could surpass HEFA feedstock capacity in the low feedstock scenario. Similarly, in the year 2029 HEFA production could surpass HEFA feedstock capacity in the high feedstock scenario. This suggests that the main limitation in producing HEFA in the longer term will be feedstock constraints.

3.46 HEFA fuel imports have also been estimated based on assumptions aligned with the government's Biomass Strategy. In addition to this, the Department has built two additional import scenarios to reflect the unique nature of the UK's demand for waste-oil feedstocks.

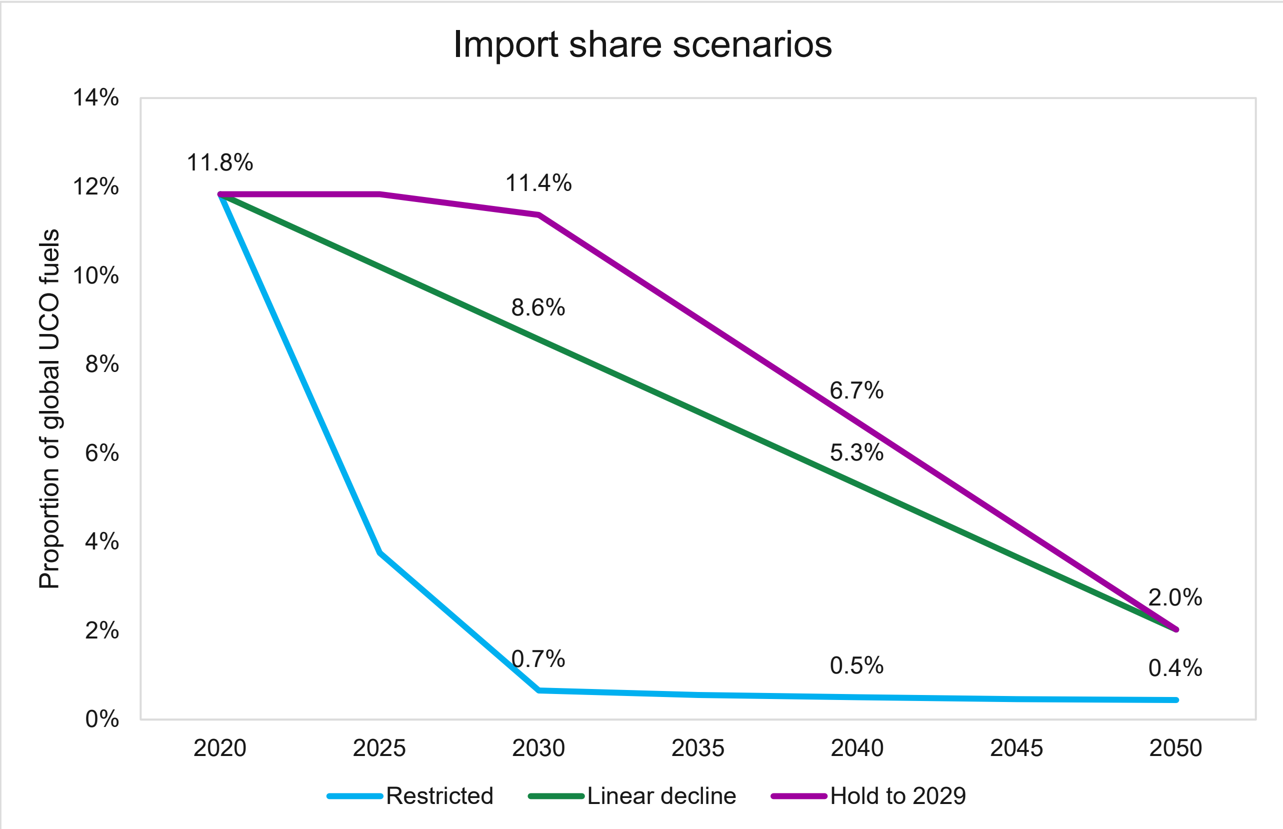
3.47 The overall availability of waste-oil feedstocks to the UK is highly dependent on import rates. This is because historically the UK has imported significant levels of waste oils from across the world.

3.48 In line with the Biomass Strategy assumptions, waste-oil imports as a share of global production are assumed to trend towards the UK's global GDP share. In the Biomass Strategy this assumption was applied to all feedstocks which was a fit for purpose methodology for an overarching economy-wide strategic piece of analysis. However, in developing the SAF Mandate these assumptions on the import of waste-oil fuels and feedstocks have been refined.

3.49 This CBA uses the 'restricted' scenario from the DESNZ Biomass Strategy to represent the lower bound of waste-oil imports. This CBA also models two new scenarios - 'linear decline' and 'hold to 2029' which show a slower decline in our imports of waste-oil fuels. This ensures a manageable number of scenarios while reflecting the high level of uncertainty associated with the UCO fuel import assumptions.

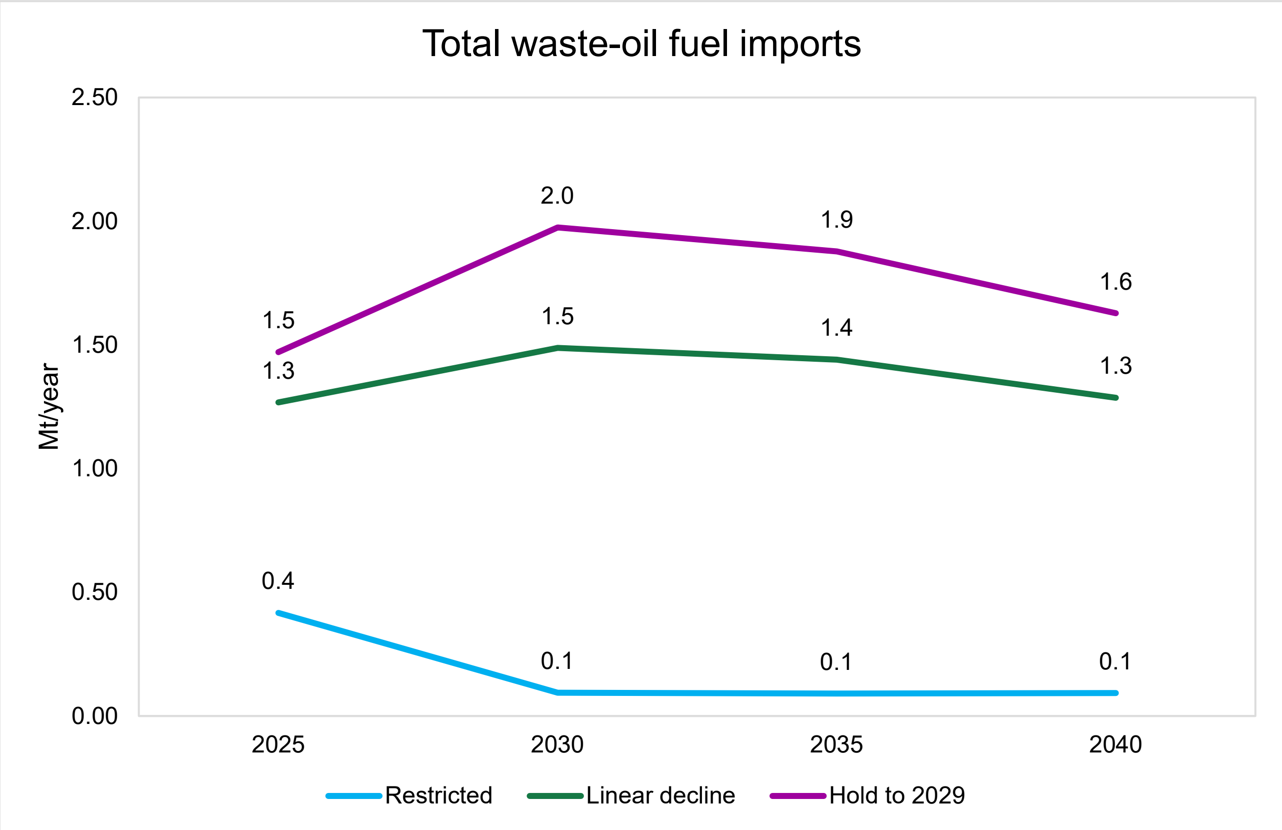
3.50 The three import scenarios are presented in Figure 12 and Figure 13 and show the restricted Biomass Strategy (blue line), linear decline (green) and hold to 2029 (purple) import shares. In the blue line, import share falls rapidly to 2030 and by 2050 falls to approximately 0.4% which reflects 1/5th of the UK's GDP share. Under the purple line import share is initially maintained and then starts falling from 2029. In the green line import share steadily declines from today's import share to the GDP share by 2050. In the green and purple lines import shares fall to approximately 2.0% by 2050 which is representative of the UKs GDP share.

Figure 12. UK Proportion of global UCO fuels across various import trajectories (2020-2050)



3.51 It should be noted that under all scenarios, global volumes of waste-oil increase due to increased collection and production levels. As shown in the Figure 13, this means that under two of the scenarios the total imports of waste-oils rise, in the period to 2030.

Figure 13. Total UK UCO fuel imports across various import trajectories (2020-2040)



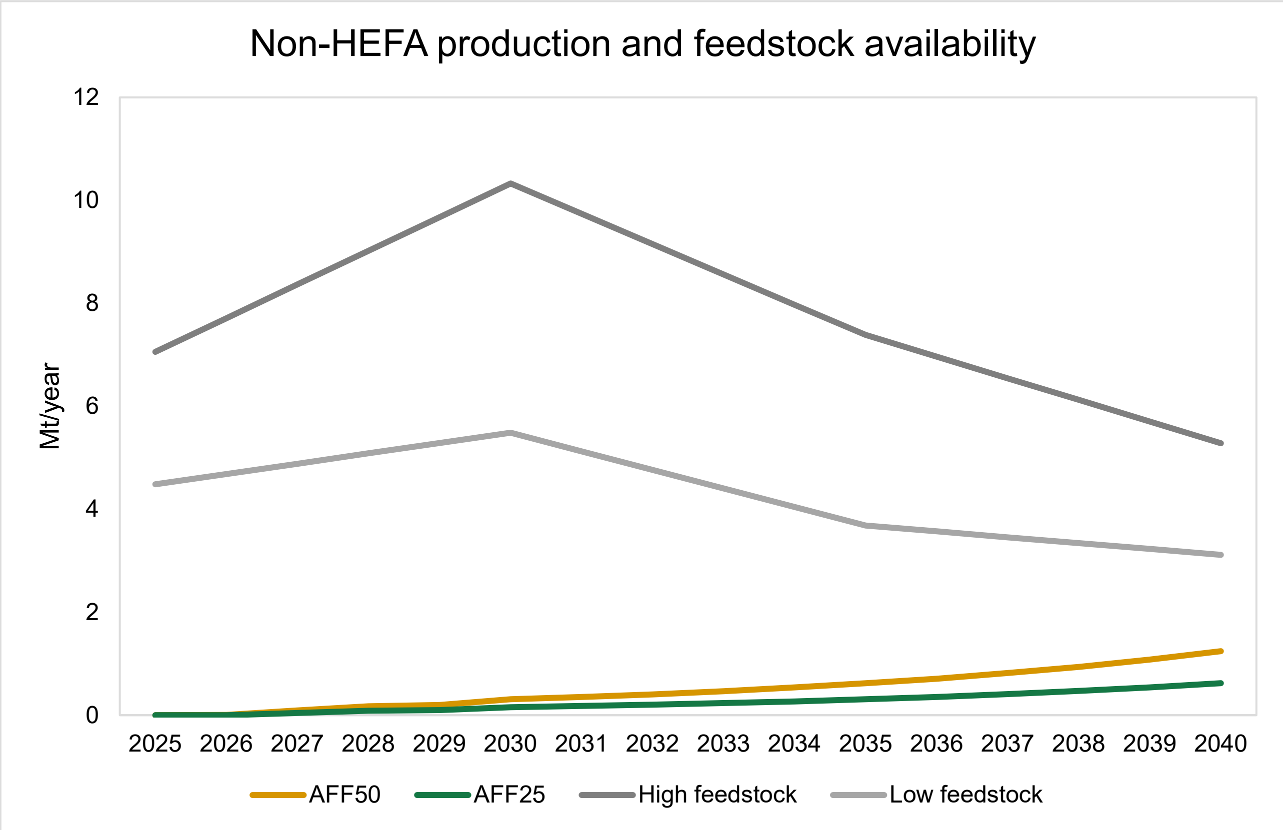
3.52 In the restricted scenario, total UCO fuel imports significantly decrease from the years 2025 to 2030 before remaining relatively constant until 2040. In the linear decline and hold to 2029 scenarios however, total UCO fuel imports increase until 2030 before gradually falling over time where total UCO fuel imports return to similar levels as 2025.

Non-HEFA SAF Feedstocks and non-HEFA UK SAF Production

3.53 UK non-HEFA SAF plants are expected to use feedstocks such as municipal solid waste (MSW) agricultural or forestry residues, or waste industrial gases. These feedstocks can be compared against estimates of the total production capacity of plants funded through the AFF to identify whether there will potentially be any feedstock constraints.

3.54 As shown in Figure 14, it is estimated that there will be sufficient feedstocks to meet production demands until at least 2040 under the AFF50 and AFF25 scenarios. From 2040 onwards however, feedstocks may become a constraining factor. This highlights the importance of non-HEFA UK SAF production capacity in the period to 2040.

Figure 14. UK non-HEFA production and feedstock availability (2025-2040)



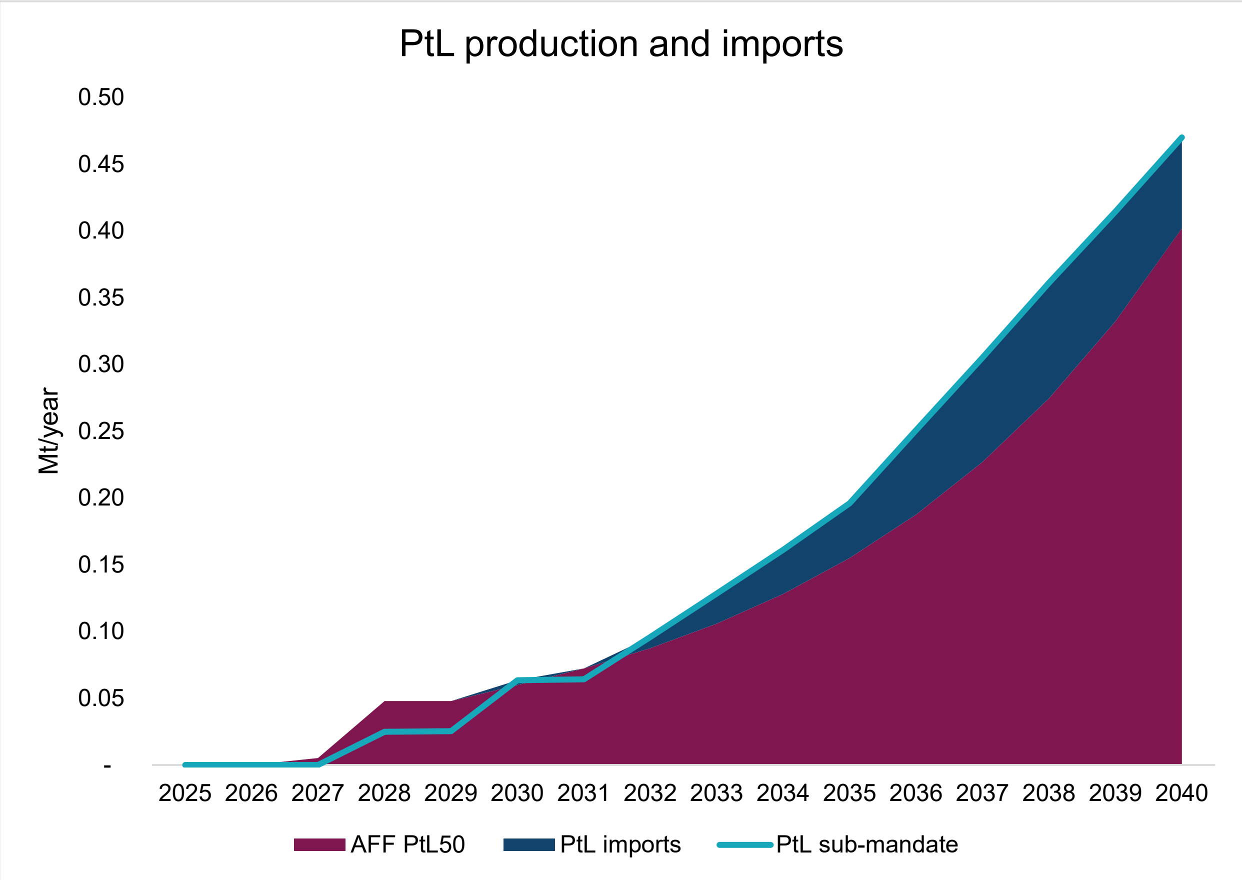
3.55 It should however be noted that feedstock energy projections represented in the above graphs are not the final fuel energy output. Total energy outputs are lower, as processing efficiencies for SAF are currently estimated to be in the range of 42%-88%, with most pathways appearing to be on the higher end of the efficiencies. This efficiency loss has been accounted for in the CBA results presented in section 4.

PtL production and imports

3.56 PtL domestic production estimates, similar to non-HEFA fuels, are based upon the AFF50 and AFF25 scenarios for technology deployment as seen in figure 9. Due to its lack of technological maturity, PtL imports are assumed to only be available from 2030 onwards. PtL global production projections have been estimated by taking capacity forecasts from Argus media and applying a 21% CAGR after 2030. The UK is then assumed to be able to access a share of global production. The analysis then assumes that the domestic PtL production will be used first in the sub-mandate with any remaining gaps in the mandate being fulfilled by PtL imports.

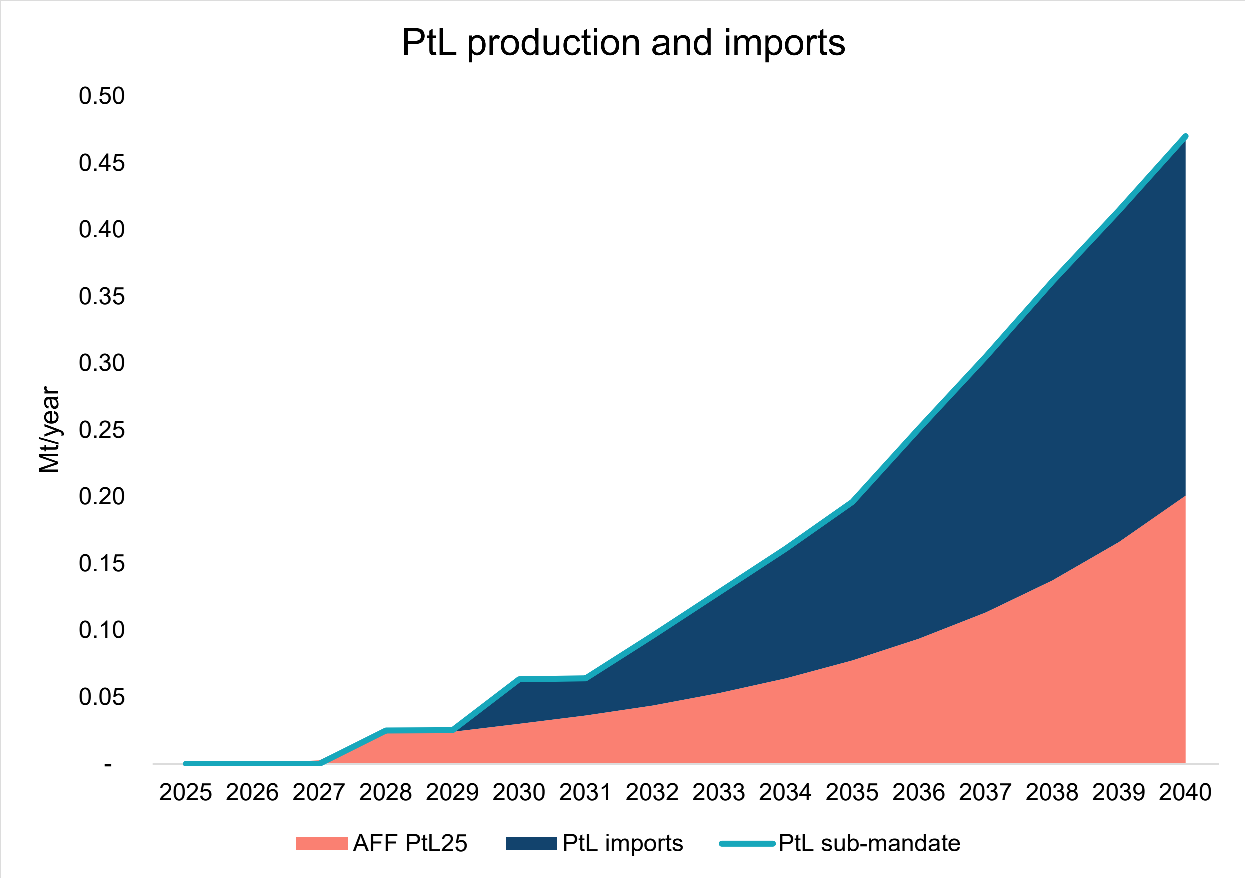
3.57 The PtL obligation trajectory has been set at a level to reflect domestic production and import potential. In the AFF PtL50 scenario, this is met predominantly with domestically produced PtL, with some PtL imports assumed to be needed from 2032 onwards.

Figure 15. PtL domestic production and imports split (2025-2040)



3.58 However, where the PtL25 assumption is used for UK PtL availability, higher levels of PtL imports are required to meet the obligation due to a lack of domestic production.

Figure 16. PtL reduced domestic production and imports split (2025-2040)



3.59 In this scenario domestic production is sufficient to meet the PtL obligation until the year 2029. After this point a growing level of PtL imports would be required to meet the sub-mandate.

Summary of core scenarios

3.60 To reflect the significant uncertainty related to the availability of feedstocks for UK SAF and the level of SAF imports accessible to the UK, the impacts of the Mandate are presented against three scenarios. Table 3 summarises the assumptions used for each of these scenarios.

Table 3. Summary of production and import features in each core scenario.

Assumption	Scenario A	Scenario B	Scenario C
UK non HEFA and PtL production	AFF50 and PtL50	AFF50 and PtL50	AFF25 and PtL25
UCO derived fuel imports	Hold to 2029	Linear decline	Restricted
Non-HEFA imports	Ambitious	Ambitious	Restricted

PtL imports	DfT PtL import potential scenario	DfT PtL import potential scenario	DfT PtL import potential scenario
Domestic feedstock availability	High	High	Low

Methodology

3.61 The methodology used to calculate the monetised costs and benefits associated with each of the policy options is described below.

Fuel mix

3.62 The fuel pathways included in the modelling are HEFA, gasification with Fischer-Tropsch (Biomass to Liquid (BtL) and Waste to Liquid), Alcohol to Jet, PtL, pyrolysis and Hydrothermal Liquefaction (HtL), as set out in Table 4. The feedstocks modelled are also shown in Table 4. These are the pathways and feedstocks used for analysis presented in this CBA but should not be interpreted as an exhaustive list of potential pathways and feedstocks eligible under the Mandate. Hydrogen and electricity as fuels are not included in the modelling, though hydrogen is an eligible fuel. The hydrogen and electricity required for SAF production is captured by the analysis.

Table 4. SAF fuel pathways included in the analysis and their feedstocks.

Fuel pathway	Feedstocks
Hydroprocessed Esters and Fatty Acids (HEFA)	Used cooking oil (UCO), tallow
Gasification with Fischer-Tropsch (Gas-FT) – Biomass to Liquid (BtL) and PBtL	Forestry residues, municipal solid waste, agricultural residues, waste wood
Hydrothermal Liquefaction (HtL)	Forestry residues, waste wood, sewage sludge, bagasse, wet manure, residual waste, unrecyclable plastic, waste rubber
Alcohol to Jet	Industrial waste gases
Pyrolysis	Waste lubricant oil
Power to Liquid (PtL)	Direct air carbon capture, point source carbon

3.63 Our internal modelling calculates the most economic fuel mix in each year to meet the proposed Mandate level and PtL Mandate level given the relative cost-effectiveness of different SAFs in delivering emission reductions. The modelling takes account of the feedstock availability and technology deployment assumptions, and proposed HEFA cap.

3.64 The key limitation to this approach is that within the modelling the forecasted fuel mix can change significantly year-on-year which in reality would be very challenging given the logistical and infrastructural challenges in SAF production.

Costs

3.65 Using the resulting fuel mix and assumptions on the relative price of SAF and kerosene, the additional cost of SAF compared to the cost of kerosene plus any carbon price obligation that applies is calculated.[42]

3.66 When the Mandate cannot be met due to a shortfall of feedstocks, we assume that suppliers must pay the buy-out price.

3.67 Buy-out is treated as an economic transfer, as it does not involve the consumption of resources. It therefore appears on both sides of the appraisal, as both a cost to business and a benefit to government and does not affect the overall social net present value of the policy.

3.68 The potential impacts on ticket prices are calculated, based on the assumption that fuel costs and carbon costs on average make up around 25% of ticket prices, and that around 75% of the additional costs of SAF will be passed onto the consumer. These costs are not additional to the additional costs of using SAF referred to above. Rather they illustrate how the additional costs imposed by the Mandate may be passed through from fuel suppliers onto airlines, and then onto consumers in the form of higher fares.

3.69 We have assessed the potential knock-on impact that increased ticket prices could have on UK aviation passenger demand using DfT's aviation model. However, the emission reductions and other indirect impacts associated with this reduction in demand are not quantified as part of the core CBA.

3.70 Many of the feedstocks used to produce SAF can be used to deliver reductions in carbon emissions in other sectors. Given that there is a limit to global feedstock supply, there is a risk that the SAF Mandate may divert feedstocks which would have been utilised in other sectors of the economy and this may increase emissions in other sectors. Despite these risks there is an important strategic case for prioritising SAF use in aviation, given that there are limited alternatives to decarbonise aviation by 2050.

3.71 Within the transport sector, road transport currently utilises large amounts of UCO and tallow refined as FAME biodiesel to meet RTFO supplier obligations.

[42] We treat the reduction in the costs of purchasing UK ETS allowances and CORSIA credits as a benefit (or a negative cost) rather than an economic transfer in the CBA. This is because we expect this reduction to reflect a reduction in the level of non-SAF related emission reductions (and in the associated costs) under these schemes relative to the BAU scenario. Section 4 explains why we would expect this to occur in the context of the UK ETS.

If the SAF Mandate results in these feedstocks being used to produce SAF rather than road fuel, the emission savings delivered by the RTFO would be reduced. This is calculated by estimating the reduction in FAME biodiesel which occurs under the RTFO. Then the extra emissions from road transport are estimated by assuming that FAME is replaced with fossil diesel. The emission factors for FAME and diesel are consistent with those used in RTFO analysis.

3.72 From a fuel supplier perspective, the impact of reduced FAME availability for the RTFO will be additional buy-out. As explained above, buy-out is treated as an economic transfer, as it does not involve the consumption of resources. It would therefore appear on both sides of the appraisal, as both a cost to business and a benefit to government and does not affect the overall social net present value of the policy. Given the focus of this CBA is on the aviation sector and impacts on the road transport sector are indirect, we have not monetised this cost and benefit in the CBA, to minimise complexity in the quantified impacts.

3.73 In order to understand the implications of the SAF Mandate on decarbonisation across the rest of the economy, we have carried out whole systems modelling. More detail on this modelling can be found in section 5.

Benefits

3.74 The main monetised benefits of the SAF Mandate are the greenhouse gas savings associated with switching from fossil kerosene to SAF.

3.75 The design of the Mandate means that if the obligations are met in full, the GHG savings of the policy will be equal to 70% of the lifecycle emissions of fossil kerosene. As noted above the core CBA results presented in section 4 do not include the indirect impact on GHG emissions associated with the impact of the Mandate on ticket prices.

3.76 As explained above, in some scenarios the modelling assumes that there will not be enough UCO and tallow feedstocks to supply the RTFO and SAF Mandate, and in these scenarios, it is assumed these feedstocks are prioritised to the SAF Mandate (given the higher buy-out price). Any reduction in the volume of FAME delivered under the RTFO will increase the amount of fossil diesel consumed. The reduction in FAME use is valued at the average historic cost of FAME from 2019 to 2023 using RTFO data. The increase in diesel is estimated using the same data. As FAME is more expensive over that period than fossil diesel the resource cost of this change in the road transport fuel mix is a cost saving in the road transport sector. It should be noted, however, that reduced emission savings under the RTFO are valued more than the resource cost fuel savings under the RTFO in the cost assumptions used in the core CBA results - so in scenarios where there is increased buy-out under the RTFO this reduces the Net Present Value of the SAF Mandate.

3.77 As noted in the benefits section above, there is also a non-monetised benefit to government if buy-out in the RTFO does occur. As this is a transfer and given the focus of this measure is on the aviation sector, this transfer is not quantified in the CBA.

3.78 Other positive impacts of the Mandate have not been monetised in this analysis but are discussed qualitatively in section 4.

4. Costs and benefits of the policy

Fuel Mix

4.1 Modelling undertaken by the Department forecasts the potential fuel mix of the SAF Mandate under the three UK SAF production and import scenarios introduced in section 3. The fuel mix is dependent on factors such as: feedstock availability; technology deployment rates; and carbon cost effectiveness of different forms of SAF.

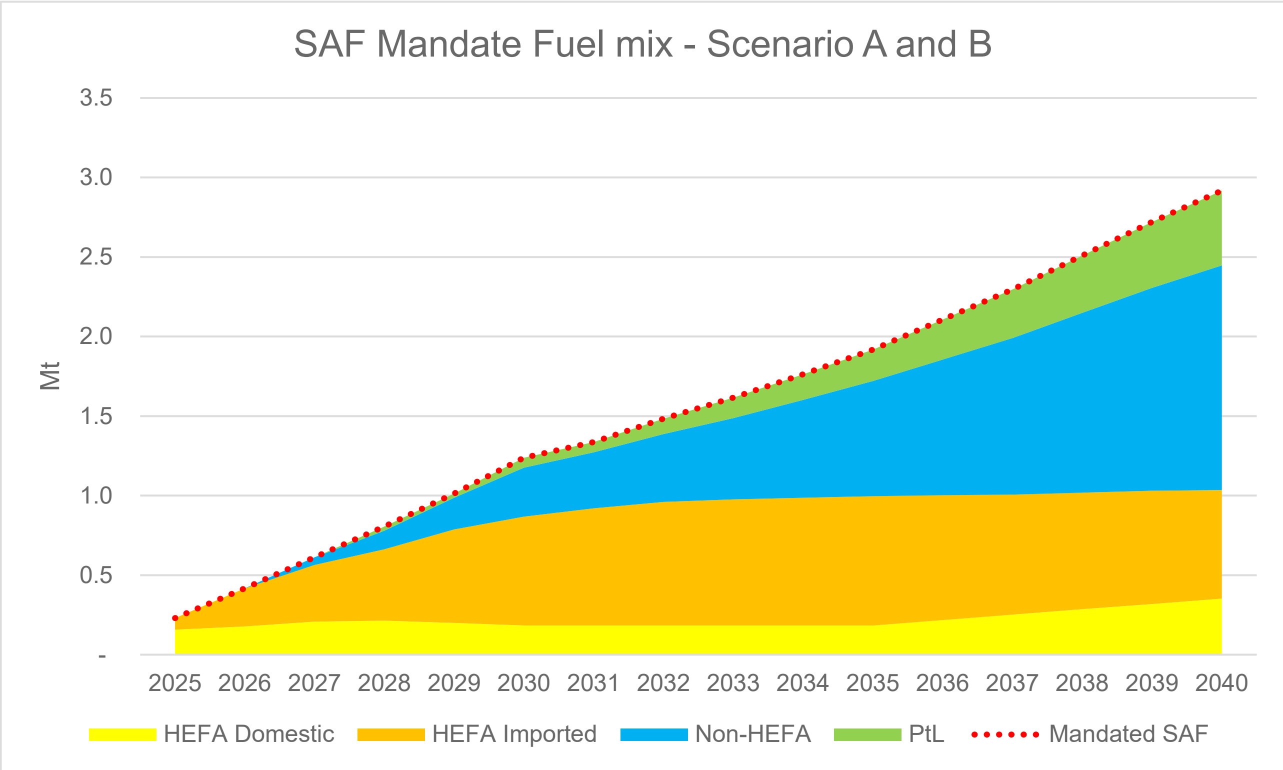
Scenario A & B fuel mix

4.2 In scenarios A and B the SAF Mandate can be met due to the increased levels of feedstock, imports and technology deployment. In these scenarios the Mandate is heavily reliant on HEFA, especially imports, until 2030 when the HEFA cap limits the amount of HEFA in the Mandate.

4.3 After 2030 the model begins to bring through more of the non-HEFA fuel pathways using agricultural and forestry residues. In addition, the PtL obligation increases deployment of the PtL pathway.

4.4 However, in Scenario A because there is more feedstock and imported fuel available to the UK, the impacts on the RTFO are significantly reduced. This is specifically due to the increased levels of used cooking oil imports available to the UK. This decreases the additional costs in the RTFO potentially caused by the Mandate but does not change the SAF Mandate fuel mix.

Figure 17. Scenario A and B SAF Mandate fuel mix (2025-2040)

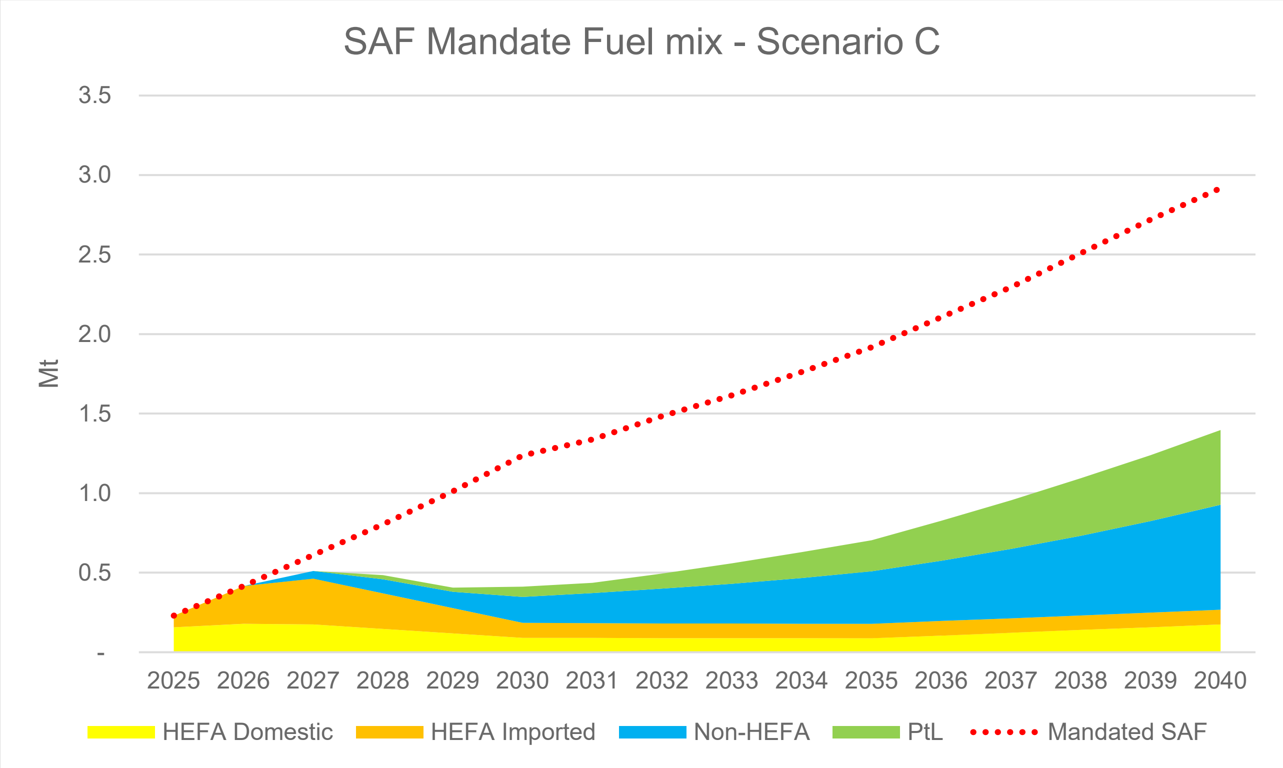


Scenario C fuel mix

4.5 In Scenario C the SAF Mandate cannot be met due to limits in feedstock, imports and technology deployment leaving a gap between the SAF Mandate demand and fuel availability. As the fuel mix in this scenario shows, the Mandate is heavily reliant on HEFA imports in the years to 2030. After this point the Mandate becomes more reliant on non-HEFA fuels including a growing proportion of PtL fuels.

4.6 In this scenario if more HEFA imports were available the modelling would choose to use it first, due to its better cost effectiveness in delivering emission reductions relative to other SAF, especially to 2030. This can be seen in the above fuel mix graphs for scenarios A and B.

Figure 18. Scenario C SAF Mandate fuel mix (2025-2040)



Costs

4.7 The costs over the baseline for the SAF Mandate policy are presented in Table 5, for the three UK SAF production and import scenarios defined in Section 3. All other input assumptions are held at their central value. The results of a range of sensitivity tests in which individual assumptions are varied are presented in Section 6.

4.8 In scenarios A and B the SAF Mandate can be met in full. In Scenario C, the modelling suggests that the Mandate cannot be met. Under this scenario, the shortfall is bought out at the buy-out price of £4.70/litre, the total cost of which is included in the tables below as a cost to business, but also in the benefits tables as a source of revenue for government.

4.9 In the tables below, costs are always presented as negative values. The change in the cost to airlines for purchasing UK ETS allowances and CORSIA credits is included as a positive value, illustrating the savings on carbon pricing under the ETS and CORSIA that airlines will make by switching to SAF, despite the increased costs of the SAF itself.

Table 5. Additional costs of Mandate (2023 prices)

Cost over baseline (£ millions, 2025-2040)	Scenario A	Scenario B	Scenario C
Fuel costs	- 11,434	- 11,434	- 6,639
ETS/CORSIA costs	2,250	2,250	658
Buy-out costs to business	0	0	- 60,465

Total costs (undiscounted)	-	9,184	-	9,184	-	66,445
Total discounted costs	-	6,442	-	6,442	-	47,237

Non-monetised costs

4.10 Fuel suppliers, airports and airlines may face additional costs above those quantified here, as a result of complying with the Mandate. These could include administration and blending costs as a result of new fuel supply requirements. The government will also face some administration costs due to implementing the Mandate.

4.11 Data gathered as part of the RTFO Post Implementation Review published in 2014[43] highlighted the following costs:

- Blending costs of £3-4/tonne of biofuel.
- Administration costs (including reporting, trading, verification, audit, marketing and general management) – estimated to be in the region of £0.5m/year for each large, obligated company.

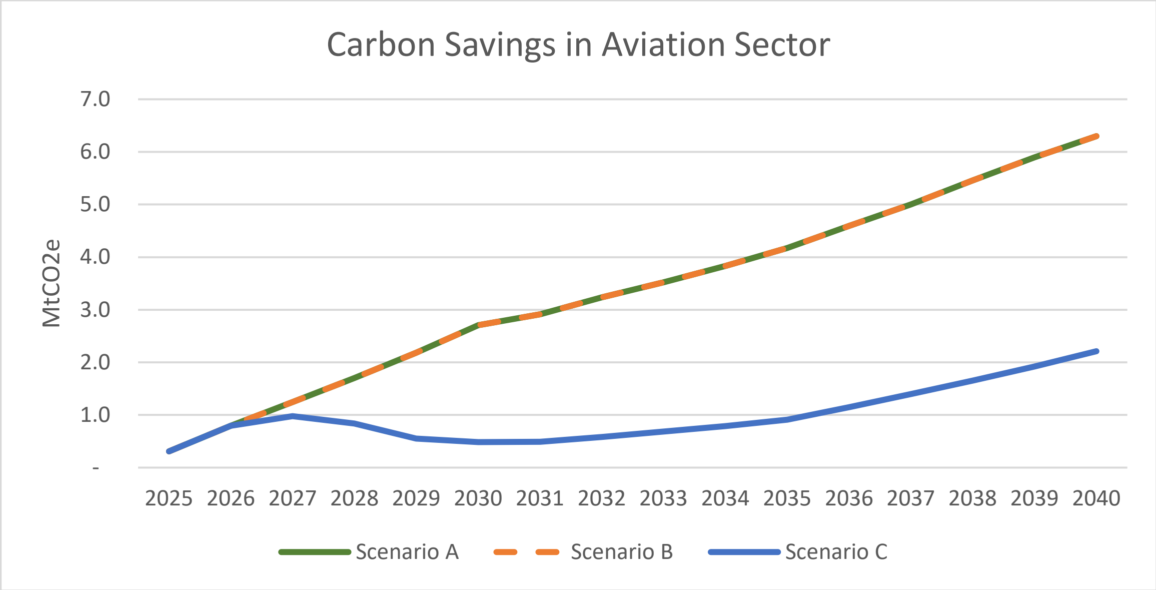
4.12 Overall, these costs have not been quantified for this CBA, given the uncertainty in adapting estimates from the RTFO to the aviation sector, and the expectation that these costs would be negligible relative to overall fuel costs.

Benefits

4.13 The annual emission reductions in the aviation sector are shown in Figure 19 for the 3 scenarios. Under scenarios A and B the SAF Mandate is met in full each year, and the carbon savings rise steadily to 2040, in line with the SAF Mandate trajectory. Under Scenario C it is assumed there is constrained production of SAF in the UK and fuel imports so that the SAF Mandate can only be partially met each year and this leads to lower emission reductions over the appraisal period.

Figure 19. Annual emission reductions benefits from the aviation sector

[43] Impact assessment: Renewable transport fuel obligation: Post implementation review (publishing.service.gov.uk)



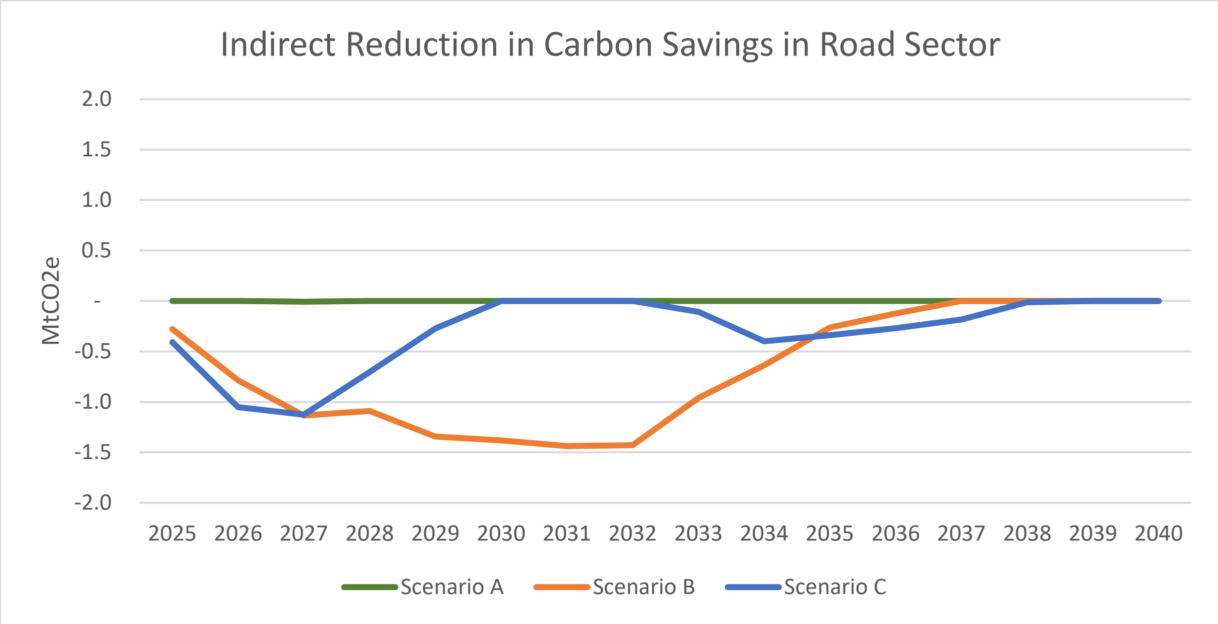
4.14 Figure 20 shows the range of potential reductions in carbon savings that could occur in road transport. This indirect reduction in carbon savings could arise in road transport due to UCO feedstocks being diverted from roads towards the SAF mandate, which leads to buy-out within the RTFO.

4.15 In Scenario A, the high total supply of UCO feedstocks and fuels means that, generally, the SAF mandate and RTFO can be met in full, and there is very little UCO feedstock diverted from roads to the SAF Mandate, which leads to only a small reduction in carbon savings in road transport in a single year.

4.16 Under Scenario B, the SAF Mandate diverts the highest amount of biodiesel from road transport, as the SAF Mandate is met in full but the total UCO availability is constrained, and this leads to the highest reduction in carbon savings in road transport arising from the SAF mandate.

4.17 In Scenario C, the level of UCO is significantly constrained such that there would already be significant buy-out of the RTFO even without the SAF mandate in place. Additionally, the limited availability of UCO means that there is buy-out within the SAF mandate. As the SAF mandate consumes less UCO feedstocks, this leads to less fuel being diverted from roads and lower indirect reduction in carbon savings in road transport, in comparison to Scenario B.

Figure 20. Indirect loss in emission reductions in the road sector



4.18 Finally, there are monetised road fuel cost benefits, which as explained in section 3 value the resource benefit from reduced road biofuel use.

4.19 Table 6 summarises the change in carbon emissions across the three scenarios in both aviation and the RTFO markets. These emission reductions are based on a well-to-wing (WtW) scope for estimating the carbon emissions from SAF, which is aligned with the approach used for the Renewable Transport Fuel Obligation but differs from that used in the Jet Zero Strategy and Carbon Budget Delivery plan. As noted in section 3, the indirect reduction in emissions associated with the impact of the Mandate on aviation demand are not included in these estimates and would be additional to those included. Annex 7.7 providers further details on the carbon accounting used in the CBA.

Table 6. Carbon savings

Carbon Savings (MtCO2e)	Scenario A	Scenario B	Scenario C
Additional aviation carbon savings from SAF mandate	53.9	53.9	15.74
Reduction in carbon savings under the RTFO	0.00	10.9	4.9
Net additional carbon savings	53.9	43.0	10.9

4.20 Table 7 shows the monetised benefits for the three UK SAF production / import scenarios. Buy-out costs are included here as a benefit to government, offsetting their being included as a cost to business in the calculation of social costs and reflecting the economic transfer that takes place.

Tables 7. Additional benefits of Mandate (2010 prices)

Benefits over baseline (£ millions, 2025-2040)	Scenario A	Scenario B	Scenario C
Monetised carbon emission reductions	11,668	9,190	2,291
Monetised road fuel cost benefit	1	1,674	1,225
Buy-out benefit to government	0	0	60,465
Undiscounted benefits total	11,669	10,865	63,980
Total discounted benefits	8,325	7,653	45,608

Non-monetised benefits

4.21 The mandated use of SAF may have wider environmental impacts, other than on CO2. Though the evidence is less developed and highly uncertain, early research suggests that the non-CO2 and air quality impacts of flying could also be reduced from switching to SAF (though this is subject to significant scientific uncertainty and impacts will vary across different SAF types). For example, some early studies have suggested that using SAF reduced the size and longevity of contrails[44] and the volume of contrail particle formation[45] [46] relative to jet fuel. The production of soot aerosols[47] [48], concentration of soot particles in the air and mass emissions also reduced significantly[49] with biofuel blending compared to jet fuel. More evidence is needed in this area to be able to make any claims about the non-CO2 benefits of a Mandate.

4.22 As part of the Jet Zero Strategy, DfT committed to improving its understanding of the non-CO2 impacts of aviation, and the potential for SAF and other decarbonisation measures to mitigate these impacts. We launched a multi-year research programme alongside the Department for Business and Trade and the Natural Environment Research Council to support the commitments made in the Jet Zero Strategy. On 13 October, we launched the first call for projects which was targeted at academia. The competition closed on 30 January and we are currently assessing the bids with projects due to start in May 2024. We will be launching a further call shortly which will seek bids from industry and this will be delivered through the Aerospace Technology Institute.

4.23 A further benefit of the Mandate is to provide long-term certainty for SAF producers and investors. We expect that this, in combination with other support

[44] Teoh et al (2022) Targeted Use of Sustainable Aviation Fuel to Maximize Climate Benefits | Environmental Science & Technology

[45] Civil Aviation Alternate Fuels Contrails and Emissions Research (2018) CAAFCER-Contrail-Results-Report_LTR-FRL-2018-0014-CAAFCER.pdf (cbsci.ca)

[46] Cleaner burning aviation fuels can reduce contrail cloudiness (2021) Cleaner burning aviation fuels can reduce contrail cloudiness | Communications Earth & Environment (nature.com)

[47] Speth et al (2015) *Black carbon emissions reductions from combustion of alternative jet fuels* Black carbon emissions reductions from combustion of alternative jet fuels | Request PDF (researchgate.net)

[48] Moore et al (2017) *Biofuel blending reduces particle emissions from aircraft engines at cruise conditions* Moore_et_al_Nature_2017.pdf (dlr.de)

[49] Bräuer et al (2021) Reduced ice number concentrations in contrails from low-aromatic biofuel blends | Atmospheric Chemistry and Physics

provided for the domestic SAF industry such as the AFF, or the revenue certainty mechanism, which the government has committed to introduce by the end of 2026, will help to support the SAF production in the UK, and in turn provide jobs and GVA benefits to the UK economy. We have not quantified any such impacts in this analysis, due to the fact that the Mandate does not specify that any amount of fuel must be produced domestically.

4.24 Research indicates that by 2035, the UK SAF sector could contribute up to £1.8 billion annually to the UK economy and support up to 10,000 jobs[50].

4.25 The inclusion of a PtL obligation could potentially bring significant further benefits to the UK which are currently non-monetised. By including a PtL obligation which will effectively incentivise further investment in these more novel fuel pathways, the UK could benefit in the long run from increased research and development funding, which generates jobs and spill-over investments. Further, increased funding today should result in cost reductions and production efficiencies being implemented more quickly, ultimately leading to lower costs in the long run. The scale-up of PtL could also accelerate the early scale-up of other technologies such as carbon capture and hydrogen production, both of which are inputs to PtL production and will be needed for future decarbonisation of aviation and other sectors.

Overall results

4.26 Table 8 below shows the overall results of the cost benefit analysis for each of the three scenarios.

Table 8. Total costs, benefits, and net present value under each scenario (2025-2040) (2010 prices)

Total costs and benefits over baseline (£ millions, 2010 prices, 2025-2040)	Scenario A	Scenario B	Scenario C
Discounted social costs	- 6,442	- 6,442	- 47,237
Discounted social benefits	8,325	7,653	45,608
Net Present Value	1,884	1,212	- 1,629

4.27 The results show that under Scenarios A and B with high/very high domestic and imported biomass the NPV is positive, but in Scenario C where there is low domestic/imported biomass, the Net Present Value (NPV) is negative. This reflects the importance of sufficient feedstock availability in ensuring cost-effectiveness of the Mandate. It also captures the high-cost impact associated with several types of SAF, including PtL SAF. It is important to note that these calculations do not include several non-monetised benefits which are discussed above.

[50] Roadmap for the development of the UK SAF industry, April 2023 https://www.sustainableaviation.co.uk/wp-content/uploads/2023/04/Sustainable-Aviation-SAF-Roadmap-Final.pdf

Other impacts

Interaction with the UK Emissions Trading Scheme

4.28 Under the UK ETS, airlines are able to claim emission reductions for their use of SAF. Airlines are able to make an Emissions Reduction Claim (ERC) for their use of SAF, so long as it meets defined sustainability criteria. ERC eligibility is currently based on the sustainability criteria defined for the RTFO.[51] Currently eligible SAF has an emissions factor of zero. This means that, currently, all types of eligible SAF are assigned zero emissions irrespective of their actual life cycle emissions. A successful ERC reduces an airline's emissions for the scheme year, which in turn reduces the number of allowances it has to surrender to meet its obligations under the scheme.

4.29 The UK ETS Authority will continue to develop proposals on how the UK ETS should treat the use of SAF by aircraft operators and will consult on these in due course. The Authority will consider full alignment with the SAF Mandate sustainability criteria. In addition, while SAF will continue to be zero rated under the UK ETS in the short-term, the Authority will continue to explore alternative options to SAF being zero rated in the future.

4.30 The Mandate is expected to drive an increase in the overall supply of SAF in the UK, relative to the business-as-usual scenario. A significant proportion of the SAF supplied under the SAF Mandate is also expected to be eligible under the UK ETS, although UK ETS legislation does not permit airlines to claim for forms of SAF which are not biofuels, such as recycled carbon fuels or PtL. [52]

4.31 By increasing the number of ERCs airlines make under the UK ETS, the SAF Mandate is expected to result in an equivalent reduction in the demand for UK ETS allowances (UKAs). The associated reduction in the costs airlines face to comply with the UK ETS, which partially offsets the additional costs they face to use SAF, is captured in the monetised CBA results presented above.

4.32 The reduction in the demand for UK ETS allowances will likely result in a reduction in the price of allowances relative to its levels were the SAF Mandate not to be introduced. We would expect this to lead other UK ETS participants to increase their demand for UKAs relative to the counterfactual, as this becomes more affordable versus direct emission reduction options.

4.33 The Green Book guidance on valuing GHG savings in appraisal[53] recommends that where a policy affects traded sector emissions they are treated as net emission changes and valued in the same way as emissions reductions elsewhere in the economy. However, in the context of a cap-and-trade scheme for emissions (like the UK ETS) where a cap remains fixed, and where that cap

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[51] These are defined in Schedule 1 of the Renewable Transport Fuels Obligation Order 2007.

[52] Currently, only biofuels meeting the RTFO sustainability criteria are eligible under the UK ETS. Fuels which do not meet this criterion i.e. that have GHG savings less than 65% or fuels that are not bio-based cannot be claimed.

[53] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK (www.gov.uk)

is binding, any reductions in emissions by one participant lead to offsetting emissions by other participants, with no overall impact on net emissions. In 2023 the UK ETS Authority set a Net Zero-consistent cap on the supply of UK ETS allowances, which accounted for the impact of planned UK government decarbonisation measures including increased SAF supply[54]. This suggests that policies such as the SAF mandate may contribute to a more ambitious UK ETS cap, limiting the risk that emission savings under the SAF mandate lead to offsetting emissions by other participants. Section 6 explains this issue in more detail and presents the results of a sensitivity test, which shows the impact on the headline CBA results if it is assumed that none of the emission reductions on flights in scope of the UK ETS in the period to 2030 are additional.

4.34 The scale of the impact on UK ETS allowance prices will depend on what proportion of the SAF supplied under the SAF Mandate airlines claim against their UK ETS obligations. In estimating the monetised costs presented earlier in this section, we assume that the proportion of the SAF supplied under the Mandate that is claimed under the UK ETS is equal to the proportion of their emissions on UK departing flights that are in scope of the scheme.

4.35 Under these assumptions, we estimate that the SAF Mandate would result in airlines claiming use of an additional 4.36 Mt of SAF, resulting in an additional 13.75m ERCs over the period 2025-40. This represents a very small proportion of the overall legislated UK ETS emissions cap in the period to 2030 (e.g. 2% of the legislated cap in 2030).

4.36 Airlines are likely to face a greater financial incentive to claim the SAF supplied under the Mandate against their obligations under the UK ETS than under other carbon pricing schemes[55]. Therefore, we have also considered the impact on our analysis of assuming that all SAF supplied under the Mandate is claimed as ERCs under the UK ETS. Under these alternative assumptions, we estimate that the SAF Mandate would result in airlines claiming use of an additional 15.97 Mt of SAF, resulting in an additional 50.30m ERCs over the period 2025-40. This represents a more significant proportion of the UK ETS legislated cap in the period to 2030 (e.g. 6% of the legislated cap in 2030).

4.37 Ttable 9 below shows how the costs, benefits and NPV change if we assume all SAF supplied under the Mandate is claimed as ERCs under the UK ETS. The social costs are lower than under the core analysis presented above because the additional costs of using SAF over the costs of using kerosene (including carbon price) are lower.

Table 9. Total costs, benefits, and net present value under each scenario assuming all SAF is claimed under the UK ETS (2025-2040) (2010 prices)

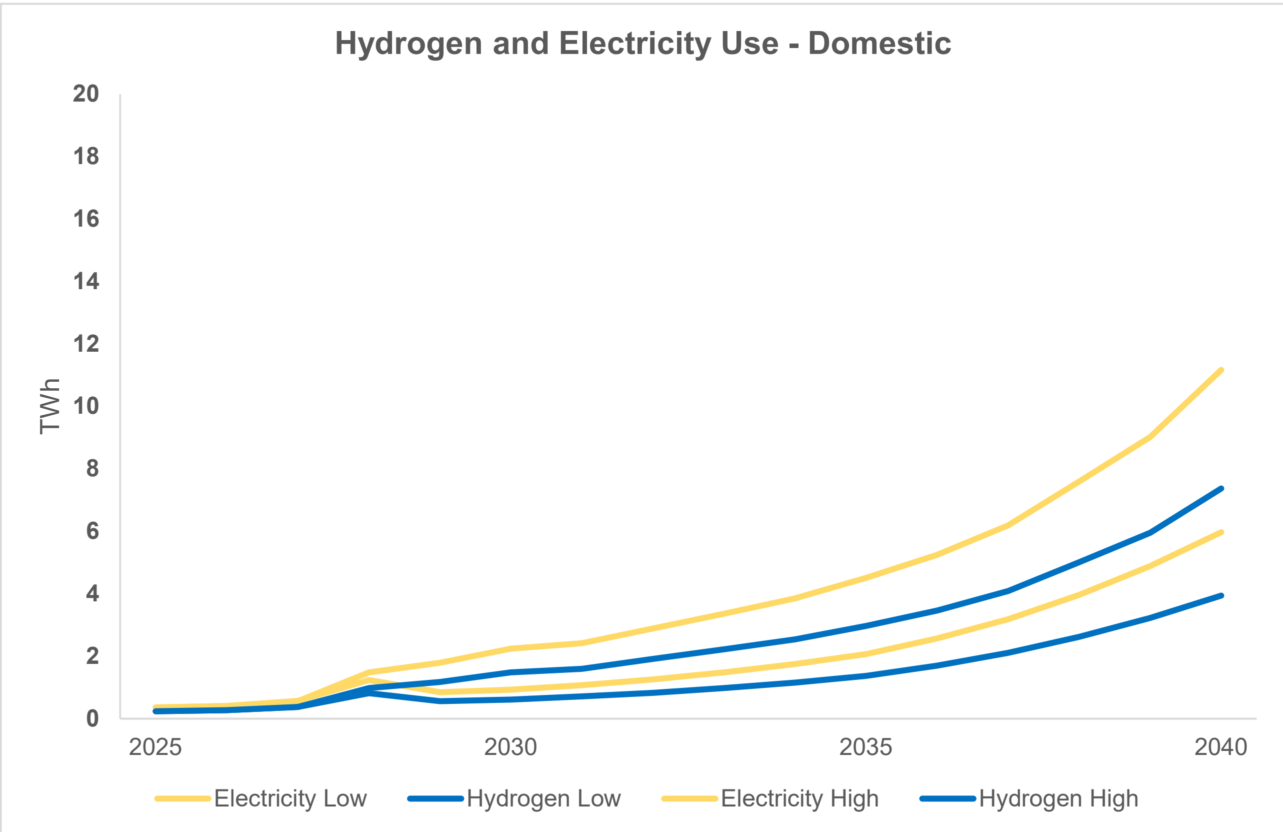
[54] Developing the UK Emissions Trading Scheme (UK ETS) - GOV.UK (www.gov.uk)
Jet Zero Strategy illustrative CORSIA price assumptions are on average ~70% lower than DESNZ UK ETS traded carbon values over the appraisal period:
Jet zero: further technical consultation (publishing.service.gov.uk)
Traded carbon values used for modelling purposes, 2023 - GOV.UK (www.gov.uk)

Total costs and benefits over baseline (£ millions, 2010 prices, 2025-2040)	Scenario A	Scenario B	Scenario C
Discounted Social Costs	-3,252	-3,252	-46,293
Discounted Social Benefits	6,108	5,436	44,952
Net Present Value	2,856	2,184	-1,341

Electricity and hydrogen demands

4.38 The potential electricity and hydrogen demand associated with the Mandate have been presented in Figure 21 and 22. Figure 21 presents the demands associated with domestically produced SAF only; Figure 22 presents total demands including imported fuels and feedstocks. Ranges have been presented to account for different levels of feedstock and import availability. The upper bound is consistent with Scenarios A and B defined in section 3, and the lower bound is consistent with the UK SAF production / import Scenario C.

Figure 21. Hydrogen and electricity use (2025-2040) - Domestic



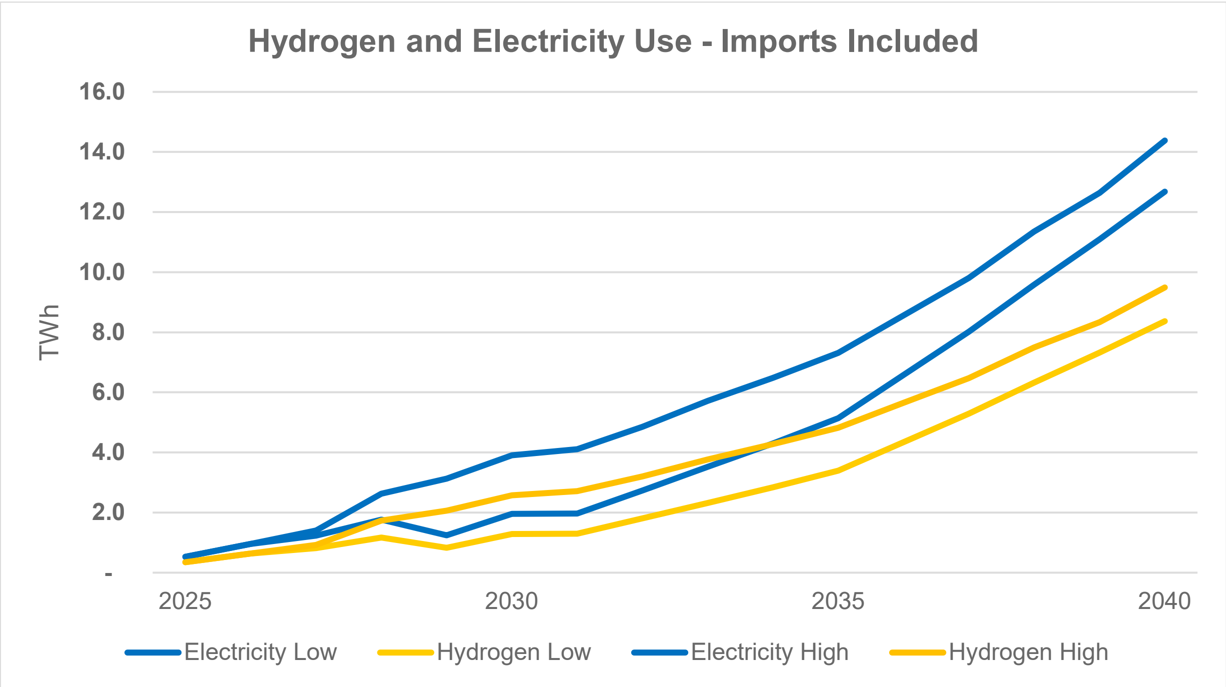
4.39 Electricity demand due to the domestic production of SAF could range between 6TWh and 11.2TWh by 2040 whilst hydrogen demand could range between

3.9TWh and 7.4TWh by 2040. For context, the UK's electricity demand in 2022 was 320.7TWh.[56].

4.40 The level of additional electricity demand to 2040 is relatively small. However, scaling up of low-carbon electricity generation capacity, alongside wider demands for electricity as the economy decarbonises could mean that the energy system is required to deliver near its maximum capacity. Each additional unit of electricity would also require additional infrastructure which would ultimately be an additional cost to UK consumers.

4.41 A significant proportion of the SAF required to meet the Mandate will be imported. When accounting for imports, the electricity and hydrogen demands associated with SAF production significantly increase as seen in Figure 22. This is because the mandate requires increased volumes of SAF through time, and greater volumes of PtL which requires relatively high levels of electricity and hydrogen to be produced.

Figure 22. Hydrogen and electricity use (2025-2040) - Including Imports



4.42 When accounting for imported fuel, electricity demands could range between 12.7 TWh and 14.4 TWh by 2040. Similarly, hydrogen demand could increase substantially to a range between 8.4 TWh and 9.5 TWh by 2040.

4.43 The energy demands modelled here are just those associated with SAF production, and do not consider any by-products which may also be produced as part of the product slate and used within other sectors. For example, when

[56] Digest of United Kingdom Energy Statistics Chapter 5 (DUKES 2023) (https://assets.publishing.service.gov.uk/media/64c23a300c8b960013d1b05e/DUKES_2023_Chapter_5.pdf)

HEFA from UCO is produced, we assume that 54% of the final product is SAF with the remaining proportion being primarily by-products that can be used in the road market. The estimated energy demands quoted above only take into account the proportion of energy used to produce the SAF.

4.44 Hydrogen as a direct fuel will also be eligible under the Mandate. However, this has not been included in the analysis due to the very significant uncertainty surrounding the penetration of hydrogen powered aircraft into the fleet and expectation that their impact on hydrogen use is likely to remain limited in the period to 2040, the appraisal period used in this CBA. If this option scales up sufficiently and offers a cost-effective alternative for decarbonising aviation, hydrogen demands for use within aviation could be higher than the estimates presented in Figures 21 and 22.

Air fare, motoring cost and demand impacts

4.45 We expect that airlines will pass on at least part of the increases in their operating costs in the form of increased ticket prices. These are not an additional cost to those outlined above, rather they reflect how these costs may be passed on. The methodology and assumptions used to calculate ticket price impacts are included in Annex 7.4.

4.46 The average one-way ticket price under the Business As Usual scenario is expected to remain fairly stable at around £173 in 2030 and 2040 (in 2023 prices), based on data from DfT's aviation model. Our indicative analysis suggests that under Scenarios A and B the Mandate could increase the average one-way ticket price by £3.90 (2%) in 2030 and by £9.40 (5.5%) in 2040 (2023 prices). Changes in average air fares of this magnitude fall within the range of annual variations in average air fares seen in the period since 2010.[57]

4.47 Our indicative analysis suggests, however, that a lack of available HEFA and 2nd generation SAF leading to significant levels of buy-out in the main obligation under Scenario C could lead to more significant increases in average one way ticket prices - £22.00 (13%) in 2030 and £37.80 (22%) in 2040[58]. As set out in the main consultation response if this scenario were to materialise the government could immediately review the Mandate and prevent such significant increases in ticket prices materialising.

4.48 There is significant uncertainty associated with many of the assumptions that feed into the calculation of ticket prices. Annex 7.4 provides further detail.

4.49 We have also considered the knock-on impact that the increased ticket prices associated with Scenarios A and B could have on UK aviation demand using DfT's aviation model. Results suggest that under these scenarios the Mandate could lead to demand reductions of around 1.5% in 2030 and 3% in 2040. This

[57] DfT analysis using Quarterly and Annual Average Air Fare Prices - Office for National Statistics (ons.gov.uk)
[58] 55

reduction in demand would lead to indirect impacts, including on aviation GHG emissions, but these impacts were beyond the scope of the CBA model.

4.50 The Government's approach to decarbonising aviation is set out in the Jet Zero Strategy, which focuses on the rapid uptake of new fuels and technologies in a way that maintains the benefits of air travel. The uptake of SAF is a key part of the Strategy and failure to adopt and meet the SAF mandate will restrict the sector's ability to achieve net zero 2050 through this approach. Alternative approaches, such as actively restricting the ability for people to fly to reduce aviation's carbon emissions, would have wide ranging implications, including on ticket prices, potential impacts on jobs in the UK aviation and aerospace sectors, and on UK connectivity.

4.51 Across the scenarios, constraints in biofuel available to road transport can lead to buy-out under the Road Transport Fuel Obligation. This can lead to rises in road fuel prices which vary from 0p to 2p (0-1.4%) per litre of road fuel. As noted above, if insufficient biofuel or other forms of SAF were available, the government could revise regulations to avoid the more significant ticket and road fuel price impacts.

5. Wider Systems Impact

Introduction

5.1 This section describes the results from modelling to assess the implications of the SAF Mandate for a cost-effective transition to net zero across the whole energy system.

5.2 Solid biomass feedstocks are required for many SAF production processes but are an important resource for decarbonisation outside of aviation, for instance hydrogen production for use in power, industrial production and potentially heat. PtL creates additional demand for electricity over and above that required for decarbonisation of other sectors. Therefore, mandating airline operators to source a certain proportion of their fuel from such sources could have implications for decarbonisation and/or energy security outside of aviation. This section describes the whole energy system analysis carried out to assess whether the proposed level of the SAF Mandate is consistent with cost-effective pathways to net zero and overall security of supply.

5.3 We used the UK TIMES model[59] for this analysis, developed by University College London in collaboration with DESNZ and its predecessors. This is a whole energy system optimisation model that finds the least cost way of meeting carbon budget and net zero targets under a given set of assumptions. UK TIMES models five-year periods from 2010 to 2060 and so can explore how the energy system is able to decarbonise over time.

Summary of conclusions

5.4 UK TIMES modelling indicates that SAF is important for reducing the costs of transitioning to net zero across the energy system, where greater amounts of biomass are available. This conclusion holds providing the main UK production

[59] https://www.ucl.ac.uk/energy-models/models/uk-times

method is gasification-Fischer Tropsch (gasification-FT) coupled with Carbon Capture and Storage (CCS). This is because production of SAF through gasification-FT with CCS is a relatively cost-effective way of generating negative emissions, and alternative options for decarbonisation of aviation over the period to 2040 are extremely limited. This analysis indicates the importance of integrating CCS into SAF production, where viable, as early as possible.

5.5 Under reference assumptions for CCS availability (see below), UK production of PtL SAF would increase costs of decarbonisation across the energy system. This is because it is more cost effective to store captured carbon than to use it for SAF production. However, PtL would become more important if carbon capture increases faster than accessible storage infrastructure, since the carbon can be used in this process. Imports of PtL SAF could also be important for meeting net zero where there is lower biomass availability (such as in the restricted biomass import scenario). Therefore, a PtL obligation helps mitigate risks arising from uncertainty around technology and biomass availability.

5.6 Under low biomass availability, there would be a moderate risk to security of electricity supply if the Mandate were met through increased UK production of PtL instead of imports. However, in practice, limits on how quickly SAF production facilities can feasibly be built and deployed mean that adverse impacts in the next 5 to 10 years are unlikely even in the case of lower biomass supply or lower SAF imports. Therefore, the regular review mechanism within the SAF Mandate should provide enough flexibility to adjust the Mandate in time to mitigate against these risks.

Methodology

Approach

5.7 The implications for the whole energy system were investigated using multiple scenarios which varied the amounts of biomass and SAF imports available, and the extent to which CCS is available in the UK and for SAF production, in particular.

5.8 Two core scenarios were modelled, to identify the optimal level of SAF and the potential impact of the Mandate respectively.

5.9 In the first core scenario, no minimum level of SAF is imposed on the modelling, this identifies the optimal level of SAF, as the model is free to choose the optimal feasible level.

5.10 In the second the Mandate is imposed on the model i.e. the model can only select levels of SAF that meet the proposed minimum SAF, minimum PtL and maximum HEFA percentages.

5.11 If the optimal level meets all the Mandate requirements the two scenarios will be the same.

5.12 To test the optimal level of SAF and the impact of the Mandate, the two core scenarios were run under the ambitious and restricted biomass import availability scenarios used in the main CBA analysis. We also ran additional sensitivities varying CCS availability because this has a large impact on the relative cost-effectiveness of SAF. Table 10 below has further details.

5.13 The maximum feasible rates of increase in UK SAF production are aligned to those described in the main CBA. These are based on development pathways following on from the initial AFF project deployment and have been included as an upper limit in the UK TIMES modelling in all scenarios.

Limitations and differences from main CBA assumptions

5.14 A simplified representation of the Mandate was used for the modelling. Under this approach the Mandate percentages are applied on a simple energy basis with no adjustment for the emissions intensity of different sources of SAF. The Mandate is also applied on an energy basis but the contribution of each unit of SAF from a particular source is scaled up or down depending on its emissions intensity, relative to the average intensity specified in the regulations. This scaling could not be applied in UKTIMES because it does not model bioenergy and SAF imports at the level of detail required. In scenarios where the UKTIMES modelled optimal SAF production mix has an average emissions intensity close the regulated SAF average, the simplified representation of the Mandate will be a good approximation for the equivalent Mandate level. However, in all scenarios where gasification-FT with CCS is part of the optimal mix, the simplified approach will tend to overestimate the level of SAF required to meet the Mandate. This method generates negative emissions and therefore, 1 TWh of SAF produced in this way will count as more than 1 TWh towards the Mandate. This is because this method generates negative emissions and therefore saves more emissions per TWh, compared to fossil fuel kerosene, than the average saving to be stated in the regulations. However, we have ensured all our following conclusions regarding the overall value of SAF in the context of meeting net zero and sensitivity to biomass and CCUS availability are robust to this simplification.

5.15 As described in the Technical Annex of the Biomass Strategy, SAF production technologies have recently been added to the UK TIMES model, based on recent evidence reviews by University College London (UCL) researchers[60]. These have not been aligned to those gathered by the Aviation Impact Accelerator and used in the main CBA approach. This means that the cost and efficiency assumptions for these technologies used in the whole energy system modelling will differ somewhat from those used in the main CBA. However, there is value in using different technical assumptions between these separate analyses: these processes are still novel, with a wide range of uncertainty in how they will perform and how expensive they will turn out to be over the coming decades, and it is important to ensure our conclusions are robust to varying expert expectations.

[60] Kim et al., 'Technoeconomic characterisation of low-carbon liquid hydrocarbons production', published in Energy, volume 294, 2024: https://doi.org/10.1016/j.energy.2024.130810

5.16 Hydrogen-fuelled aircraft have also been added to the UK TIMES model recently, using as an upper limit the deployment rate set out in the High Ambition scenario of the Jet Zero Strategy. These are not included in the main CBA above. When the SAF Mandate was included in the whole systems modelling, hydrogen provided for direct burn fuel was also not included but will count towards meeting the Mandate. Maximum deployment before 2040 is low and therefore neither the inclusion of hydrogen aircraft in the modelling nor the omission of hydrogen from the modelled Mandate has a significant impact on results.

5.17 Aviation demand in UK TIMES has not been updated to match the latest DfT projections, as there was insufficient time to repeat the UK TIMES modelling following this update. DfT's latest projections, which are used in the main CBA, are higher. However, the increase is relatively small compared to other sources of uncertainty in the modelling. There would be some impact on the optimal modelled level of SAF, if updated, but this would be more than offset by a more accurate representation of the SAF Mandate. The update therefore does not affect the conclusions reported here.

5.18 The practical operation of the scheme and incentives faced by individual businesses are not modelled. For instance, 'buy-out' is not represented so the model must meet the Mandate regardless of the cost of supplying SAF, even in the absence of affordable feedstocks, for example. UK TIMES identifies the least cost pathway achievable under a given set of assumptions. This indicates the potential benefit or cost of mandating a certain level of SAF under different scenarios if optimal choices are made both for the SAF production mix and across the whole energy system. Therefore, the scenarios provide an indication of risks and benefits associated with SAF under alternative scenarios but are not predictions of what will happen under the Mandate.

Choice of scenarios modelled

5.19 We have constructed several scenarios to help explore the costs and benefits of SAF under different possible eventualities. The table below sets out the rationale for the scenarios and explains how they were constructed.

Table 10. Modelled Scenarios

Scenario factors varied	Rationale for scenario variation
Biomass availability: "Ambitious" and "Restricted" import scenarios for biomass feedstocks as set out in the Biomass Strategy. Imports of processed SAF were added, which had not been included in the Biomass Strategy, as described elsewhere in the CBA, with the 'restricted' and 'ambitious' scenarios used.	Many sectors across the system could beneficially use biomass feedstocks and fuels to decarbonise. If there is less biomass and biofuel available to the UK, decarbonising the whole system becomes more challenging and this will affect the relative cost effectiveness of SAF biofuel compared to other uses.

	Ambitious and Restricted scenarios were run in combination with other sensitivities.
SAF Mandate (i.e., imposed minimum level of SAF consumption): Reference case: model is free to choose the optimal level of SAF production. To enable maximum flexibility in how the model allocates its scarce biogenic resources, a new "minimally constrained" reference scenario was developed. This removes some of the constraints in the Net Zero Strategy scenarios that were used to illustrate contrasting pathways for decarbonisation of space heating. Imposed Mandate: model is constrained to force it to use the Mandated minimum SAF proportion and minimum PtL proportion on an energy basis.	To identify the optimal level of SAF and compare this with the proposed Mandate level. Reference and imposed Mandate scenarios were run in combination with other sensitivities.
CCS availability: Reference/ Central assumption: CCUS available from 2028 across all sectors, with potential storage capacity increasing over time. Sensitivities: Carbon capture not available for SAF: As in the reference case but CCUS not available at gasification-FT SAF production sites Low CO2 storage: Illustrative scenario with limited carbon storage available across all sectors. This is an illustrative scenario to test sensitivity of results to technology availability and does not indicate any change to current expectations.	Negative emissions from application of CCUS to bioenergy production are important for meeting net zero. In addition to central CCUS assumptions we have therefore run two illustrative scenarios to test the sensitivity to technology uncertainty. If CCS is not used in SAF production but is available for competing biomass technologies, alternative uses are likely to be more cost effective for achieving the UK's decarbonisation targets. If carbon storage was more limited across the whole energy system than we currently expect, this would be likely to increase the importance of power to liquid SAF but could also create competition for the limited storage available.

Findings from the analysis

SAF Mandate implications for meeting net zero

5.20 UK TIMES modelling suggests SAF is important for achieving net zero under high biomass availability scenarios, providing CCS is used at gasification-FT facilities[61]. When CCUS is available for SAF production, the modelled optimal level of SAF is consistent with the level of the proposed Mandate under both the ambitious and restricted biomass availability scenarios.

5.21 Under central assumptions for CCUS availability, and after allowing for modelling simplifications, overall results suggests that, providing CCS is used, the cost-optimal level of SAF is likely to be above the Mandate under higher biomass availability scenarios. However, if CCS is not used for gasification-FT

[61] This is consistent with the conclusions of the Biomass Strategy, which highlighted the importance of BECCS in reaching Net Zero; and with the proposed implementation structure of the SAF Mandate, which will incentivise SAF producers to install carbon capture technologies at their facilities where appropriate.

SAF production but is available elsewhere in the energy system, UK TIMES modelling suggests that the cost-optimal level of SAF would be below the proposed Mandate level, since using solid biomass feedstocks to produce SAF without CCS is not the most cost-effective way of using these scarce resources (in a net zero consistent energy system). Under this scenario, the costs of meeting net zero would be higher if the Mandate level were met. The cost-optimal level of SAF would also be below the proposed Mandate level under the restricted biomass availability scenario.

5.22 Analysis in the main CBA suggests that the Mandate would not be met under the restricted biomass scenario due to buy-out and therefore the risk to achievement of net zero is minimal even under this scenario. In conclusion, this analysis suggests some risks if the Mandate were set at a higher level than that proposed.

5.23 The cost-optimal level of PtL SAF is lower than the proposed PtL obligation in all modelled scenarios except the low carbon storage scenario (in other words, the PtL Mandate tends to lead to greater overall system costs). Under central CCUS assumptions, PtL SAF only features in modelled least-cost pathways before 2040 in scenarios where this is imposed by the PtL obligation. However, PtL SAF is important for reaching net zero under the low carbon storage scenario as it does not require long-term storage of carbon. Therefore, although the PtL obligation is not cost-optimal under our central assumptions, it helps to mitigate against uncertainty about the future levels of CO2 storage capacity and biomass imports. It is also important to note, as highlighted in section 2, the high level of uncertainty surrounding the future costs of PtL. The section 2 analysis shows that, if considering aviation in isolation, PtL could be cost effective significantly before 2040 under lower bound estimate of future costs. This result might not hold for the cost-optimal level of PtL across the whole energy system but does suggest that this is subject to uncertainty.

SAF Mandate implications for energy security

5.24 Electricity demand will increase during the transition to net zero due to demands outside of aviation, e.g., the electrification of heating and transport. UK production of PtL SAF could therefore put pressure on the power sector if the overall SAF Mandate or PtL obligation is set too high, and imports aren't available to meet the obligation.

5.25 The highest risk would occur if biomass or SAF imports are low or if CCS is not used for production of SAF. We have assessed the risk associated with low biomass availability, using the restricted biomass scenario with the SAF Mandate (including the PtL obligation) imposed on the model. Under this scenario there could potentially be moderate additional pressure on the power system by 2040 if the shortfall in available biomass were compensated for by UK production of PtL SAF. However, limits on the rate at which UK SAF production can feasibly be increased mean that adverse impacts in the next five to 10 years are unlikely even in the event of lower biomass supply or lower SAF imports. Therefore, the review mechanism within the SAF Mandate should provide enough flexibility to adjust the Mandate in time to mitigate against these risks if necessary.

5.26 In scenarios where the Mandate is imposed, there is greater UK production of PtL SAF before 2040 than when a Mandate is not imposed because of the incentive the PtL obligation provides. However, the additional amount of electricity required is small due to assumed limits on the rate at which UK SAF production can be increased. Modelling results suggest this increased demand can be accommodated with negligible increase in electricity generation by reducing the amount of electricity used for hydrogen production elsewhere in the energy system. If UK SAF production grows faster than currently assumed, or the global market grows slower, this could lead to higher levels of electricity demand from UK SAF production. The Mandate can be reviewed and parameters adjusted if such impacts were to occur.

5.27 There will also be increased competition for certain feedstocks as international policies, such as the EU mandate and US tax incentive scheme, seek to ramp up the use of SAF. These feedstocks are a finite resource and could therefore limit the availability to the UK SAF sector.

5.28 UCO is expected to play a significant role in the international SAF market as well as the low carbon road fuel sector. We have assessed the impact of different levels of UCO availability in this analysis. In scenario A and B, the SAF mandate can be met due to increased levels of feedstock while in scenario C the mandate cannot be met. The HEFA cap creates space for the development of new advanced SAF technologies and mitigate the risks of relying on UCO.

5.29 Government has considered international policy when considering the feedstock availability in each of the scenarios in this analysis. However, we will continuously monitor the implementation of the Mandate in the context of the global SAF Market as part of the review mechanism. This will provide sufficient flexibility to amend the Mandate should the availability of feedstock to the UK differ from the assumptions in this analysis.

6. Risk, Uncertainty and sensitivity testing

Risks and Uncertainties

Fuel and Feedstock availability

6.1 As discussed in Section 3 there is inherent uncertainty related to the future supply and demand for low carbon fuel feedstocks and fuels. Given the criticality of this issue, this CBA presents the impacts of the Mandate against three potential UK SAF production and import scenarios.

HEFA cap

6.2 Modelling of the potential levels and types of non-HEFA SAF was undertaken to calculate the level of the HEFA cap. This modelling relies heavily on assumptions of the production costs and GHG savings associated with each SAF type, along with assumptions on feedstock availability, both to aviation and road transport. The novel nature of these technologies means that there are high levels of uncertainty associated with these assumptions.

PtL Obligation

6.3 There are several considerations to be made regarding the level of the PtL obligation including technological and commercial readiness, availability of renewable electricity and hydrogen, and the additional costs of the obligation if targets are not met.

6.4 PtL is currently the only fuel pathway eligible for the PtL obligation and is itself at the very early stages of technology development. Other potential future novel fuels are even less developed. There is therefore large uncertainty around the market's readiness to meet a high PtL obligation level in the short-term. Setting an overly ambitious PtL obligation now could ultimately lead to high levels of buy-out, if the market is not sufficiently developed in time, increasing costs to business and passengers.

6.5 In addition, there will be limited amounts of low-carbon hydrogen and electricity available in the UK, which will impact the availability of domestically produced PtL. PtL is a very energy-intensive fuel and the electricity grid in the UK would need significant expansion to meet SAF demand entirely through domestic production, alongside meeting the energy demands associated with the decarbonisation of other sectors in the UK. Further, there will be limited access to low-carbon hydrogen and direct air capture carbon required for the production of PtL in the short run, which also has competing uses across the economy. The estimated impacts on electricity and hydrogen demand of the Mandate are set out in Section 4. As explained in this section, SAF produced in the UK and internationally can be used to meet the mandate, and we expect a large part of the mandate to be met by imports. Therefore, much of the increased demand for electricity and hydrogen will be met through production outside of the UK.

6.6 Between 2030 and 2040, the confirmed PtL trajectory sits within the range of options we consulted on. During this timeframe there is less certainty regarding international production capacity as well as the availability of CCUS, low carbon energy and low carbon hydrogen that these plants rely on. However, by showing ambition and establishing a market, we will encourage investment to accelerate the development of PtL and capitalise on the environmental benefits it offers.

Buy-out

6.7 As already highlighted, SAF remains a nascent industry with many production processes and technologies yet to reach commercial scale. As such, key data inputs such as production costs associated with SAF production and the GHG emission reductions associated with each of the SAF pathways remain uncertain and highly variable. Furthermore, it is very difficult to accurately forecast how these inputs may evolve in the future. Feedstock prices and the evolution of other production costs depend on many factors, including uncertainty linked to global conflict and the increased demand for biofuels from other countries as they also decarbonise. There is a risk, therefore, that future SAF production costs are significantly different to those assumed. We have sought to mitigate this by setting a buy-out price which equates to the central estimate of production costs, plus a 50% margin, allowing the Mandate to operate without buy-out over a wider range of production costs.

Carbon Capture and Storage

6.8 Production plants may choose to incorporate a Carbon Capture and Storage (CCS) facility which could potentially deliver up to 236% life cycle emission reductions[62] over jet fuel, leading to the opportunity for large negative emissions. Given uncertainty about the timing of CCS roll out, the risk of double counting benefits with the case for government interventions to support CCS,

[62] Michaga et. al (2022) Bioenergy with carbon capture and storage (BECCS) potential in jet fuel production from forestry residues: A combined Techno-Economic and Life Cycle Assessment approach

and the fact that CCS is not a requirement for SAF within the Mandate, this opportunity has not been reflected in the main costs and benefits section.

Interaction with emissions trading schemes

6.9 The main monetised benefits of the SAF Mandate are the GHG savings associated with switching from kerosene to SAF. However, a key assumption underpinning this calculation relates to the extent to which reductions in aviation sector emissions resulting from the use of SAF represent a net reduction in emissions across the UK.

6.10 As explained in Section 4 we would expect the Mandate to lead other UK ETS participants to increase their demand for UKAs relative to the counterfactual, as emission reduction options become less cost-effective under a lower carbon price. This suggests that other UK ETS participants will reduce their own emission reduction activities.[63]

6.11 Based on this causal link it can be argued that reductions in emissions from flights in scope of the UK ETS will not lead to a change in total UK economy emissions, unless the ETS cap is tightened in parallel, due to what is called the ‘waterbed effect’. This describes how, in the context of a cap-and-trade scheme for emissions (like the UK ETS), where the cap remains fixed, any reductions in emissions by one participant leads to offsetting increases in emissions by other participants, with the overall impact that net emissions remain at the level of the cap.

6.12 When the CBA supporting the second consultation was developed DfT appraisal guidance recommended that changes in emissions under the traded sector were excluded from appraisals due to this effect.

6.13 However, cross-government guidance for valuing GHG savings within the traded sector was published by the Department for Business, Energy and Industrial Strategy (BEIS) in 2021. This guidance recommends that any changes in traded sector emissions be treated as net emission changes and valued in the same way as emission reductions elsewhere in the economy, with an appropriate adjustment made for the impact of any trading.

6.14 There are several arguments for this change: Firstly, the cross-government carbon appraisal values seek to represent the cost of abating the marginal tonne of carbon required to meet our decarbonisation targets, as such it is appropriate to use the same values for all sectors. Secondly, the previous approach failed to sufficiently recognise that additional government action to support decarbonisation may be required alongside any emissions trading scheme. And thirdly, the level of future caps in the traded system is not

[63] A similar logic applies in the case of CORSIA. Where airlines claim for the use of SAF under CORSIA, there will be less need for them to invest in reducing their own emissions through other means or to purchase CORSIA credits. These indirect impacts on emissions will partially offset the direct impact of the SAF mandate on aviation emissions. The sensitivity test later in this section considers this issue in the context of the UK ETS rather than CORSIA given the relatively greater financial incentive airlines face to claim for their SAF use against their UK ETS obligations.

independent of emissions in the sector, therefore any reduction in emissions from the sector may lead to lower cap levels in the future.

6.15 Given the differences between DfT and cross-government appraisal guidance at the time, the CBA published alongside the second CBA considered both a case where the emissions savings in the traded sector were excluded and one where they were included.

6.16 Since the second consultation, DfT's guidance has been updated to reflect the cross-government guidance. As such the CBA results presented in Section 4 values the impact of the Mandate on all aviation emissions, including those in scope of the UK ETS, using the same appraisal values.

6.17 However, in the absence of further policy action, we expect the direct impact of the Mandate on aviation emissions to be partially offset by the indirect impact on emissions amongst participants of the UK ETS scheme. This particularly applies for periods in which the UK ETS cap is already set (up to 2030).

6.18 In 2023 the UK ETS Authority set a Net Zero-consistent cap on the supply of UK ETS allowances[64], which accounted for the estimated impact of planned UK government decarbonisation measures included in the 2021 Net Zero Strategy, including increased uptake of SAF. Similarly, the UK ETS Authority will be able to take account of policies such as the SAF Mandate in defining the approach to the UK ETS cap and setting its level post-2030. In this way policies such as the SAF mandate may contribute to a more ambitious UK ETS cap in the longer term, limiting the risk that direct emission reductions under the Mandate lead to offsetting indirect emission increases by other participants.

Sensitivity Tests

6.19 This section presents the results of a range of sensitivity tests we have performed to illustrate the impact on the CBA results of varying key assumptions.

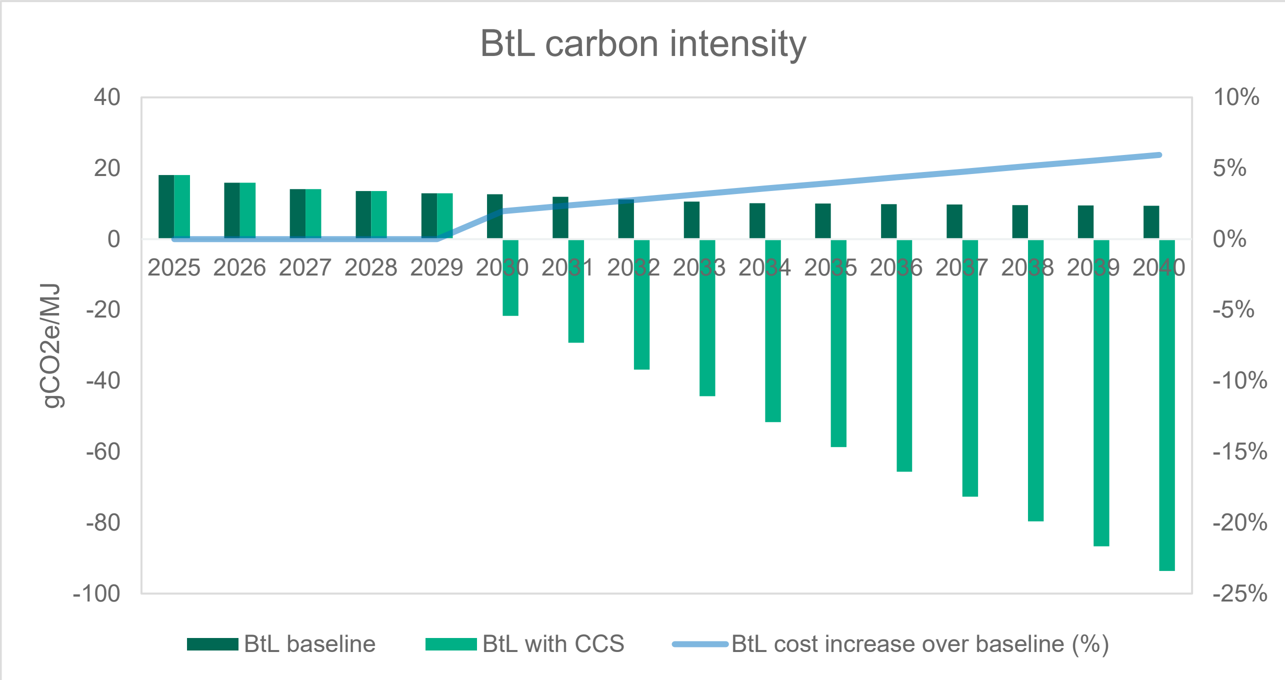
Carbon Capture and Storage sensitivity

6.20 Production plants may choose to incorporate a Carbon Capture and Storage (CCS) facility which could potentially deliver up to 236% emission reductions[65] over jet fuel, leading to the opportunity for large negative emissions. While CCS can be applied to a number of SAF pathways, for the purposes of this sensitivity test, only facilities producing SAF through Biomass to Liquid (BtL) pathways are assumed to attach CCS to their plants. The rate of deployment assumed in this sensitivity begins at 25% deployment in 2030, with a 5% increase each year, reaching 100% integration of CCS technology for BtL pathways in 2040.

64 Developing the UK Emissions Trading Scheme (UK ETS) - GOV.UK (www.gov.uk)
65 Michaga et. al (2022) Bioenergy with carbon capture and storage (BECCS) potential in jet fuel production from forestry residues: A combined Techno-Economic and Life Cycle Assessment approach

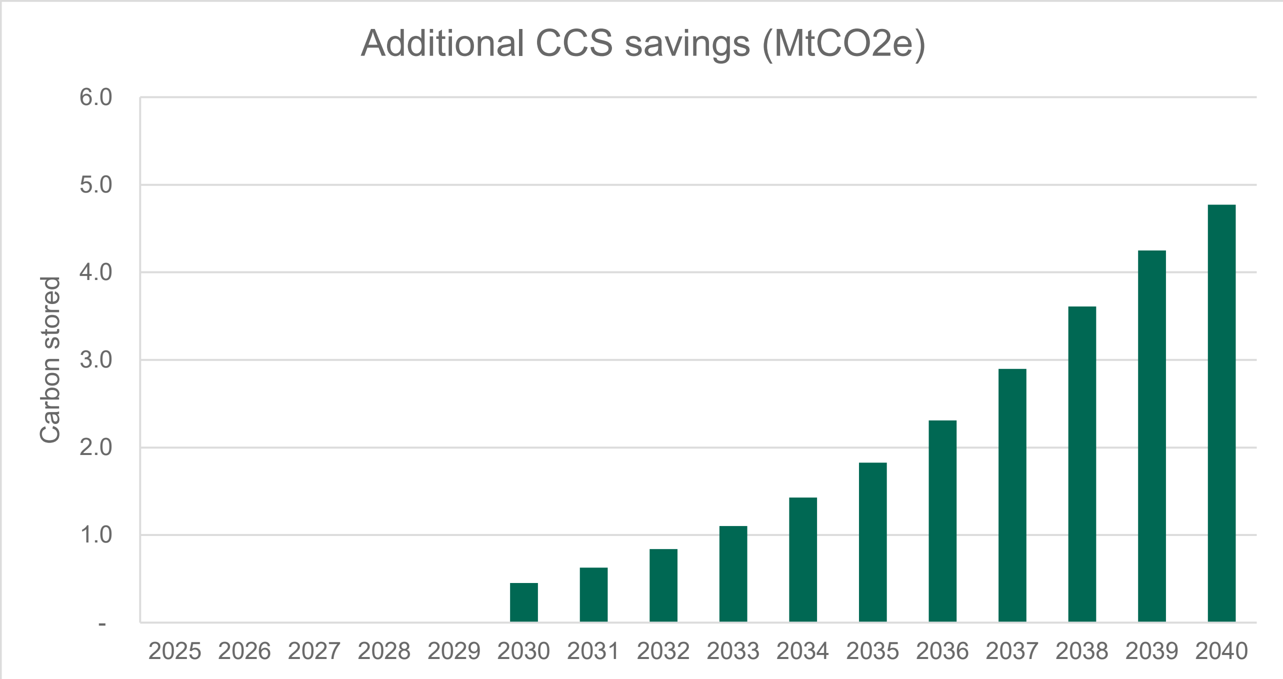
6.21 As shown in Figure 23, when CCS technology begins to be deployed carbon emissions fall from 13gCO2e/MJ in 2029 to -22gCO2e/MJ in 2030, showing a 35gCO2e/MJ decrease in emissions from CCS, immediately leading to negative emissions. In 2040, BtL emissions without CCS are estimated to produce 9gCO2e/MJ whereas BtL SAF pathways with CCS are estimated to bring around 92gCO2e/MJ in negative emissions.

Figure 23. BtL pathway carbon intensity with CCS technology (2025-2040)



6.22 As shown in Figure 24, as early as 2030, there is potential for 0.45MtCO2e to be stored out of the atmosphere through utilising CCS, rising to 4.77MtCO2e in 2040. CCS prevents CO2 released during SAF production from entering the atmosphere, mitigating its impact on the concentration of CO2 in the atmosphere. This would bring down the social costs of the Mandate through emissions savings and drive social benefits gained from negative emissions.

Figure 24. Potential emission reductions from integrating CCS technology starting in 2030 (2025-2040)



6.23 The core scenarios tested at varying biomass levels with the option of adding CCS technology onto SAF production facilities, as shown in Table 11 below.

Table 11. Sensitivity impact of CCS technology in SAF production on costs, benefits and net present value (2025-2040) (2010 prices)

(£ millions, 2010 prices, 2025-2040)	Scenario A	Scenario B	Scenario C
Discounted Social Costs	-5,380	-6,165	-46,531
Discounted Social Benefits	8,441	8,669	45,326
Net Present Value	3,061	2,504	-1,205

6.24 The Net Present Value is higher under each scenario when CCS is implemented as a result of the lower lifecycle emissions, which lead to larger benefits. Under all scenarios, incorporating CCS makes the total Net Present Value significantly higher, as shown, for example, in Scenario B where the NPV doubles from £1,212m to £2,504m.

Carbon Valuation Method Sensitivity

6.25 Under updated cross government and DfT guidance, changes in emissions in the traded sector should be treated as additional and valued at the carbon value minus the price of any allowances adjusted for any applicable carbon prices. As explained above, however, in the years that the ETS cap is fixed (currently up to 2030), any carbon savings made on flights in scope of the UK ETS, could be offset by increased emissions elsewhere in the UK ETS.

6.26 Table 12 below shows the headline results of the CBA if we assume that none of the emissions reductions associated with SAF assumed to be claimed under the UK ETS in the period to 2030 are additional. Emission reductions related to flights outside the scope of the UK ETS are assumed to be unaffected. This sensitivity test does not reflect government appraisal guidance on the valuation of changes in emissions in the traded sector.

Table 12. Impact of alternative carbon valuation approach on costs, benefits and net present value (2025-2040) (2010 prices)

(2025-2040) £m	Scenario A	Scenario B	Scenario C
Discounted Social Costs	-6.442	-6.442	-47,237
Discounted Social Benefits	7,966	7,294	45,446
Net Present Value	1,524	852	-1,791

6.27 Under Scenario C, which delivers lower aviation GHG emission reductions, the reduction in the NPV (£-160m) is significantly lower than under scenarios A and B (£-360m).

6.28 Table 13 below shows the headline CBA results assuming that 1) all SAF supplied under the Mandate is claimed as ERCs under the UK ETS; and 2) none of the of the emissions reductions associated with SAF assumed to be claimed under the UK ETS in the period to 2030 are additional.

Table 13. Impact of alternative carbon valuation approach on costs, benefits and net present value under the assumption that all SAF supplied under the Mandate is claimed under the UK ETS (2025-2040) (2010 prices)

(2025-2040) £m	Scenario A	Scenario B	Scenario C
Discounted Social Costs	-3,252	-3,252	-46,293
Discounted Social Benefits	4,865	4,193	44,399
Net Present Value	1,613	942	-1,895

Carbon and kerosene price sensitivity

6.29 This test considers the sensitivity of the CBA results to varying carbon and kerosene price assumptions. For the 'low' and 'high' sensitivities, the UK ETS allowance prices are assumed to be equal to the lower and upper bounds, respectively, of the ranges published by DESNZ[66]; and kerosene prices are assumed to be at levels consistent with the lower and upper bound of DESNZ oil price forecasts published in November 2023. The CORSIA price assumption in the low sensitivity test is the same as in the core analysis and in the high

[66] DESNZ (2023) https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2023/traded-carbon-values-used-for-modelling-purposes-2023

sensitivity is equal to the central illustrative CORSIA price series published by the DfT alongside the Jet Zero Strategy[67].

6.30 In running this sensitivity test we have not taken account of the impact of the impact of varying assumptions about kerosene and carbon prices on fuel demand. This would have required an additional run of the DfT aviation model which wouldn't have been proportionate for a sensitivity test.

Table 14. Sensitivity impact of varying kerosene and carbon prices on costs, benefits and net present value (2025-2040) (2010 prices)

Total costs and benefits over baseline (£ millions, 2010 prices, 2025-2040)	Scenario A		Scenario B		Scenario C	
Carbon and Kerosene Price	Low Prices	High Prices	Low Prices	High Prices	Low Prices	High Prices
Discounted Social Costs	-9,561	631	- 9,561	631	-50,422	-41,095
Discounted Social Benefits	8,605	7,432	7,933	6,761	47,950	41,274
Net Present Value	-956	8,063	-1,628	7,391	-2,471	179

6.31 Under all scenarios, lower kerosene and carbon prices lead to significantly lower net present values compared to the core analysis. This is because the Mandate's impact on fuel costs is larger in a scenario with lower kerosene and carbon prices.

6.32 Conversely, if higher kerosene and carbon prices are assumed, the impact of the Mandate on fuel costs is significantly smaller. This causes the net present value of the Mandate to improve significantly for all three scenarios.

Carbon value sensitivity

6.33 This test considers the sensitivity of the CBA results to varying the assumed social value of carbon. Rather than using the central value presented in the cross-government guidance for valuing GHG savings, it uses the low and high values presented in the guidance.[68]

6.34 Unsurprisingly given that the main monetised benefit of the Mandate is the reduction in GHG emissions, varying the value applied to changes in these emissions has a very significant impact on the results. Table 15 shows that the NPVs for all scenarios are negative when using the low carbon values and the

[67] See Annex B for details of the illustrative CORSIA prices Jet zero: further technical consultation (publishing.service.gov.uk).We have not varied the CORSIA prices under the low sensitivity because the core analysis already used the low price series published alongside the jet zero strategy. These prices are illustrative and do not represent the UK Government's view on the most likely evolution of market prices under any carbon pricing mechanism.

[68] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK (www.gov.uk)

NPVs increase significantly compared to the core analysis when using the high carbon values.

Table 15. Sensitivity impact of varying value of carbon (2025-2040) (2010 prices)

Total costs and benefits over baseline (£ millions, 2010 prices, 2025-2040)	Scenario A		Scenario B		Scenario C	
Carbon value	Low	High	Low	High	Low	High
Discounted Social Costs	-6,442	-6,442	-6,442	-6,442	-47,237	-47,237
Discounted Social Benefits	3,611	13,039	3,982	11,325	44,695	46,520
Net Present Value	-2,830	6,598	-2,460	4,883	-2,541	-717

Higher SAF price sensitivity

6.35 The trading prices of SAF are uncertain. Given the SAF Mandate will deliver a significant increase in demand for SAF, there is the possibility that markets will trade above the production cost of SAF over some of the time period. Where SAF is produced domestically, higher SAF prices combined with the same cost of production will result in higher profits for UK SAF suppliers, and this can be considered a transfer in economic appraisal terms. Where the cost of imported SAF is higher due to higher prices this results in a higher cost to the UK of delivering the policy.

6.36 In this sensitivity test, we assume that the cost of imported HEFA fuels is higher than the production price of imported HEFA fuels due to constrained availability of UCO. We assume there is some buy-out under the RTFO, and the buy-out price of the RTFO is £1 per litre. We assume this cost increase is passed on to the SAF market. This leads to an additional £1 per litre (£1,282 per tonne) cost of HEFA.

6.37 Non-HEFA and PtL SAF pathways are at an earlier stage of development and therefore there are greater risks of constrained supply until the production routes are well established. Therefore, we make a conservative assumption that the cost of fuels rises to just below the buy-out price over the period of the policy.

6.38 As Table 16 shows these assumptions result in a significant reduction in the NPVs of all three scenarios. These assumptions can be seen as a worst-case price scenario. While it is possible that the cost of SAF may trade at the buy-out price, this is only likely to occur over a relatively short time period, as it will encourage greater supply of fuels and the government will be able to change the Mandate parameters as necessary. Under this sensitivity test we assume these inflated prices are maintained over the full period to 2040 which the government would not let materialise in practice

Table 16. Sensitivity impact of varying SAF production cost projections on benefits. costs and net present value (2025-2040) (2010 prices)

(2025-2040) £m	Scenario A	Scenario B	Scenario C
Discounted Social Costs	-7,609	-7,609	-48,502
Discounted Social Benefits	8,325	7,653	45,608
Net Present Value	716	44	-2,444

7. Annexes

Annex 7.1. Methodology behind ETS and CORSIA price series

7.1 The ETS price series is taken from the latest DESNZ Traded carbon values used for modelling purposes[69] published in November 2023.

7.2 The CORSIA price assumptions are taken from Annex B of the Jet Zero further technical consultation[70] and are designed to illustrate the potential range of carbon prices faced by airline operators in future for use in scenario analysis.

CORSIA Price Assumptions	Rationale
Low - based on CAEP ICAO post-COVID modelling for 2021 – 2026.[71] The same growth rate of 9.5% per year is then applied consistently thereafter.	This methodology aims to reflect a scenario in which carbon prices under CORSIA (or a similar international scheme post 2035) remain relatively low. This series implies the scheme continues beyond its current 2035 endpoint but is not adjusted or replaced to converge with a Paris Agreement consistent emission reduction goal by 2050.
Mid - based on CAEP ICAO post-COVID modelling for 2021 – 2026. The same growth rate of 9.5% per year is then applied consistently until 2035. After 2035 we linearly interpolate up to the DESNZ central appraisal value in 2050.	This methodology aims to reflect a scenario in which CORSIA continues as designed until its current end point in 2035 and thereafter it is adjusted or replaced such that carbon prices converge with the DESNZ central appraisal value by 2050.
High - based on CAEP ICAO post-COVID modelling for 2021 – 2026. The same growth rate of 9.5% per year is then applied consistently until 2035. After 2030 we linearly interpolate up to the DESNZ central appraisal value in 2050.	This methodology aims to reflect an ambitious scenario in which CORSIA continues in its current design until 2030 and is then adjusted or replaced such that carbon prices grow to meet the DESNZ high appraisal values by 2050.

[69] DESNZ (2023) *Traded carbon values used for modelling purposes* https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2023/traded-carbon-values-used-for-modelling-purposes-2023.

[70] DfT (March 2022) *Jet Zero: Further Technical Consultation* Jet zero: further technical consultation (publishing.service.gov.uk)

[71] International Civil Aviation Organisation (2021) *Update to Scenario Based Analyses of Potential Impacts of Covid19 on CORSIA Organization* https://www.icao.int/environmental-protection/CORSIA/Documents/CAEP_Update%20COVID-19%20impact%20analyses.pdf

Annex 7.2. SAF production cost assumptions used in analysis

Production cost (£/tonne) in 2023 price base

		2025			2035			2040		
		Best Case	Mid	Worst Case	Best Case	Mid	Worst Case	Best Case	Mid	Worst Case
HEFA	UCO	807	1288	1914	764	1227	1859	751	1211	1836
HEFA	Tallow	834	1132	1659	790	1070	1604	778	1055	1581
BtL	Forestry residue	2066	2641	4742	1339	1719	3529	793	1027	2620
BtL	MSW	3869	4617	7088	2473	2855	4770	1422	1529	3029
BtL	Agricultural Residues	2125	2751	4916	1397	1829	3703	850	1136	2794
BtL	Waste Wood	3894	4775	7565	2494	3521	5247	1441	1682	3506
PBtL	Forestry residue	1854	3379	6241	1132	2421	5068	686	1811	4383
PBtL	MSW	3323	4815	7829	2096	3246	5852	1250	2156	4526
HTL	Forestry residue	5612	3379	17371	4137	2421	14421	3148	1811	12412
HTL	Waste Wood	5577	12422	23845	3278	9217	19611	1833	7111	16912
HTL	Sewage Sludge	2196	3965	8014	1339	2650	6067	751	1731	4714
HTL	Bagasse	6407	10663	17772	4845	8422	14692	3827	6911	12655
HTL	Wet Manure	1404	2274	5052	783	1264	3493	356	556	2405
HTL	Residual Waste	5041	9024	17145	2010	4913	11650	-52	2053	7854
HTL	Unrecyclable Plastic	2501	4355	8735	1127	2370	5947	201	999	4040
HTL	Waste Rubber	1968	3027	6502	811	1338	4059	-4	132	2314
PtL	DAC	2423	6799	10697	1422	4714	8493	1111	4025	7946
Pyrolysis	Waste Lubricant Oil	4070	7156	12778	2978	5636	10639	2204	4547	9105
PtL	Point Source Carbon	1345	3837	7704	834	3034	6685	612	2620	6265

Annex 7.3. SAF GHG saving assumptions used in analysis

Percentage Reduction in lifecycle GHG intensity, relative to kerosene

		2025			2035			2040		
		Best	Mid	Worst	Best	Mid	Worst	Best	Mid	Worst
HEFA	UCO	98%	97%	95%	99%	97%	95%	99%	98%	95%
HEFA	Tallow	88%	86%	80%	94%	89%	80%	96%	90%	80%
BtL	Forestry residue	94%	94%	84%	97%	95%	86%	98%	95%	86%
BtL	MSW	73%	72%	31%	93%	91%	77%	95%	92%	79%
BtL	Agricultural Residues	95%	92%	75%	98%	94%	78%	98%	95%	78%
BtL	Waste Wood	72%	68%	17%	93%	88%	64%	94%	90%	66%
PBtL	Forestry residue	97%	97%	92%	98%	97%	93%	99%	98%	93%
PBtL	MSW	83%	83%	59%	96%	94%	86%	97%	95%	87%
HTL	Forestry residue	84%	83%	22%	92%	87%	25%	94%	88%	26%
HTL	Waste Wood	No savings	No savings	No savings	71%	55%	No savings	78%	61%	No savings
HTL	Sewage Sludge	65%	63%	No savings	95%	93%	76%	96%	94%	79%
HTL	Bagasse	98%	97%	86%	99%	98%	86%	99%	98%	87%
HTL	Wet Manure	85%	82%	58%	97%	95%	88%	98%	96%	89%
HTL	Residual Waste	9%	9%	No savings	85%	83%	No savings	88%	86%	9%
HTL	Unrecyclable Plastic	40%	40%	No savings	89%	88%	61%	92%	90%	68%
HTL	Waste Rubber	50%	50%	No savings	91%	89%	72%	93%	91%	76%
PtL	DAC	100%	100%	79%	100%	100%	97%	100%	100%	98%
Pyrolysis	Waste Lubricant Oil	82%	80%	27%	97%	95%	77%	97%	96%	79%
PtL	Point Source Carbon	100%	100%	100%	100%	100%	100%	100%	100%	100%

Annex 7.4. Ticket price impact methodology

7.3 Evidence from DfT's aviation model suggests that fuel costs make up 22% of ticket prices on average, and carbon costs a further 3%.[72] These figures vary with market and route length, among other factors. For example, routes within the UK and Europe are currently subject to higher carbon costs than routes to

[72] Based on 2023 estimates in DfT aviation model.

outside Europe, and the share of fuel costs are higher for long-haul routes, given the larger volume of fuel needed.

7.4 In estimating the potential ticket price impacts, a 20% premium has been applied to the SAF production costs presented in section 2, which were provided by AIA. This premium reflects the potential margin that SAF producers add to production costs. The size of this premium is subject to high levels of uncertainty.

7.5 There is significant variation in the potential for airlines to pass costs on to customers. The literature suggests a wide range of passthrough rates, ranging from 0% at congested airports to 100% at non-congested airports. Research by the ICF et al. estimates average passthrough rates of around 74% for intra-EEA flights, and 77% for other routes.[73] Research into the impact of carbon pricing on aviation by Frontier Economics claims that 65-80% of airline operating costs tend to be passed onto passengers.[74]

7.6 For the ticket price estimates included in section 4, we assume that fuel and carbon costs comprise around 30% of fares, and that airlines pass through 75% of the additional costs of the Mandate to consumers. Estimated Business As Usual ticket prices are taken from DfT's aviation model. We assume for simplicity that all costs faced by fuel suppliers are passed on to airlines.

Annex 7.5. Historic production build-rates

7.7 Global and country-level electricity production statistics are used[75] alongside historic biofuel production to understand the range of compound annual growth rates for various energy vectors from 2000-2020.[76]

7.8 CAGRs for biofuels are only calculated from 2000-2015 as after 2015 biofuel policies and government investment or subsidy slowed down combined with blend limits on traditional biofuels. As a result, this does not reflect the upper bound of feasible market build-rates for fuel production but rather a series of other constraints in the market.

Historic Production Build Rates

Energy Vector	**Low**	**Average**	**High**
Biofuels	5%	15%	24%

[73] ICF, ATA, Cambridge Econometrics, HFW, NewClimate, & Starcx, S., 2020. *Assessment of ICAO's global market-based measure (CORSIA) pursuant to Article 28b and for studying cost passthrough pursuant to Article 3d of the EU ETS Directive*.

[74] Frontier Economics, AIR Transportation Analytics (2022) *Economic research on the impacts of carbon pricing on the UK aviation sector*, page 129. https://www.frontier-economics.com/media/5109/economic-research-on-the-impacts-of-carbon-pricing-on-the-uk-aviation-sector.pdf

[75] https://ourworldindata.org/grapher/electricity-production-by-source?tab=table&time=2008..latest

[76] https://ourworldindata.org/grapher/biofuels-production-by-region?facet=entity&uniformYAxis=0

Wind	14%	22%	27%
Solar	27%	40%	52%
Bioenergy renewables	5%	7%	9%
Non-bio renewables	2%	3%	4%

Annex 7.6. Aviation Demand Forecasts

7.9 Our analysis uses updated aviation demand forecasts from the Department's aviation model. The model forecasts air passenger demand for UK-departing flights and allocates across the UK's airports based on a number of factors, including a passenger's final destination, location of and accessibility to airport, availability of flights, travel times, cost and the capacity of airports to accommodate projections of passengers and flights to 2050 and beyond.

7.10 CO2 and fuel demand forecasts are produced by combining these outputs with assumptions about the future fuel efficiency of planes based on a fleet model.

7.11 We have used a new version of the aviation model for this analysis. More detail on the changes to the latest version of the model can be found in the DfT Aviation Modelling Suite document.

7.12 The analysis uses the aviation model forecasts in two ways. Firstly, the fuel demand forecasts derived from the CO2 forecasts are used as input into the cost benefit analysis. Secondly, we use the aviation model to understand the impact that the SAF mandate may have on passenger demand.

7.13 To assess the impact on passenger demand, we have used two runs of the aviation model. One run considers a counterfactual scenario where no SAF mandate is introduced, and the other considers the scenario where the SAF mandate is introduced as per the final Mandate design. The difference between these two runs represents the impact of the SAF mandate on aviation demand. The results of this are shown in Chapter 4.

7.14 The table below shows the assumptions used in the counterfactual scenario model runs. The assumptions relating to uptake of decarbonisation technologies are consistent with those made in the Continuation of Current Trends scenario published in Jet Zero: illustrative scenarios and sensitivities.

Model input	Central assumptions

UK GDP and Consumption Expenditure Growth Rates	ONS, OBR, and DfT Tag Databook[77]
Foreign GDP Growth Rates	Weighted average GDP growth rates based on IMF (2022) and OECD (2021) forecast
Oil Prices	Central DESNZ fossil fuel price assumptions, 2023[78]
SAF prices	Weighted average SAF price based on AIA cost data and DfT modelling
Carbon prices	ETS prices: "Market carbon values" series published in DESNZ Traded carbon values used for modelling purposes, 2023[79] CORSIA prices: DfT Low price series published in Jet Zero: further technical consultation[80]
Fuel efficiency improvements	Central Efficiency 1.5% pa (2017-2050) based on 'likely, nominal' case from ATA research[81]
SAF uptake	2% by 2030 4% by 2040
Zero emission tech uptake	None

Annex 7.7. Carbon Accounting Used in the CBA

7.15 The SAF mandate CBA uses a well-to-wake (WtW) scope for estimating the carbon emissions from SAF, which is aligned with the approach used for the

[77] ONS GDP time series and OBR Economic and fiscal outlook for historical data. OBR Economic and fiscal outlook March 2023 and DfT Tag Databook May 2023 for forecast data. All are central assumptions.
[78] https://www.gov.uk/government/publications/fossil-fuel-price-assumptions-2023
[79] https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2023/traded-carbon-values-used-for-modelling-purposes-2023
[80] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1062042/jet-zero-further-technical-consultation.pdf
[81] ATA (2018) Understanding the potential and costs for reducing UK aviation emissions. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785685/at apotential-and-costs-reducting-emissions.pdf

Renewable Transport Fuel Obligation[82]. This accounts for the tailpipe emissions of fuels and the upstream emissions associated with extraction of raw materials, processing and transportation of fuel and indirect land use change. It does not account for emissions from the manufacture of machinery and equipment needed for renewable fuel production or to use fuels, for example, oil refinery construction, or vehicle production.

7.16 For fossil fuels, this accounts for the tailpipe emissions of fuels and also the upstream emissions associated with fuel extraction, processing and transportation.

7.17 Wastes and residues are assumed to have zero emissions up to the collection of these materials.

7.18 Where CCUS is combined with biofuel production processes, the negative emission savings associated with CCUS are accounted for in the carbon savings and can lead to overall negative emissions associated with fuel production, where the carbon savings from CCUS are higher than the emissions associated with producing the fuel.

7.19 This analysis considered four possible routes to power-to-liquid SAF. Two of which use biomass combustion as both an electricity source and source of carbon and the other two using renewable electricity as described above and either point sourced carbon or direct air captured carbon.

7.20 For power-to-liquid fuels, atmospheric CO2 is considered to have zero lifecycle greenhouse gas emissions up to the process of collection of these materials. Waste fossil CO2 is also considered to have zero lifecycle greenhouse gas emissions up to the point of collection.

7.21 Where a power-to-liquid fuel has been produced using wholly additional renewable or nuclear electricity the GHG emissions associated with the qualifying electricity used to produce it can be taken as zero. Where a RFNBO has been produced using renewable electricity drawn from an electricity grid and doesn’t meet the criteria for additionality, the carbon-intensity of the grid must be used.

7.22 In the case of Recycled Carbon Fuels (RCF) our methodology accounts for the emissions from displaced energy use (i.e. accounting for the diversion of feedstock from energy from waste (EfW) production to SAF production, and assuming energy from waste production would be replaced by grid emissions). This reflects that the fundamentally different nature of RCFs, which embody fossil rather than biogenic carbon.

7.23 It should be noted that the WtW approach taken here differs from the methodology used in the Jet Zero Strategy and in the Carbon Budget Delivery Plan. The Carbon Budget Delivery Plan uses a narrower scope of emissions that accord with our legally binding carbon targets. These account for tank-to-

[82] Further information on the GHG methodology adopted in the RTFO and described here can be found at: https://www.gov.uk/government/publications/renewable-transport-fuel-obligation-rtfo-compliance-reporting-and-verification

wake emissions from fuels but assumes the emissions of biofuels are zero (as it accounts for carbon captured in biofuels when they are grown). The Carbon Budget Delivery Plan also does not account for emissions savings from International Aviation and Shipping before Carbon Budget 6, as this is the first budget in which they are included. The Jet Zero Strategy uses tank-to-wake but partially accounts for upstream emissions from biofuel use by assuming that biomass derived SAF delivers 70% carbon savings versus fossil fuels. The carbon estimates in this CBA should not be directly compared to either of these documents.