A ROUTE TO NET ZERO EUROPEAN AVIATION

EXECUTIVE SUMMARY

Dedicated to innovation in aerospace

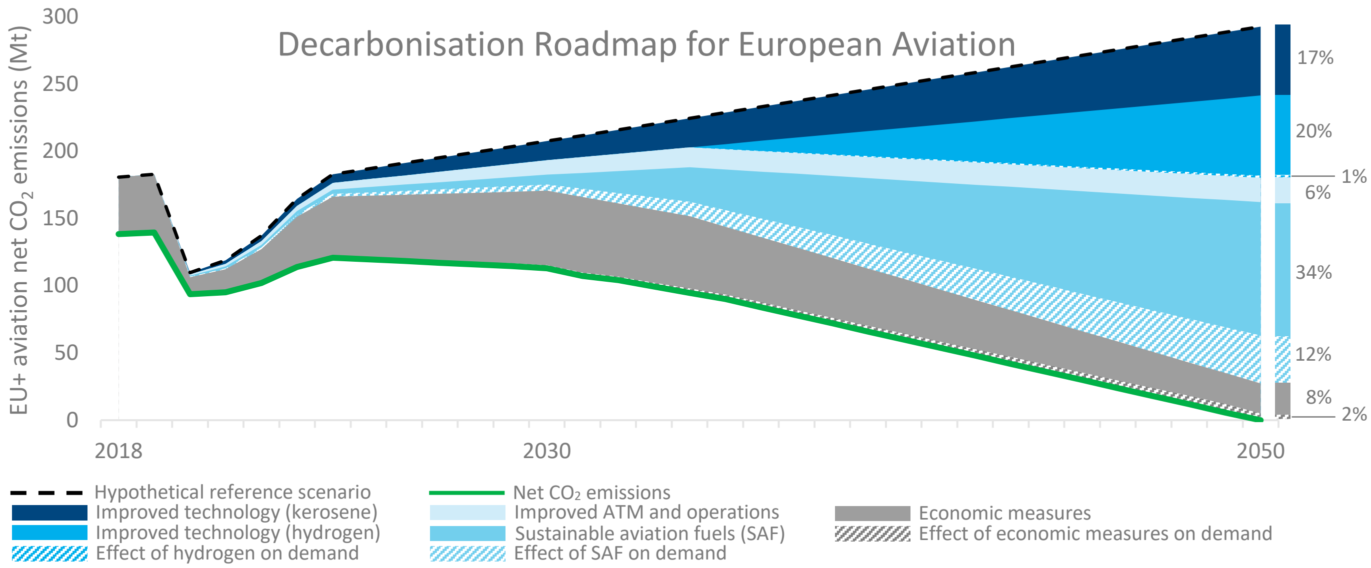
Destination 2050

Net zero CO_2 emissions[1] from all flights within and departing from the EU[2] can be achieved by 2050 through joint, coordinated and decisive industry and government efforts. The European aviation industry is committed to reaching this target and contribute to the goals set in the European Green Deal and the Paris Agreement. Destination 2050 shows a possible pathway that combines new technologies, improved operations, sustainable aviation fuels and economic measures. Absolute emissions are reduced by 92%, while the remaining 8% is removed from the atmosphere through negative emissions, achieved through natural carbon sinks or dedicated technologies.

Royal Netherlands Aerospace Centre and SEO Amsterdam Economics conducted this study commissioned by the representatives of European airports, airlines, aerospace manufacturers and air navigation service providers. It assesses to what extent four groups of sustainability measures are able to reduce carbon emissions until 2050, strongly influenced by policies and actions. The effects of these measures are compared to a hypothetical reference scenario taking into account continuous demand growth and the recent COVID-19 impact. These sustainability measures result in the following net CO_2 emissions reductions in the year 2050:

- 111 $MtCO_2$ through improvements in aircraft and engine technology:
  - 60 $MtCO_2$ by hydrogen-powered aircraft on intra-European routes and
  - 51 $MtCO_2$ by kerosene-powered or (hybrid-)electric aircraft;
- 18 $MtCO_2$ through improvements in air traffic management (ATM) and aircraft operations;
- 99 $MtCO_2$ through using drop-in sustainable aviation fuels (SAF);
- 22 $MtCO_2$ through economic measures (carbon removal projects only).

The combined cost of these sustainability measures is modelled to impact ticket prices, resulting in a lower air travel demand. This would avoid 43 $MtCO_2$ whilst maintaining an average compound annual passenger growth rate of 1.4%.



Results are presented for all flights within and departing from the EU region[2]. Improving aircraft and engine technology, ATM and aircraft operations, SAF and economic measures all hold decarbonisation potential. Modelled for 2030 and 2050, the impacts are linearly interpolated. The base year for this study is 2018.

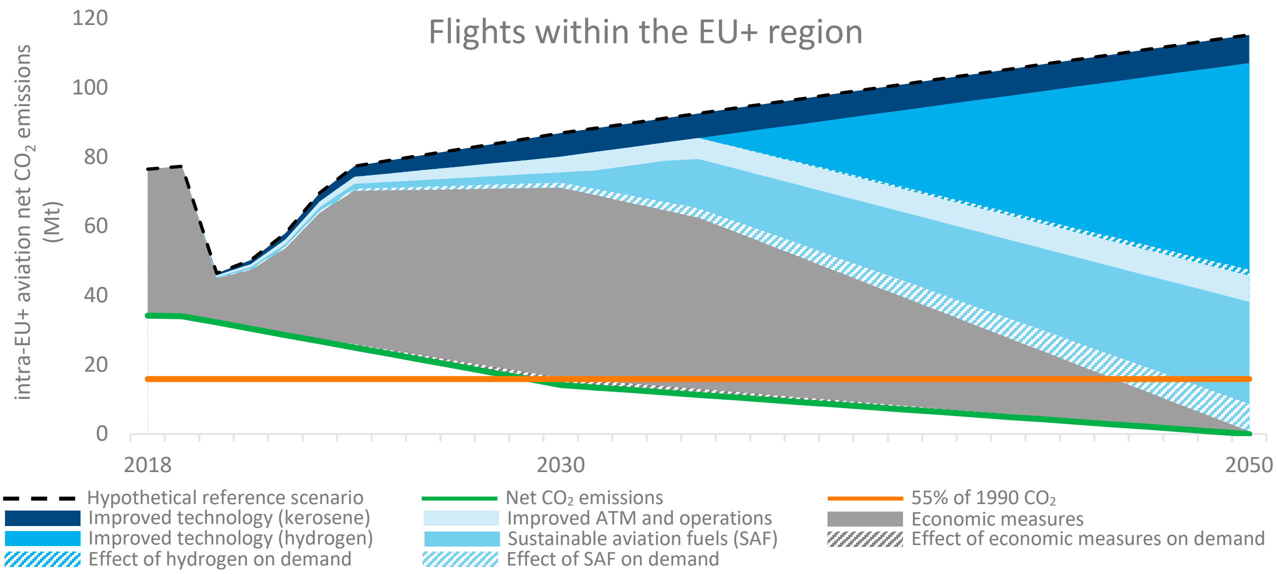
[1] While acknowledging that aviation is also responsible for non-CO_2 climate impacts, the scope of this study is limited to a quantitative assessment of CO_2 emissions. Further study is required to develop a roadmap to take these non-CO_2 emissions into account.
[2] Specifically, the European Union (EU), the United Kingdom (UK), and the European Free Trade Association (EFTA).

A pathway to 2050

Implementing these measures **could make 2019 the peak year in absolute CO_2 emissions** from European aviation, thereby surpassing the industry target of carbon neutral growth from 2020 onwards. In the year 2030, net CO_2 emissions are reduced by 45% compared to the hypothetical reference scenario as a result of continued fleet renewal, improvements in ATM and aircraft operations and a substantial reliance on economic measures. Compared to the CO_2 emissions in the year 1990, on which European Green Deal targets are based, this however means a 36% increase of net CO_2 emissions from European aviation. This is due to the fact that most substantial emission reductions measures – a next generation of aircraft and substantial uptake of sustainable aviation fuel – take more time to materialise. It is nonetheless **essential that the foundations for post-2030 reductions are laid in the coming years**, to realise net zero CO_2 emissions in 2050 and reduce reliance on economic measures.

A detailed look at flights within the EU

For flights within the EU[2], the results highlight that net zero CO_2 emissions in the year 2050 can be achieved with **close to zero economic measures**. The largest contribution is made by **hydrogen-powered aircraft introduced in 2035** followed by sustainable aviation fuels. Net emissions can be limited to **13 $MtCO_2$ in the year 2030, estimated to be 55% below the emission levels in 1990** and thereby contributing to the implementation of the European Green Deal.



Intra-EU[2] only. Modelled for 2030 and 2050, the impacts are linearly interpolated. The base year for this study is 2018.

Recommendations to industry and government

The measures leading to net zero CO_2 emissions from European aviation need to be realised through **collective policies and actions by governments and industry**. Both should work towards **global commitment to a net zero carbon future for aviation**, to avoid differentiated policies, carbon leakage and transfer of activity. Europe should maintain and evolve its leading position in sustainable aviation by the following policies and actions:

Industry should

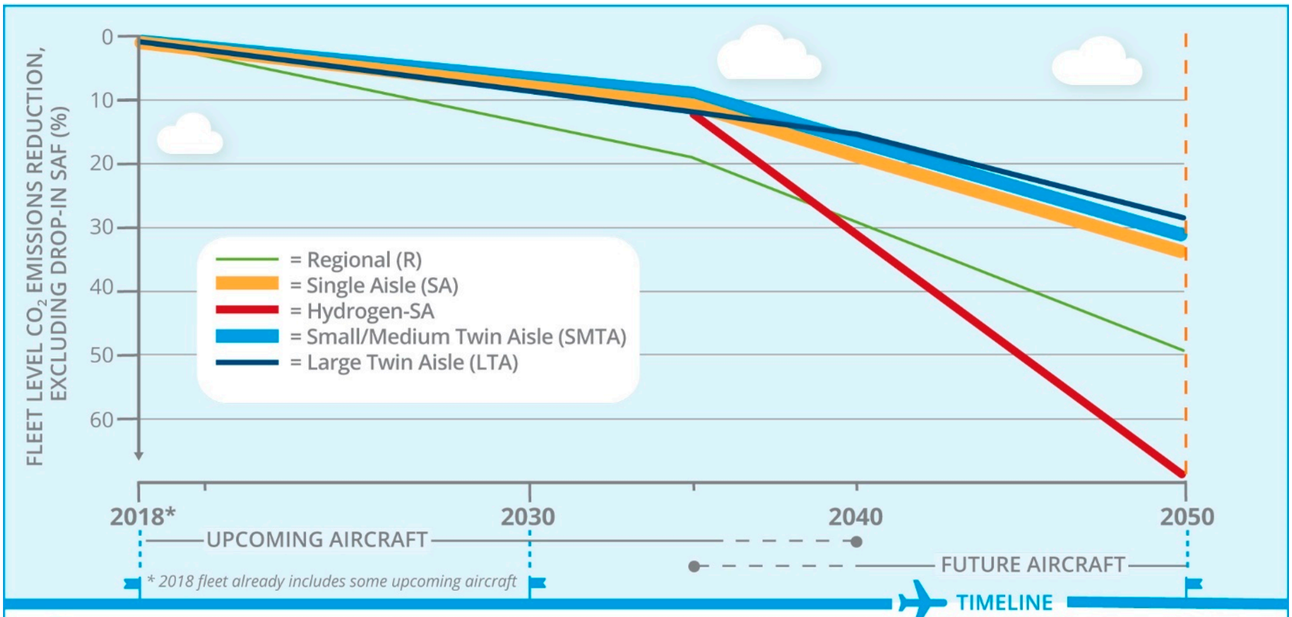
- Continue to substantially invest in decarbonisation
- Develop more fuel-efficient aircraft and bring these into operation through continued fleet renewal
- Develop hydrogen-powered and (hybrid-)electric aircraft and associated supporting (airport) infrastructure and bring these into the market
- Scale up drop-in SAF production and uptake
- Implement the latest innovations in ATM and flight planning
- Compensate remaining CO_2 emissions by removing carbon dioxide from the atmosphere

Governments should

- Support industry investments by direct stimuli or by reducing investment risk through a consistent and long-term policy framework
- Stimulate further development and deployment of innovations by funding research programmes and promoting carbon removal technologies
- Work with the energy sector to ensure sufficient availability of renewable energy at affordable cost
- Support the development of the SAF industry
- Contribute to optimising ATM, in particular by fully implementing the Single European Sky

Improvements in aircraft and engine technology

By 2050, improvements in aircraft and engine technology and subsequent **fleet replacement** hold the largest promise for decarbonising European aviation. This includes the **introduction of a hydrogen-powered single-aisle aircraft on intra-European routes in 2035**. The generation of commercial passenger aircraft to be developed in the next 10 years has potential to realise a **step-change in energy efficiency**. Introduced from 2035 onwards, these aircraft types are forecast to reduce fuel burn by 30% or more per flight compared to predecessors. Range and capacity optimised **hybrid-electric** regional aircraft are anticipated to bring down CO_2 emissions by 50% per flight in that market segment. Future small aircraft and rotorcraft, introduced from 2030, may become drivers for larger aircraft development.



JOINT AND COLLABORATIVE INDUSTRY AND GOVERNMENT ACTIONS REQUIRED

Market segment	Seats	Aircraft-level CO_2 emissions reduction: Upcoming aircraft*	Aircraft-level CO_2 emissions reduction: Future aircraft**
Regional (R)	20 - 100	25% excl. drop-in SAF	50% excl. drop-in SAF
Single Aisle (SA)	101 - 240	15% excl. drop-in SAF	30% excl. drop-in SAF
Hydrogen-SA	165		100%
Small/Medium Twin Aisle (SMTA)	241 - 350	18% excl. drop-in SAF	30% excl. drop-in SAF
Large Twin Aisle (LTA)	>350	19% excl. drop-in SAF	30% excl. drop-in SAF

**) with respect to previous generation; **) with respect to upcoming generation*

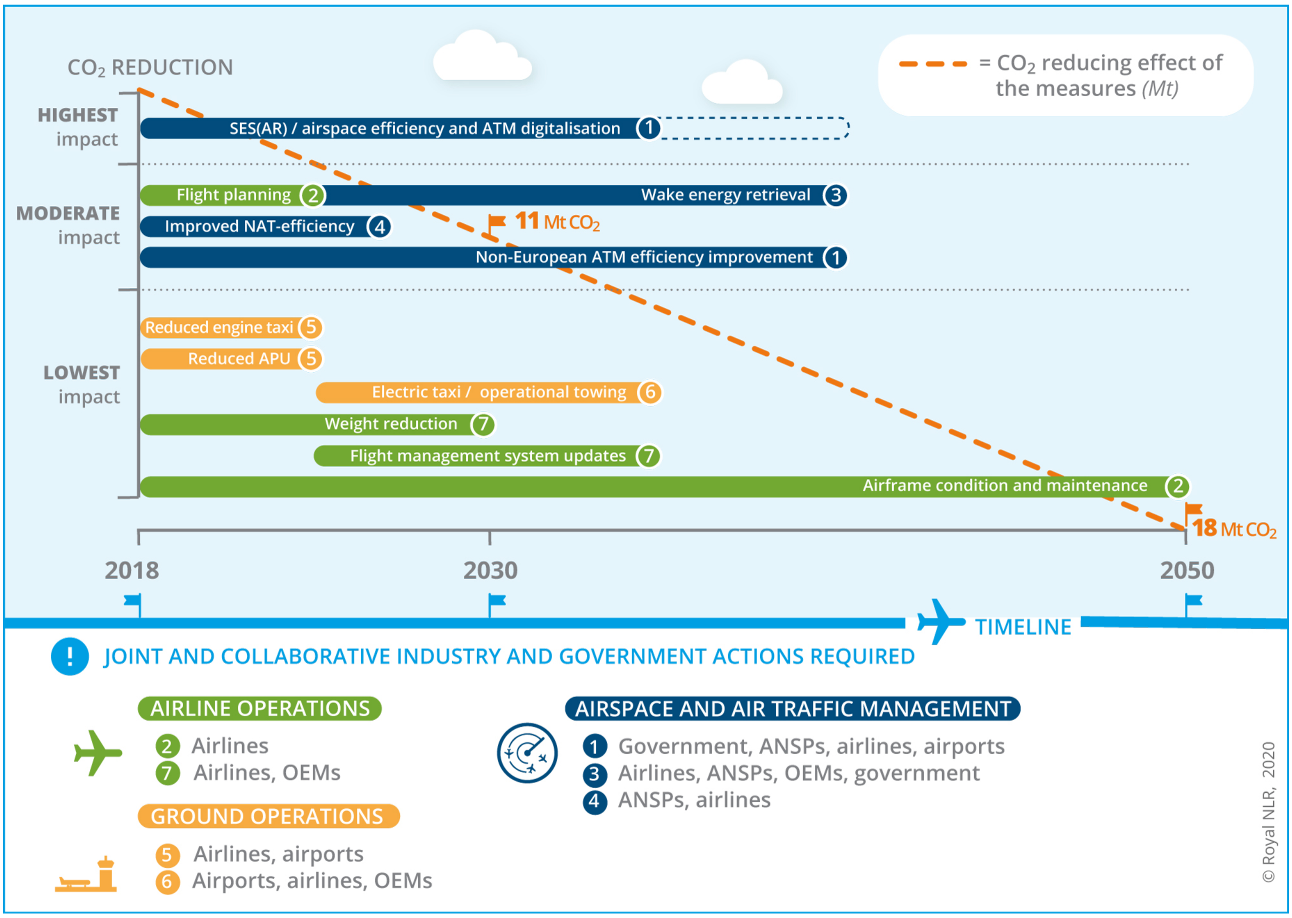
Continued replacement of current aircraft with upcoming models would reduce emissions until 2040. Next-generation future aircraft would yield aircraft-level CO_2 emissions reduction of 30 to 50% compared to upcoming aircraft types. Specifically for the intra-European market, a hydrogen-powered aircraft would enable zero-CO_2 flight. At fleet level the CO_2 emissions reduction by upcoming and future aircraft reaches levels of 28 to 67% in 2050.

Future aircraft availability by 2035 requires technology readiness by 2027 to 2030. The proposed Partnership for Clean Aviation provides a well-structured stimulus framework to realise this. A **collaborative research programme should also address more disruptive technologies modelled in this study**, such as hydrogen-powered or other zero-CO_2 emission aircraft. Collaboration and cross-pollination with other European and national R&D programmes and instruments should be ensured. New technologies should be swiftly incorporated in commercial products, helped by **efficient new certification for disruptive technologies**. Additional improvements should be delivered by accelerating previous R&D results for market uptake, through new product offerings or upgrades to in-production aircraft. Expedited replacement of older aircraft by state-of-the-art models may realise CO_2 emission reductions even earlier.

Besides substantially reducing fuel consumption and fostering green technologies by design, the policies and actions recommended in this roadmap would more firmly **establish the European aviation sector as leading the way towards sustainable aviation**. With environmental concerns intensifying around the world, this offers Europe an important first-mover advantage.

Improvements in air traffic management and aircraft operations

Improvements in ATM and aircraft operations are estimated to be a **crucial opportunity to reducing CO_2 emissions in the short to medium term**. Ensuring full and complete implementation of most measures by 2035 at the latest would, furthermore, allow such benefits to continue yielding impacts between 2035 and 2050.



An array of improvements in ATM and aircraft operations yields a 5 to 6% system-level CO_2 emissions reduction in 2030 and 2050 compared to the reference scenario. Requiring actions from all industry actors and governments, most of these improvements could be realised by 2035. Within each of the three groups (highest / moderate / lowest impact), the measures have not been sorted according to impact.

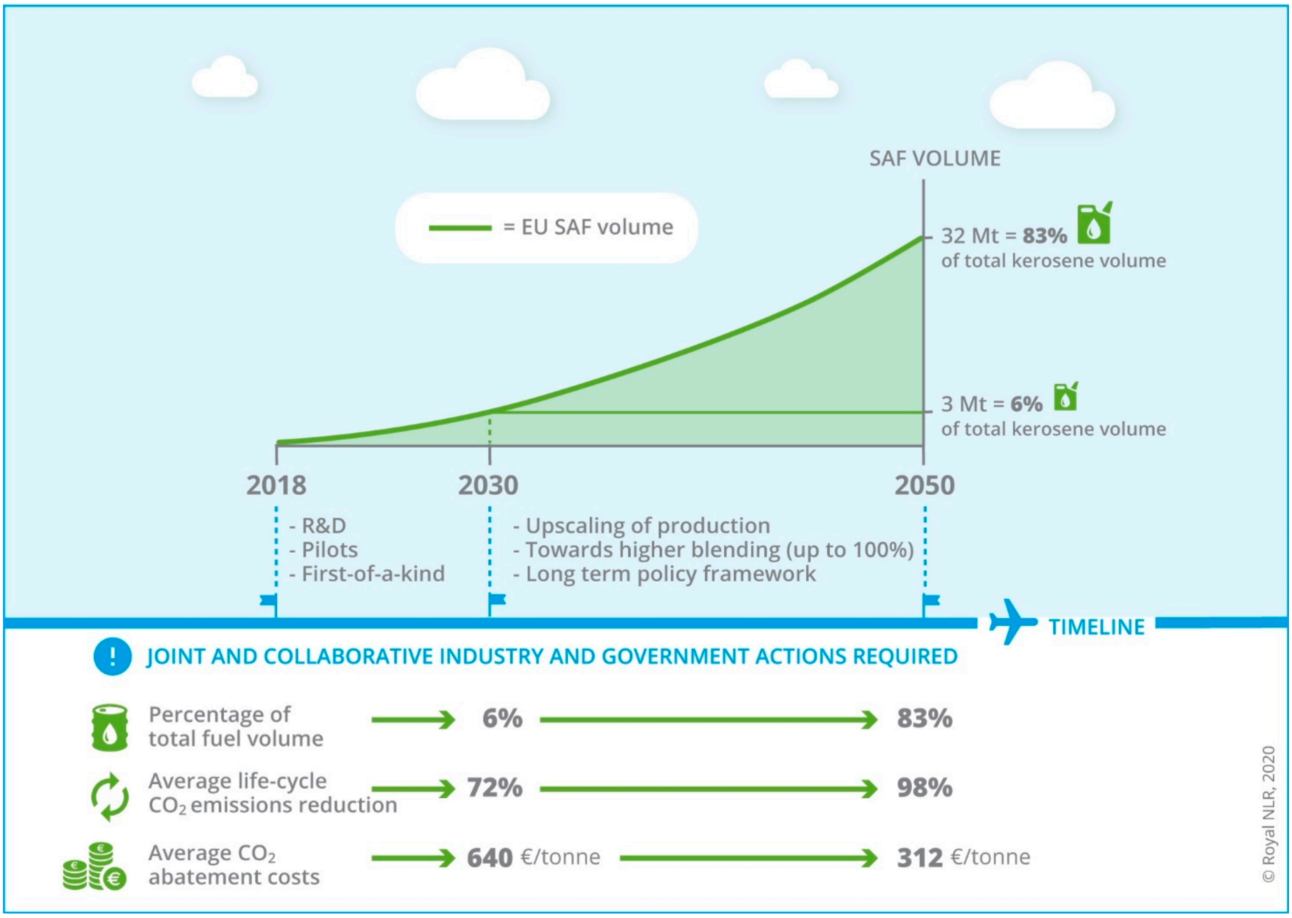
For Europe's residents and visitors to enjoy the full benefits of the Single European Sky, it is **imperative to move more towards a network-centric and digital ATM system and requires political willingness to implement many of the SESAR solutions**. Regulation and R&D efforts must optimally support that goal. First and foremost, such a system would include a renewed set of KPIs with clearly defined accountabilities; a seamless upper airspace; and an R&D policy ensuring steady progress of new technology development and deployment. Better quantifying **the anticipated benefits following from fuel and CO_2 optimized routing** are near-term priorities.

Innovation in communication, navigation and surveillance equipment and processes should also be encouraged, such that these can be swiftly put into practice. Beyond SES and SESAR, European governments and industry should **globally stimulate regions and States to improve ATM efficiency**.

Finally, regulations and incentives should **enable and encourage the rapid decarbonisation of ground operations**. Electric operational towing or taxiing solutions should be developed for all common aircraft and, when parked, aircraft should use renewable energy. Along with possibly stimulating or supporting companies to make such investments, European governments have a crucial role to ensure the supply of renewable energy can match its increased demand.

Sustainable aviation fuel

SAFs deliver a **major contribution** to achieving net zero carbon emissions in 2050. The supply of SAF may increase from 3 Mt in 2030 to 32 Mt in 2050, equal to **83% of the total kerosene consumption**. The SAF contribution is directly linked to the development of industrial production capacity and strongly influenced by a supporting long-term policy framework. SAF contribution in 2030 may be increased if a strong political support is given to SAF development. Over time, life-cycle CO_2 reduction increases to nearly 100% while production costs decrease.



Over time, SAF production volumes and life-cycle CO_2 reductions increase while production costs decrease.

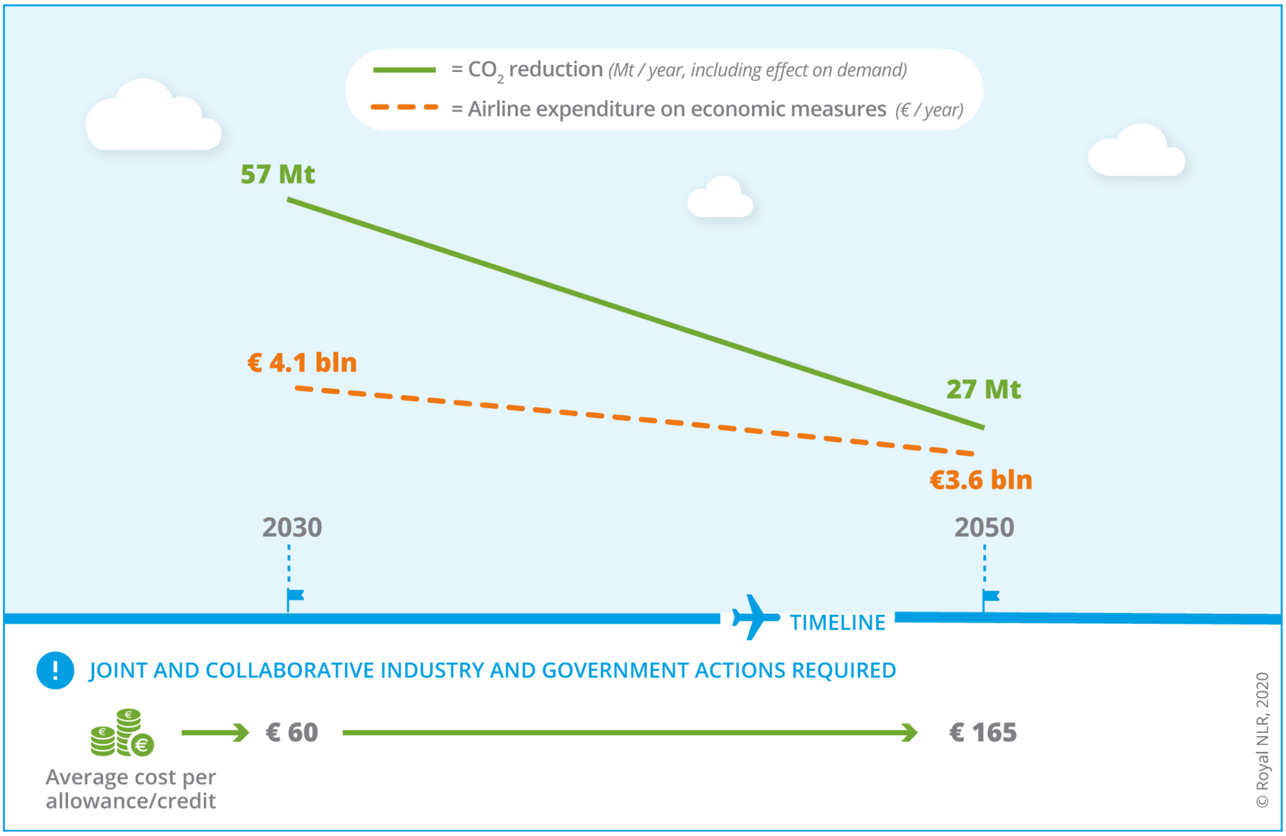
Crucial steps must be taken to **scale up and commercialise SAF deployment**. While making **robust and transparent sustainability criteria** the foundation of a long-term policy framework, a **diversified and sustainable feedstock base** should be established. This would combine biofuels from wastes, residues and non-food (lignocellulosic) crops as well as e-fuels from renewable electricity and CO_2 sourced from direct air capture. Multiple production pathways should be tested in pilot and first-of-a-kind facilities. This increases technological learning, reduces risk and decreases production costs. If the price gap with fossil fuels is overcome, SAFs could fulfil the entire kerosene demand from intra-European flights, necessitating increasing the blending ratio allowed by **ASTM certification from 50% currently to 100%**.

To effectively address the price difference with fossil fuel throughout the value chain and thereby make SAF more affordable, policies need to include measures to de-risk investments and boost production and off-take. These measures could include financial incentives (e.g. carbon pricing, subsidies, auctioning mechanisms and capital grants) and regulatory measures such as the implementation of an **EU wide blending obligation**. The timing and conditions for implementing these measures are currently being investigated in ReFuelEU Aviation. To further reduce cost and increase emissions reductions, a transparent **monitoring and accounting framework** should be implemented, similar to the framework for renewable electricity. This would give airlines the possibility to claim the use of SAF in the most economically efficient way across the fleet, regardless of where SAF has been physically uplifted.

Economic measures

In the short term, smart economic measures are central in the reduction of carbon emissions from aviation. Such measures assign a price to CO_2 emissions ensuring that airlines take climate costs explicitly into account in their business decisions. **To ensure cost-effectiveness, economic measures must be market-based.** The European Emission Trading Scheme (EU ETS) is the mechanism that is implemented in Europe and which is complemented by the ICAO CORSIA scheme for international flights. They trigger the acceleration towards the energy transition and **bridge the gap until breakthrough technologies and SAFs become widely available**. By 2030, economic measures are expected to reduce net CO_2 emissions by 27% compared to the reference scenario.

Over time, breakthrough technologies and the use of SAF reduce the role of economic measures. The price of allowances and carbon credits will increase as they become increasingly scarce. This will eventually lead to a price whereby carbon removal projects become economically attractive to investors. In 2050, any remaining emissions can therefore be balanced by **carbon removal projects**, which are assumed to lead to the issuance of additional emissions allowances and carbon credits. A global approach is critical to prevent market distortion and carbon leakage.



Smart economic measures are a key mechanism to reducing carbon emissions, especially in the short term when radical breakthrough technologies and SAFs are not yet widely available. The compliance costs to European airlines would add up to around 3.6 billion euros by 2050 – € 165 per tonne CO_2 – as allowances and carbon credits become increasingly scarce.

Guaranteeing the quality of carbon credits through both industry action and policy intervention is key to realising these necessary reductions in CO_2. Implementing the global economic measure CORSIA is crucial to keeping international aviation on track to reduce emissions and contribute to the net zero ambition globally. Earmarking of revenues ensures the economic measures fully contribute to the development of aviation decarbonisation solutions. **Direct Air Capture** is seen as important enabling technology for deployment in the short to medium term in order to create high quality carbon allowance and credits.