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The real cost of green aviation

Evaluation of SAF ramp-up scenarios and cost implications for the European aviation sector

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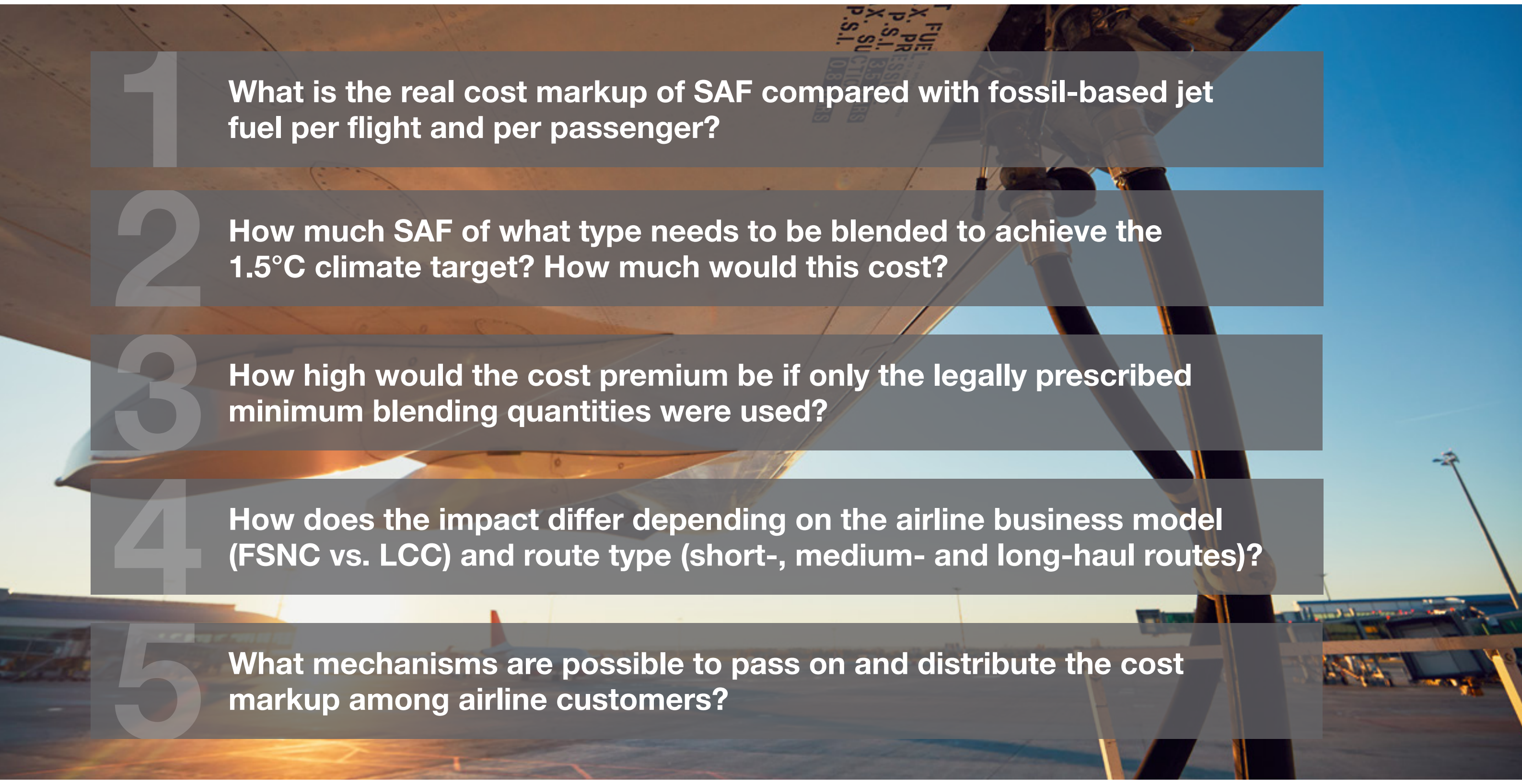
Disclaimer: This paper was prepared mainly before the outbreak of the war in Ukraine. Remarks on potential consequences are discussed in the study. However, the numbers used for the calculations are from before. Current highly fluctuating oil price developments as well as biological feedstock prices are, thus, not fully considered. For the aviation data, including the jet fuel demand levels, 2019 data was used. Here, current industry developments show that we can expect the industry to fully rebound to pre-COVID-19 levels soon.

EXECUTIVE SUMMARY

Rapidly reducing greenhouse gas (GHG) emissions to limit the effects of climate change is one of the biggest challenges of our time. The resulting need to act applies to all sectors including the transportation sector. Aviation currently contributes around 2.5% of global anthropogenic (human-caused) CO_2 emissions and around 5% to global warming if non-CO_2 emissions are included[1]. Thus, it plays an important role in reducing worldwide GHG emissions. Reduction measures currently discussed include, for example, technological innovations (e.g., hydrogen-powered aircraft) and increased operations efficiency. However, sustainable aviation fuels (SAFs) are considered a key pillar in the effort to create a more sustainable aviation industry. SAFs are anticipated to reduce GHG emissions in aviation by 53% while still utilizing existing infrastructure.

SAF has been developed to substitute fossil jet fuels[2]. Currently being blended with fossil kerosene, the SAF component of the blend enables CO_2 emissions reduction depending on the feedstock and the SAF conversion pathway. The three families of feedstocks/conversion pathways most referenced and likely to scale up in the market are Hydroprocessed Esters and Fatty Acids (HEFA), Advanced Biomass to Liquids (ABtL), and Power to Liquids (PtL). Currently, less than 1% of aviation fuels used in Europe are SAFs. SAF capacities are limited due to demand insecurities driven by both, the cost premium for SAF compared with fossil kerosene and by the high capital expenditures for initial investors. Such cost premiums can be a critical inhibitor in the somewhat low-margin and cost-sensitive airline business. Thus, to assess the economic feasibility of SAF, the following questions arise:



1 **What is the real cost markup of SAF compared with fossil-based jet fuel per flight and per passenger?**

2 **How much SAF of what type needs to be blended to achieve the 1.5°C climate target? How much would this cost?**

3 **How high would the cost premium be if only the legally prescribed minimum blending quantities were used?**

4 **How does the impact differ depending on the airline business model (FSNC vs. LCC) and route type (short-, medium- and long-haul routes)?**

5 **What mechanisms are possible to pass on and distribute the cost markup among airline customers?**

This study answers these questions by calculating the estimated cost markup for SAF use from 2025 to 2050 based on two ramp-up scenarios. These scenarios differ in the degree of GHG emissions reduction they aim to achieve, as well as in the resulting SAF blending ratios.

The first scenario is based on the minimum required SAF blending ratios of the ReFuelEU Aviation directive (draft July 2021), and we call it the EU Quota Pathway. The second scenario is based on the SAF blending ratios required to achieve the International Energy Agency (IEA) Net Zero Pathway by 2050 and is accordingly called the IEA Net Zero Pathway. For these scenarios, we assessed the needed amount of the different SAF types and the resulting costs. Since both fossil kerosene but also SAF feedstock prices can be subject to (strong) fluctuations due to market developments and external impacts, we have based our long-term prediction on a consensus model of the available SAF production cost forecasts. We then calculated the expected real cost markup by comparing the resulting SAF costs to a "no SAF" baseline scenario. This baseline scenario assumes that no SAF is used and is determined by the anticipated kerosene price development and CO_2 prices based on the "Sustainable Development" scenario of the IEA.

To evaluate the implications for airlines, we calculated a prospective cost markup for the two archetypal airline business models (full-service network carrier, FSNC and low-cost carrier, LCC), as well as for three route types (short-, medium-, and long-haul).

The results show that in general, on the fuel input cost side no cost decline is expected for SAF until the late 2030s. Assuming a SAF mix based on the minimum legal requirements in the EU Quota Pathway (Scenario 1), the maximum resulting cost markup on fuel costs will be reached in 2040 at 9% per ton compared with the baseline scenario. When following the IEA Net Zero Pathway (Scenario 2), the maximum markup is reached in 2038 at about 16%. The late peaks result from an increasing usage of SAF over time and a growing share of more expensive PtL, owing to its technological availability and ability to meet the high SAF demands over time (*see Exhibit 1, page 8*).

Looking at different flight route types, the largest relative cost markup per flight can be expected in the long-haul segment, with 6% in 2038 (compared with 2% in the short-haul segment) for the IEA Net Zero Pathway. On the contrary, when looking at different airline business models, the low-cost carrier (LCC) model is expected to experience greater effects, with potential relative cost markups being around 2-times higher than those for full-service network carriers (FSNCs).

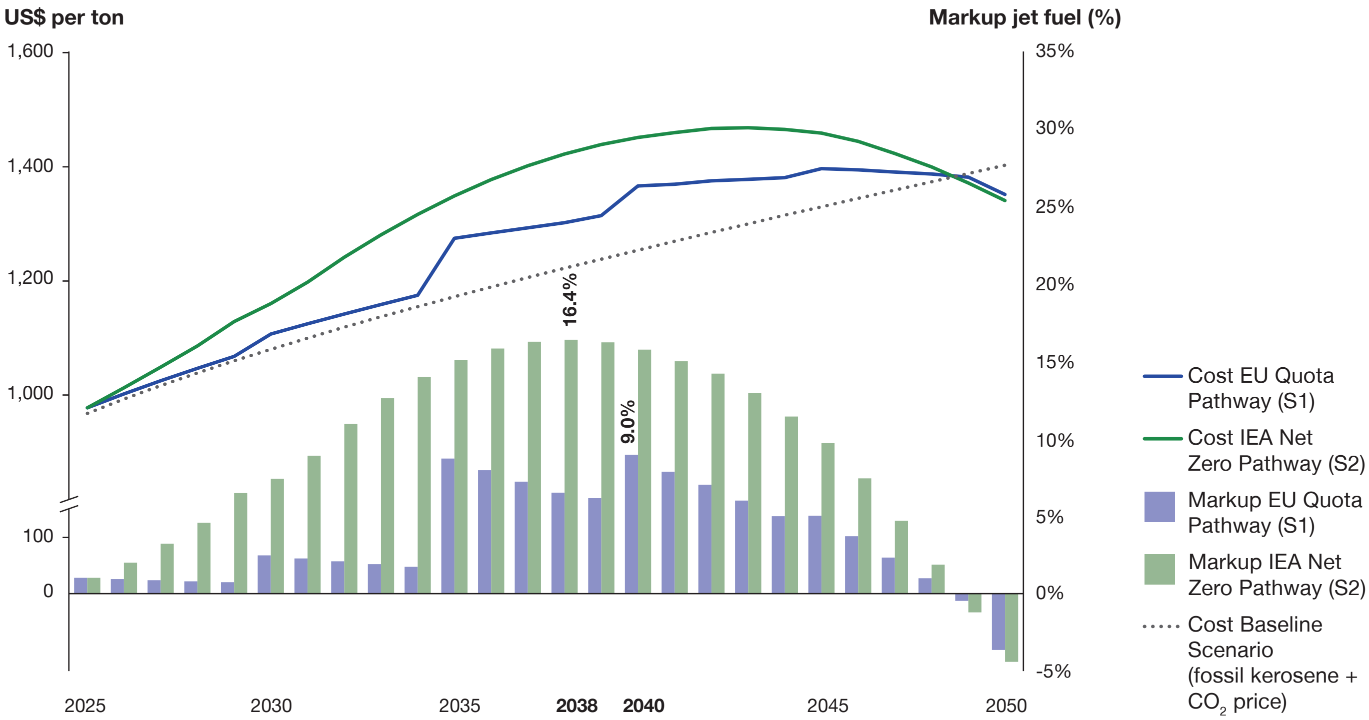
9%
maximum cost increase per ton fuel (2040, following the EU Quota Pathway)

16%
maximum cost increase per ton fuel (2038, following the IEA Net Zero Pathway)

EXHIBIT 1

Cost markup per scenario

Comparison of prices and cost markup for the two SAF admixture scenarios compared to the baseline scenario



Source: Strategy& analysis

To cover the additional costs, airlines can establish a cost distribution mechanism. Here we analyzed the extent to which the ticket prices would increase in 2035 if the cost markup was fully passed on and distributed among the different customer groups. The distribution was calculated using three approaches, (a) the customer's revenue share, (b) their reason for travel, and (c) their preference for sustainable customers' traveling. Taking the revenue-based distribution as an example, the ticket price for a typical long-haul flight (e.g., Frankfurt to Singapore, or Munich to New York) would rise by around US$10–17 for an economy-class passenger. The ticket price for the non-economy-class passenger would rise by around US$36–63.

Based on the results, the outlook for SAF from an airline cost perspective is encouraging. The study shows that the cost markup of SAF compared with the baseline scenario remains manageable for airlines and their customers due to expected CO_2 price increases on fossil kerosene and SAF cost decreases. A sensitivity analysis at the end of the study further supports this argument. On the one hand, it shows that also in case of 100% SAF in 2050, costs per ton fuel can be expected to increase by maximum 24% in 2038. On the other hand, it emphasizes the importance of CO_2 prices for the market development. Considering that regulatory requirements are likely to soon become stricter and we are witnessing a trend towards sustainability, as well as a potentially increasing willingness of private and corporate customers to pay extra, these results are even more promising. This makes investments in SAF important from an ecological, a legal, and a financial perspective. To dramatically ramp up the needed production capacities, joint efforts of all players in the SAF ecosystem are needed now (*see Illustration, page 9*).

The main SAF ecosystem players and their strategic actions regarding SAF market development

Private customers

- Increase awareness for sustainable travel

Corporate/cargo providers

- Embed SAF in corporate and ESG strategy
- Explore options to reimburse or forward SAF costs

Fuel producers

- Decide on your SAF strategy based on your portfolio
- Develop a market for SAF fuels
- Build strategic alliances to ensure a fully functioning supply chain

SAF ecosystem players

Airlines

- Decide on your decarbonization strategy and the role of SAF within it
- Establish mechanisms to deal with the additional costs of SAF

Capital providers

- Bundle and support airline investments for SAF ramp-up

Aircraft OEMs

- Identify and develop business opportunities in an evolving SAF ecosystem

Regulators

- Establish a SAF certificate system
- Set more ambitious SAF blending quotas that are net zero-aligned and do not distort competition
- Compensate the first-mover disadvantage

Source: Strategy& analysis

INTRODUCTION

Rapidly reducing greenhouse gas (GHG) emissions to limit the effects of global warming is one of the biggest challenges of our time. These effects are already being felt today. Extreme weather conditions become more frequently, and the financial costs of natural catastrophes reached a new all-time high of of around US$250 billion in 2021.[3] The challenge of limiting GHG emissions is compounded by significantly increasing time pressure, as irreversible damage to our planet could be reached very soon[4]. Thus, there is an urgent need for rapid action on the part of various stakeholders, including policymakers,[5] industry players, and individuals. The Paris Climate Agreement signifies today's global commitment to mitigate the effects of climate change and aims to limit the increase in long-term global average temperature to less than 1.5°C over pre-industrial levels.[6] At the same time, the European Green Deal envisages net zero GHG emissions in the European Union by 2050.[7]

All industries, including aviation, need to transform to meet these commitments. Aviation contributes around 2.5% of global anthropogenic (human-caused) CO_2 emissions.[8] The industry has been continuously implementing various measures to decrease environmental effects, even though they were mainly driven by the motivation to reduce operational costs. One example is the increase in fuel efficiency. Today's aircraft emit 80% less CO_2 per seat than it was the case in the 1950s.[9] Moreover, between 2005 and 2017 the amount of fuel burned per passenger decreased by 24%,[10] and according to the European Union Aviation Safety Agency (EASA), global commercial aviation achieved an average fuel efficiency improvement per year of 2% between 2009 and 2016.[11] Additionally, the International Air Transport Association (IATA)[12] and the Air Transport Action Group (ATAG)[13] have proposed first measures to reduce aviation's GHG emissions, which were further specified by key stakeholders in the Destination 2050 initiative.[14] However, there is still more to do, as these actions are insufficient to limit aviation's climate impact. Especially as global air traffic is expected to grow further, effective measures to reduce overall GHG emissions become more difficult and require an immense, coordinated political, technological, and economic effort.[15]

"Aviation allows us to travel and connect globally to a greater extent than any other industry. While experiencing an increasing demand, immediate actions are necessary to reduce GHG emissions and enable us to fly more sustainably."

Dr. Jan Wille, PwC Strategy& Germany, Aerospace and Defence Leader

GHG emission reduction in aviation

For the key stakeholders in the aviation industry, the need to reduce GHG emissions is further induced by three main developments.

Airline and customer GHG emissions reduction targets

Companies worldwide are taking responsibility to achieve a zero-carbon economy. By now, more than 3,100 companies are committed to an emissions reduction target, of which 1,400 already received an approval from the Science Based Targets initiative (SBTi[16]). Hence, they committed to provide the investments required to reduce their impact on climate change. In addition, society is increasingly pressuring companies to reduce their GHG emissions—and companies' reluctance to act can lead to substantial competitive disadvantages and reputational losses. Especially in the transport sector, companies are facing the risk of losing up to 50% of their earnings when they fail to take any measures to reduce their carbon footprint.[17] Airlines have recognized the need to act and have taken initial measures. Examples are participating in carbon-neutral growth (Carbon Offsetting and Reduction Scheme for International Aviation, or CORSIA) and making a commitment to increasing use of SAF (Destination 2050).

Regulatory requirements

Many governments around the world see an urgent need for action. Thus, they are imposing more regulations. One significant instrument is the stipulation of blending mandates for SAF. Such mandates have already been introduced in national air traffic markets of individual EU countries, and they are currently being negotiated at EU level. Besides this, increasing CO_2 pricing, taxing fossil fuels, and creating investment subsidies for SAF production are instruments that policymakers are using to reduce GHG emissions in aviation.

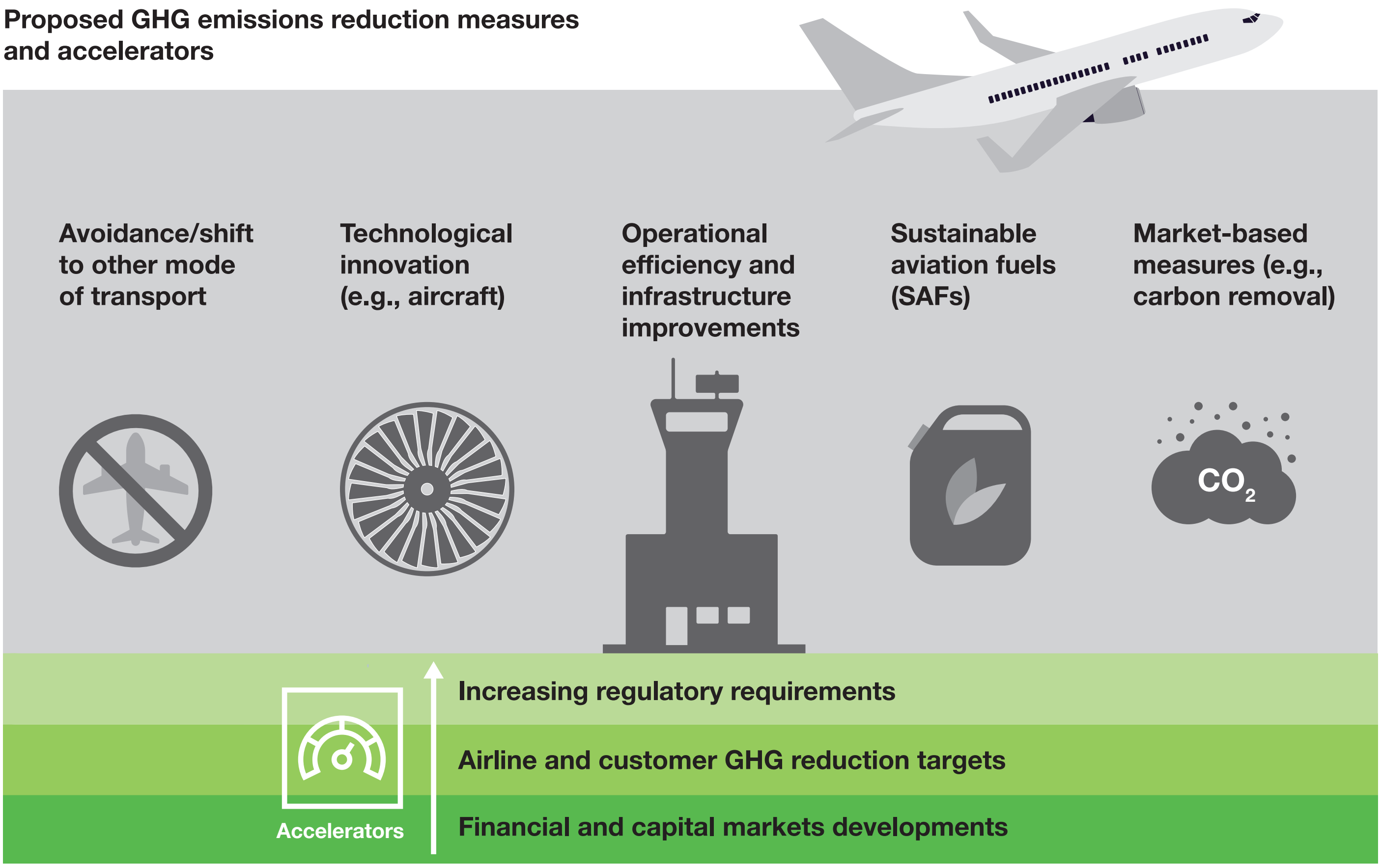
Financial markets' requirement of climate protection

Financial institutions use climate risk scores, and investors increasingly measure the institutions against those scores. As a result, in 2021, all-time high levels of investments were directed into sustainable funds.[18] These developments are supporting investments in climate-friendly but cost-intensive activities in the aviation market, such as SAF production.

To achieve substantial reduction in aviation industry emissions, a combination of measures is envisaged, including operational and infrastructure efficiency improvements, technological and fleet renewal, increased use of SAFs, and out-of-sector reductions and economic incentives (*see Illustration below*).

As shown in *Exhibit 2, page 13* one large pillar of emissions reduction (34%) is represented by **technological innovations**, which aim at increasing propulsion and aerodynamic efficiency, as well as achieving lightweight system construction. Such innovations can range from evolutionary to radical aircraft technologies. Evolutionary innovations focus on continually improving the efficiency of existing aircraft systems. They are playing an integral part in reducing the environmental impact of aviation. However, such improvements are about to reach their technical limits, and without changing the carbon intensity of the energy carrier, environmental goals cannot be fully met.[19]

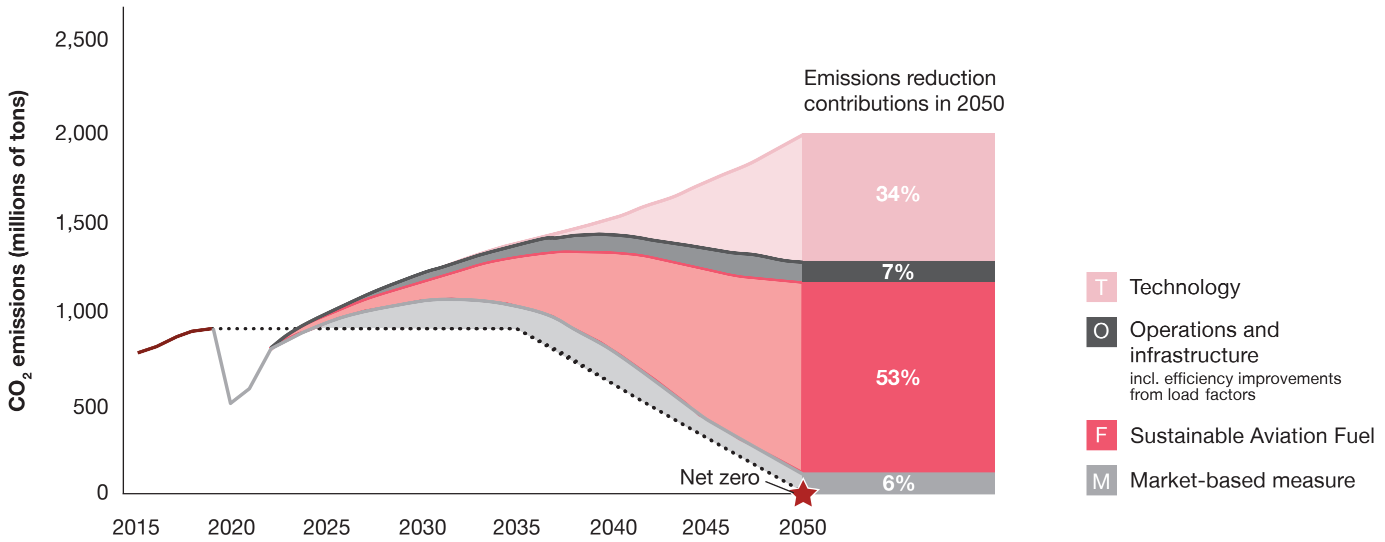
Proposed GHG emissions reduction measures and accelerators



Source: Shell International B.V. (2021): Decarbonizing aviation: Cleared for take-off. Industry perspectives. Retrieved from: https://www.shell.com/energy-and-innovation/the-energy-future/decarbonising-aviation/_jcr_content/par/toptasks.stream/1632757263451/e4f516f8d0b02333f1459e60dc4ff7fd1650f51c/decarbonising-aviation-industry-report.pdf, Strategy& Analysis

EXHIBIT 2

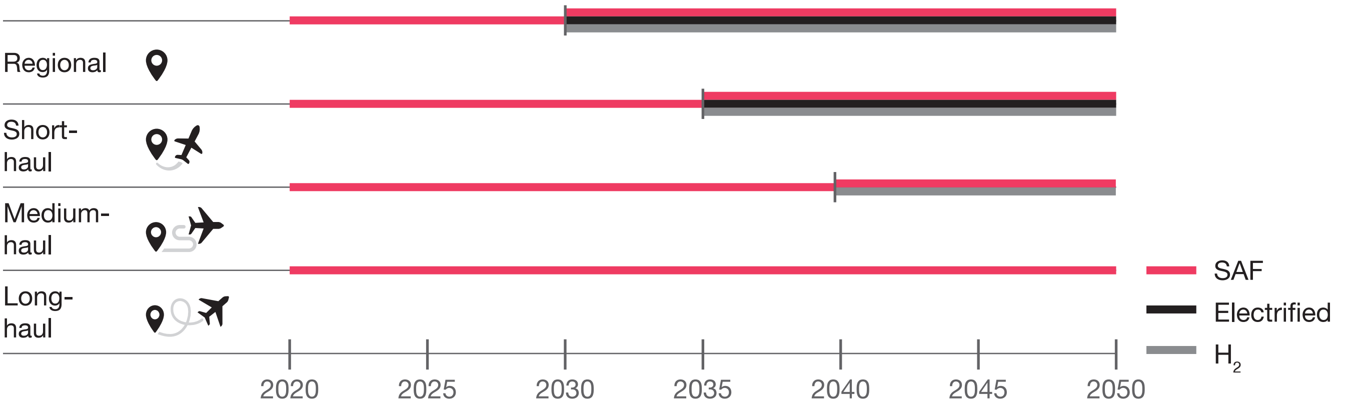
Available options for achieving aviation's emissions reduction goals[1]
(based on graphic from Waypoint 2050)



1 ATAG (2022): Waypoint 2050. Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency: a vision of net-zero aviation by mid-century. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050
Source: Waypoint 2050

Thus, more revolutionary innovations using alternative energy to power an aircraft are needed. Electric propulsion, hybrid-electric propulsion, and hydrogen-powered aircrafts are considered to be key solutions.[20] Electric and hybrid-electric propulsion are likely to become available soon (*see Illustration below*) and show an overall emissions reduction potential most notably in the short-haul segments.[21] Hydrogen (H_2) as a carbon-neutral energy source can be used for direct combustion in turbines or fuel cells and covers a wider spectrum of distance segments. However, the technology is still emerging, and the market entry is expected to be no earlier than 2035.[22]

Expected deployment of low- and zero-carbon emission technologies in aircrafts[1]
(based on graphic from Waypoint 2050)



1 ATAG (2022): Waypoint 2050. Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency: a vision of net-zero aviation by mid-century. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050
Source: Waypoint 2050

Operational efficiency and infrastructure improvements are another important pillar in reducing CO_2 emissions. These efforts could result in reductions of as much as 7%, as shown in *Exhibit 2, page 13*. They comprise in-flight, flight planning, and air traffic management measures, as well as airport ground operations and more radical concepts (e.g., formation flight, reduced cruise speeds, and intermediate stopover operations).[23]

Beyond these measures, **sustainable aviation fuels (SAFs)** are the key element for the aviation sector to meet its climate goals. Sustainable aviation fuel is supposed to substitute[24] fossil jet fuels. Due to a high SAF CO_2 reduction potential, most of the GHG emissions reduction (53%) in this industry is expected to come from the use of SAF (*see Exhibit 2, page 13*). SAF's biggest advantage is that it can be used with the existing infrastructure. This means that no large technical changes in aircraft, engine fuel systems, distribution, and storage facilities will be required.

> "Sustainable aviation fuels are a key option to align the aviation sector with the Paris Climate Accord."
>
> **Dr. Jürgen Peterseim, PwC Germany, Fueling our Future Initiative Lead**

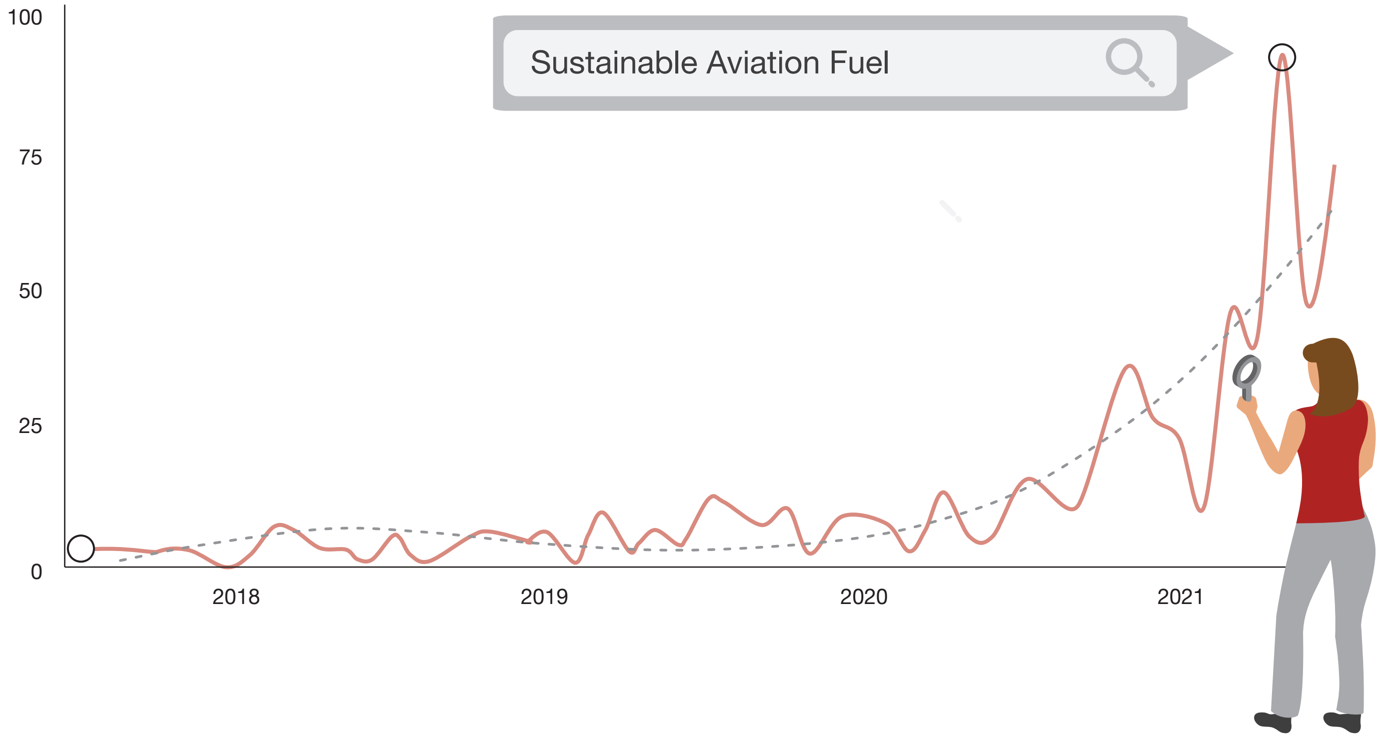
Additionally, with SAF, the dependence on oil-producing countries for fuel can be reduced. Feedstocks can be produced around the world in areas with different conditions. For instance, countries such as Chile and Australia offer favorable renewable energy conditions for a cost-efficient production of PtL. This enables more diverse geographic supply, a decreased need to be subjected to volatile price fluctuations, and increased energy security.[25] The emissions reduction potential of SAFs depends on feedstock type[26] and the specific SAF conversion pathway.

The interest in SAF has by now also resonated in public discourse (*see Exhibit 3*), and both the industry and the media are paying increasing attention to this key solution.

EXHIBIT 3

Google searches for SAF

(based on graphic from Sustainable Aero Lab)[1]



1 SUSTAINABLE.AERO Lab (2021): The State of The Sustainable Aviation Fuel (SAF) Company Ecosystem. Retrieved from: https://www.sustainable.aero/saf-study

Source: SUSTAINABLE.AERO Lab

Sustainable aviation fuels

Introducing the SAF conversion pathways

As noted above, the three most promising conversion pathways are “Hydroprocessed Esters and Fatty Acids” (HEFA), “Advanced Biomass to Liquids” (ABtL), and “Power to Liquids” (PtL) (*see Exhibit 4*).

EXHIBIT 4

Description of SAF conversion pathways[1]

SAF Pathway	Feedstocks	SAF Conversion Process	
HEFA	Vegetable oils, waste, and residue lipids	Hydroprocessing Cracking and isomerization	
ABtL	Municipal solid waste	Syngas production (gasification) Fischer-Tropsch synthesis Cracking and isomerization	
	Agricultural and forestry residues Municipal solid waste Cellulosic cover crops	Fermentation Dehydration oligomerization Hydrogenation fractionation	
PtL	Renewable hydrogen and CO_2	Additional renewable electricity generation Electrolysis (H_2 production) H_2+CO_2 utilization	Syngas production (RWGS) Fischer-Tropsch synthesis
			Methanol synthesis

1 CAAFI (2022): Fuel Qualification. Retrieved from: https://www.caafi.org/focus_areas/fuel_qualification.html
Source: Strategy& analysis

HEFA

The HEFA process is currently the most mature bio-jet fuel production path. It processes vegetable oils, waste, and residue lipids. These are treated with hydrogen to remove oxygen and break down the compounds into appropriate hydrocarbons, which are then isomerized to create SAF. The HEFA process is currently certified for a 50% blending ratio.

ABtL

This conversion pathway comprises the transformation of biomass and municipal solid waste into biofuels. With the Fischer-Tropsch (FT) synthesis technology, biomass is gasified to produce syngas, which is converted to paraffinic and olefinic hydrocarbons. Subsequently, these are cracked and isomerized to produce SAF. FT SAF is certified to be blended with up to 50% conventional jet fuel. The greatest advantage of this path is the variety of biomass inputs that can be used. As an alternative to the FT technology, through the alcohol to jet process (AtJ), sugar-rich or lignocellulosic biomass feedstocks are converted into alcohols. Subsequently, a dehydration process of isobutanol or ethanol is conducted, followed by oligomerization, hydrogenation, and fractionation. The AtJ process is also certified for a 50% blending ratio.[1]

PtL

PtL converts green hydrogen from electrolysis and green CO_2 into jet fuel and other hydrocarbon products with either the FT synthesis, or, alternatively, the methanol synthesis pathway, which produces methanol (MeOH), which then is further processed to jet fuel.[2] However, the methanol process is not yet certified for use in aircraft. Green hydrogen, one major PtL component, can be produced in large quantities from wind and solar energy, especially in regions of the world with favorable renewable energy conditions. As this conversion process uses the FT synthesis, which is already certified for AbtL, a 50% blending ratio is certified. The methanol synthesis pathways process, however, still needs to be certified.[3]

1 IATA (2019): Fact Sheet 2 Sustainable Aviation Fuel: Technical Certification. Retrieved from: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-technical-certifications.pdf
2 Currently, various definitions for green CO2 are being discussed; these range from the avoidance of setting up factories for the purpose of producing CO2 to using only direct air capture as an input source
3 Umweltbundesamt (2022): Power-to-Liquids A scalable and sustainable fuel supply perspective for aviation. Retrieved from: https://www.umweltbundesamt.de/en/publikationen/power-to-liquids
Source: Strategy& analysis

EXHIBIT 5

Additional SAF pathway characteristics

Criteria	HEFA	ABtL	PtL
Feedstock[1]	Vegetable oils, waste, and residue lipids	Agricultural and forestry residues, municipal solid waste, and cellulosic cover crops	Renewable hydrogen and CO_2
Feedstock Availability in Europe	Feedstocks are constrained by resource availability and demand competition with other sectors	Feedstocks are constrained by resource availability and demand competition with other sectors Increased availability in comparison with HEFA feedstock due to broader available range	Least restricted feedstock availability, due to large hydrogen production potential
GHG Emission Savings[2] in comparison to conventional jet fuel[3]	74%-84%[4]	66%-94%[5]	89-94%, 99% during use phase[6,7]
Readiness Level (RL)[8] considering IEA readiness scale from 1 to 11 (technological and commercial)	**Up to RL10** Commercially available (improvement in competitiveness and scale-up are needed)	**Up to RL6** Components proven in conditions to be deployed	**Up to RL5** Prototype proven at scale in conditions to be deployed

1 Considering feedstocks in compliance with the EU regulation REDII – Annex IX and GHG levels based on a Life Cycle Assessment (LCA)
2 ICAO (2019): CORSIA Eligible Fuels – Life Cycle Assessment Methodology. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20 Supporting%20Document_CORSIA%20Eligible%20Fuels_LCA%20Methodology.pdf3,4 Default life cycle emissions values for CORSIA eligible fuels. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20March%202021.pdf
5 ICAO, 2019. Default life cycle emissions values for CORSIA eligible fuels
6 Umweltbundesamt (2022): Power-to-Liquids A scalable and sustainable fuel supply perspective for aviation. Retrieved from: https://www.umweltbundesamt.de/en/publikationen/power-to-liquids
7 Ludwig-Bölkow-Systemtechnik has quantified 1 g/MJ during the use phase and 5-10 g/MJ when construction is factored in (mainly solar and wind power plants)
8 IEA (2021): ETP Clean Energy Technology Guide. Retrieved from: https://www.iea.org/articles/etp-clean-energy-technology-guide
Source: Strategy& analysis

Based on process characteristics of each SAF conversion pathway as well as the chosen feedstock, SAF enables a CO_2 emissions reduction in the range of 66%–94%[27] (*see Exhibit 5*).

ASTM International (formerly the American Society for Testing and Materials), which is the certification authority for SAF, has certified several combinations of feedstock and conversion technology[28] for aviation use. Nevertheless, even more technological combinations (e.g., AtJ based on methanol) show potential and might become certified in the future.

Currently, SAF blending ratios of up to 50% with conventional fossil jet fuel are certified. It has already been demonstrated that critical components of existing newer aircraft-types can run on 100% SAF. Thus, in the future, higher blending ratios could become certified. However, at the moment, blending ratio limitations are not a concern because SAF quantities are limited.

RED II

The Renewable Energy Directive—recast to 2030 (RED II) determines the sustainability criteria and limits of GHG emissions that biofuels must attain to be used in the European transport sector. In particular, GHG emissions from transportation biofuels must be reduced by at least 65% compared to conventional fuel. Current SAF feedstocks are often based on lipids generated from agricultural products, such as soybeans and rapeseed. Therefore, one risk is that SAF producers might use land originally intended for food production, displacing farms. Furthermore, SAF utilization can negatively impact the GHG balance if deforestation takes place. To counteract such risks and guarantee a transparent GHG emissions reduction, RED II regulates the use of feedstocks and processes to produce biofuels. It includes a cap on food-based feedstocks and a cap on fuels with high Indirect Land Use Change (ILUC) risk.[29]

SAF situation today

As detailed above, SAF can be produced in a wide variety of ways. Why, then, have SAFs not yet been used on a larger scale? Currently, less than 1% of aviation fuels used in Europe are SAFs.[30]

The status quo is determined by the following circumstances

The production of SAF is more costly than the production of conventional kerosene, and incentives are not yet sufficient to entice airlines to purchase huge fuel volumes at higher prices. Although current macroeconomic shocks and external influences on the European economy have led to an increase in the price of conventional kerosene, the biogenic feedstocks required for some SAF conversion pathways have become more expensive at the same time. As a result, SAF is currently not competitive with conventional kerosene from a purely financial perspective.

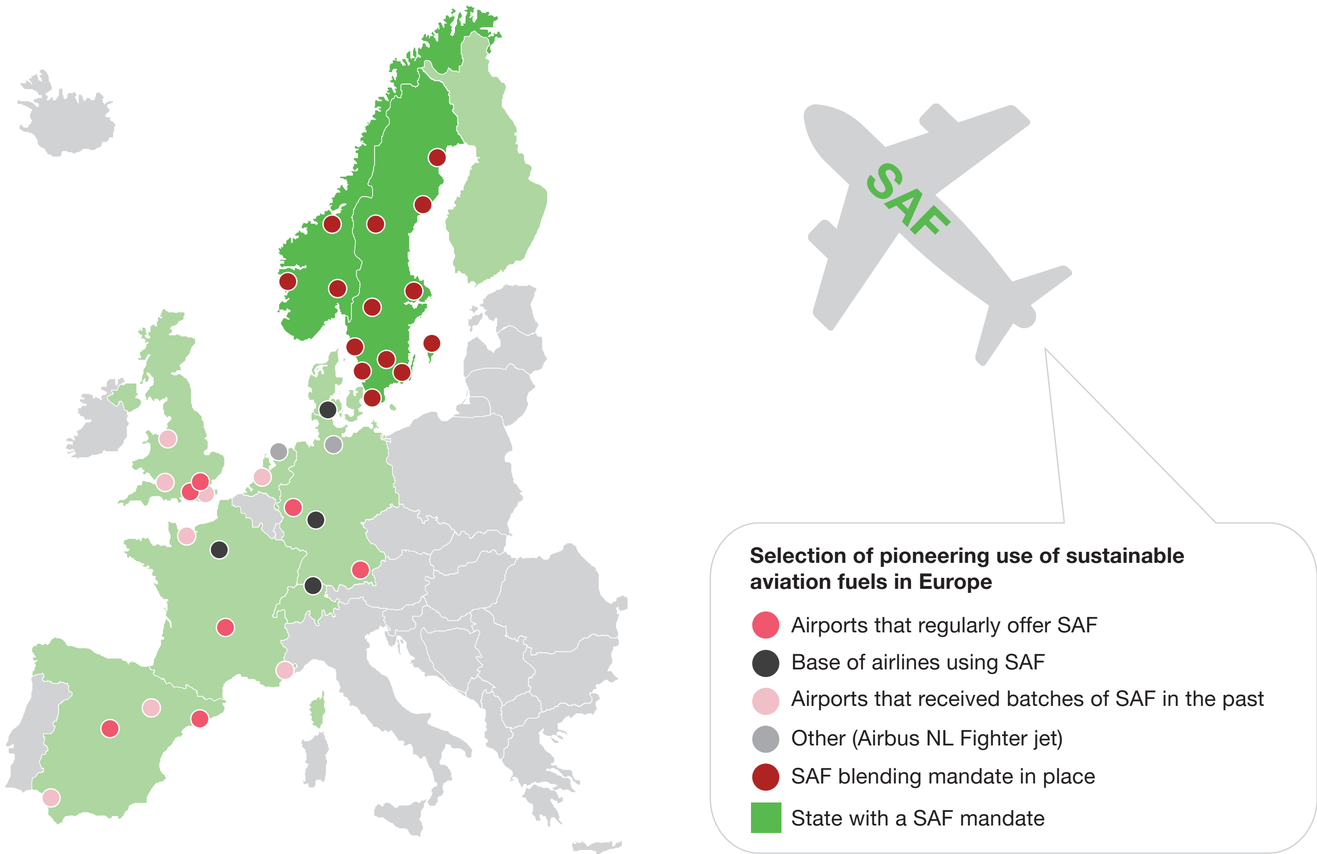
Currently, less than 1% of aviation fuels used in Europe are SAFs.

Although only very small quantities of SAF are used by airlines today, significant quantities of SAF are already committed for offtake in the future. In 2021 and 2022 alone, offtake agreements of 13 million tons have been closed.[31] The largest producer of SAF in Europe, Neste, already produces 100,000 tons annually, and is expanding its capacity to 1.5 million tons by 2023. The Norsk e-fuel consortium is building a SAF production plant in Norway with a capacity of up to 80,000 tons of PtL-based SAF by the middle of the decade. Complementary to that, airlines such as Lufthansa and DHL Express have committed to purchase these produced quantities. Finally, SAF has already been deployed at 22 airports in Europe, and the trend is growing[32] *(see Exhibit 6)*.

The voluntary market is the key driver for SAF use today: Net zero ambitions of corporate airline customers and increasingly intensified efforts to achieve more GHG emissions reductions (e.g. First Mover Coalition[33]) signal a potential willingness to pay for SAF. An important driver to increase liquidity/fungibility would be the introduction of a SAF certificate "book and claim" system that would make Scope 3 reductions tradable through certificates. This clearly would be a further driver for more SAF offtake agreements, as it would allow airlines to pass on the additional costs of SAF without themselves having to suffer competitive disadvantages due to higher fuel costs.

EXHIBIT 6

Relevant operational SAF locations[1]



1 Eurocontrol (2021): EUROCONTROL Data Snapshot #11 on regulation and focused logistics unlocking the availability of sustainable aviation fuels (SAF). Retrieved from: https://www.eurocontrol.int/publication/eurocontrol-data-snapshot-11-saf-airports

Source: Eurocontrol

SAF certificates/book and claim

The introduction of a certificate system for SAF is a key lever in enabling market ramp-up. A detailed **proposal** for a certificate system is available from the World Economic Forum (WEF) in cooperation with PwC Netherlands and the Rocky Mountain Institute (RMI),[34] which envisages the introduction of a global SAF certificate trading system based on a book and claim system. This system makes it possible to decouple the physical SAF quantities from the crediting. Additionally, SAF-enabled Scope 3 reductions become creditable for companies. Decoupling the physical SAF quantities from the crediting via certificates would have the advantage that SAF could be produced at the location with the best production conditions and used directly there, saving high-emission, expensive and time-consuming transport. By selling SAF Scope 3 certificates, airlines or fuel producers could sell the Scope 3 reduction achieved by SAF to airline customers. This decoupling would eliminate regional limitations and further boost the SAF market. Overall, in such a system, unified sustainability criteria are required, as are measures to avoid double-counting of benefits.

Airlines are reinforcing these ambitions by creating alliances such as the First Mover Coalition, a partnership formed by airlines, aircraft manufacturers, and fuel producers under the leadership of the World Economic Forum. The partners have committed to increase the share of SAF to 10% by 2030,[35] double the share that is required according to the planned EU regulation. SAF is also recognized as a compensation measure in the CORSIA agreement, in which airlines worldwide have committed themselves to growing in a climate-neutral manner from 2021.[36]

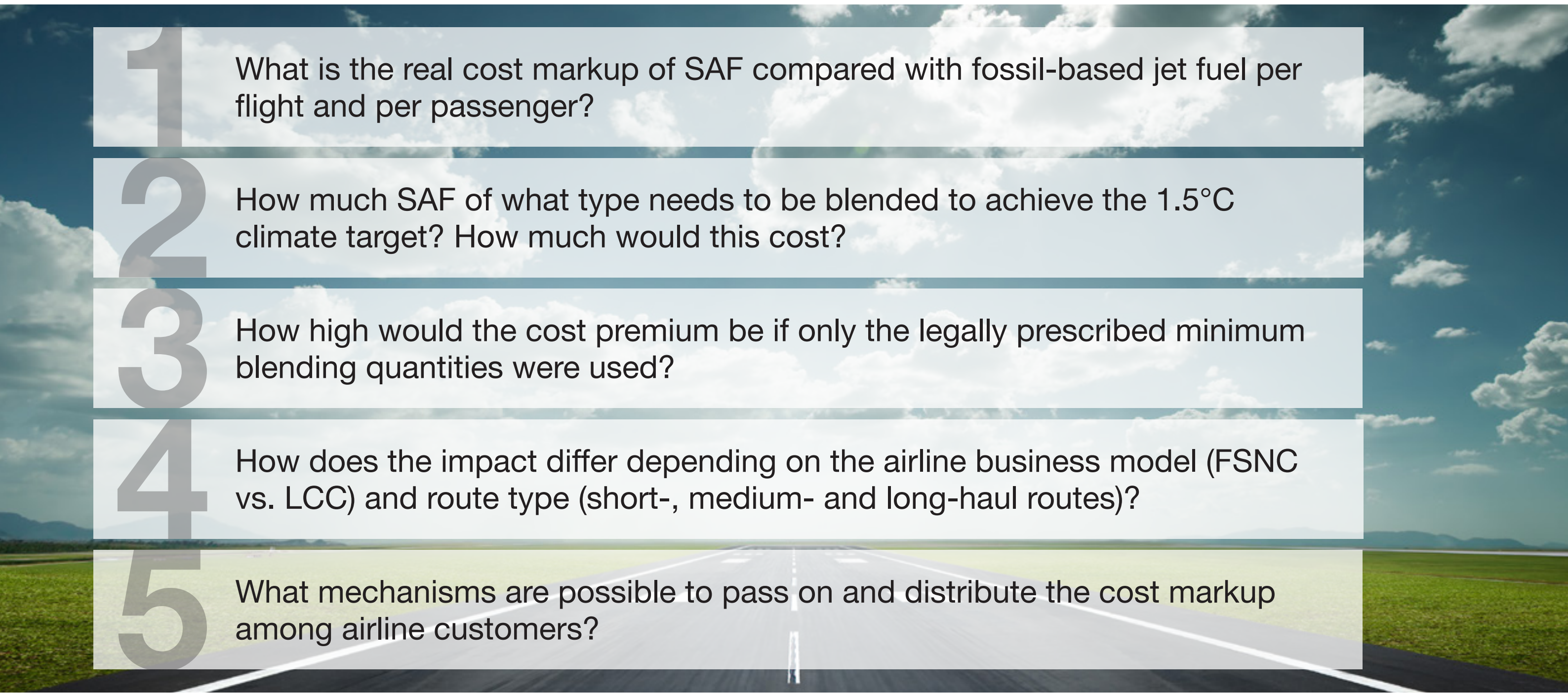
In addition, policymakers are enacting regulations to further incentivize the use of SAF. After some individual countries (such as Germany, Sweden, France, and Spain) had introduced fuel blending mandates for SAF (in some cases with sub-quotas for PtL), the EU moved, with the ReFuelEU Aviation proposal, towards uniform SAF blending mandates throughout the EU starting in 2025. This will reduce investment uncertainty and increase planning security for fuel producers, which can assume a secure sales market, and for airlines, which must prepare the purchase of SAF volumes.

This planning security for fuel producers is particularly important considering the long ramp-up times of production plants. To be able to produce larger quantities of SAF, either new plants must be built, or existing plants must be converted. HEFA is expected to grow strongly in the next years until feedstock limitations slow that growth. The fast setup of AtJ and FT plants in the following years will also play a crucial part. However, in the EU, only a few announcements of planned production sites have been made so far. The conversion of an entire refinery as well as new construction will likely take five to ten years. It is therefore crucial to start building up production capacity now if producers are to be able to produce the necessary SAF volumes later. Subsequently, the further optimization of processing technologies regarding the output are crucial—especially for FT, as this technology will be used for the PtL process in the future. If facilities are to produce PtL in large quantities, large-scale electrolyzers for hydrogen production are needed in addition to refineries, which in turn require large amounts of renewable electricity.

Study motivation

As described earlier, SAF plays an integral role in the necessary path toward a more sustainable aviation industry. So, if we look at today's SAF usage, it may seem surprising that less than 1% of aviation fuels in use in Europe are SAFs. However, an interplay of different factors (see previous section) is likely responsible, but one main reason is the higher cost of SAF compared with the cost of fossil kerosene. Despite the financial losses caused by the COVID-19 crisis, the aviation industry has always operated with low margins. High cost markups can have a significant impact on an airline's viability.

Thus, it is of high importance for airlines to understand the real cost implications of SAF. Facing different SAF conversion pathways with individual limitations and technological maturities, it is especially interesting to understand how different SAF ramp-up scenarios impact a potential cost markup. The following questions arise:



1. What is the real cost markup of SAF compared with fossil-based jet fuel per flight and per passenger?
2. How much SAF of what type needs to be blended to achieve the 1.5°C climate target? How much would this cost?
3. How high would the cost premium be if only the legally prescribed minimum blending quantities were used?
4. How does the impact differ depending on the airline business model (FSNC vs. LCC) and route type (short-, medium- and long-haul routes)?
5. What mechanisms are possible to pass on and distribute the cost markup among airline customers?

To answer these questions, we calculated the expected cost markup of SAF from 2025 to 2050 in Europe. Here, we selected two main SAF ramp-up scenarios: The **EU Quota Pathway** (Scenario 1) and the **IEA Net Zero Pathway** (Scenario 2). The EU Quota Pathway focuses on the SAF amount stipulated by the minimum SAF blend ratios in the draft of the ReFuelEU Aviation directive. In Scenario 2 the amount of SAF is determined by the requirements to achieve the International Energy Agency (IEA) Net Zero Pathway by 2050.[37] To determine the cost markup, we then compared the resulting SAF costs to a **baseline scenario**. This scenario reflects the estimated future jet fuel costs if no SAF was used at all. The costs consist of the kerosene prices and the future CO_2 prices. Below, the key assumptions and scenarios are explained in more detail.

Assumptions and SAF ramp-up

Kerosene price and demand forecast

The underlying total kerosene demand for the scenario modeling was deduced from the annual flight demand growth rate forecast from 2021 of 1.2% for the European domestic and outbound market.[38] Combined with a yearly 0.7% in efficiency gains,[39] we applied a CAGR of 0.5% to a 2019 fuel demand baseline. The other fundamental parameter for the cost comparison analysis was the fossil kerosene price including the CO_2 price. For the fossil kerosene price, we applied a yearly CAGR of 1% to a pre-COVID-19 price level of US$700/t to simulate a slow but steady price increase. The CO_2 price was conservatively based on the "Sustainable Development" scenario of the IEA and reaches US$160/t in 2050[40].

Within our analysis, we assumed that the CO_2 price will rise to steer emissions reduction. The selected CO_2 price is conservatively based on the "Sustainable Development" scenario of the IEA. By taking into consideration that 1 ton of kerosene causes 3.16 tons of CO_2, the cost comparison models starts with a fossil kerosene price in 2025 of around US$970/t and rises to a price of US$1,400/t in 2050.

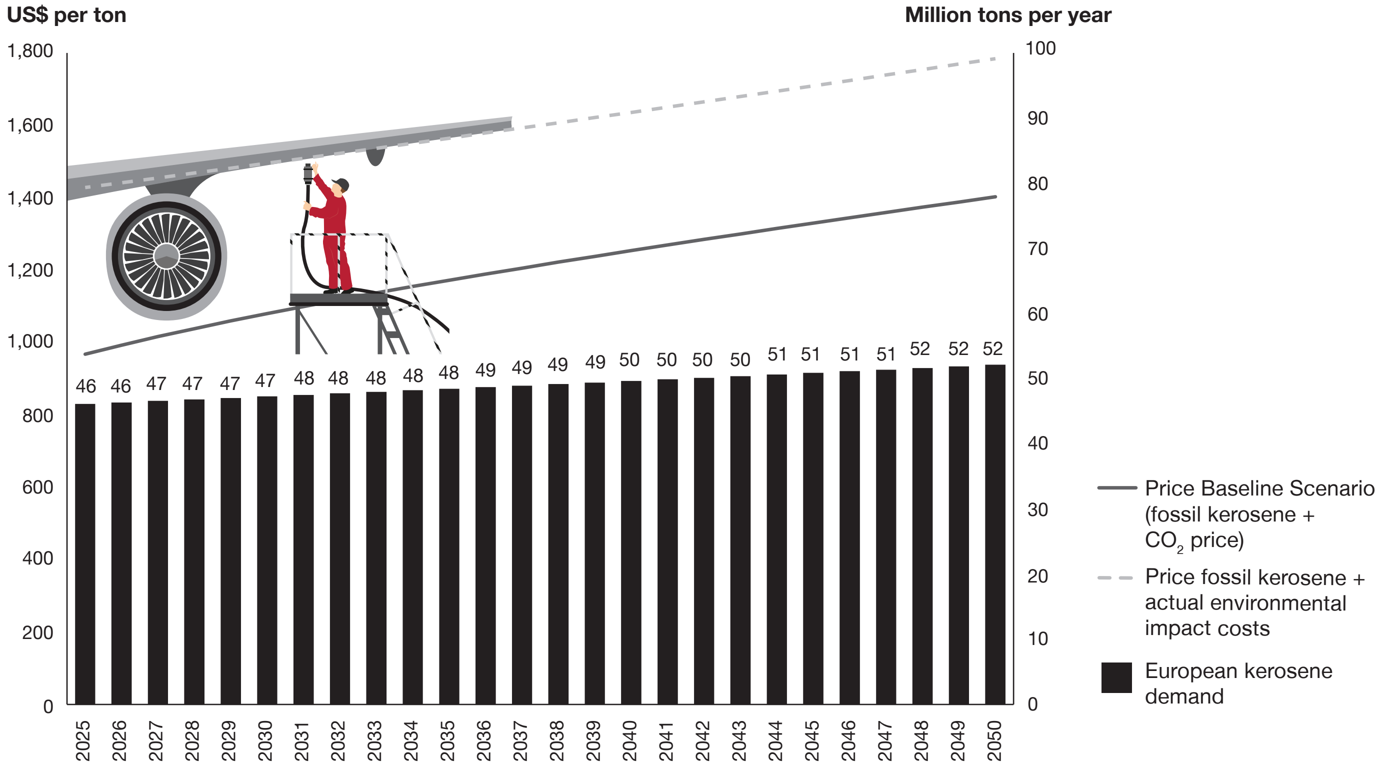
Carbon pricing mechanisms

To nourish the SAF market, regulatory and economic incentives, such as quotas or the voluntary market, are well-known measures. Another option are carbon pricing mechanisms, which make fossil kerosene more expensive. With this approach, a price based on the CO_2 emission of an energy source is added to the product price by means of either a tax or an emissions trading system (ETS). Such a mechanism adds a cost based on the carbon intensity of the energy carrier on the actual fossil fuel cost and provides a more equitable comparison between fossil kerosene and SAF. When real fossil fuel costs are accounted for, renewable energy sources increase their competitiveness. Worldwide, 65 carbon pricing initiatives have been implemented, but with varying approaches to the aviation sector.[41] The EU ETS covers aviation fuels on intra-European flights; an EU allowance of US$85/t CO_2 corresponds to a surcharge of US$268.60/t kerosene.

The whole price trend over time, as well as the underlying kerosene demand, is shown in *Exhibit 7, page 24*. In addition to the price level of the baseline scenario, another fossil-based kerosene price model, is shown. This second kerosene scenario includes the actual environmental impact cost caused by CO_2 pollution (CO_2 price is based on macroeconomic modeling recommended by the Umweltbundesamt[42]).

EXHIBIT 7

Kerosene price and demand forecast



Source: Strategy& analysis

Volatility of oil price

When assessing future jet fuel price developments, it is important to consider that kerosene prices are constantly fluctuating and are highly influenced by geopolitical developments. Within our analysis, we applied a rather conservative price development. However, due to the vulnerability to exogenic shocks, steep kerosene price increases might apply. For instance, at the time of writing this study, the actual kerosene price was around US$1,200/t due to the ongoing war in Ukraine and its political and economic consequences. Considering prices even higher than that, the forecasted cost markups might decrease further compared with the baseline scenario.

Scenarios

Baseline scenario
The baseline for the cost comparison is a theoretical scenario in which an airline uses as fuel solely fossil-based kerosene. The resulting cost baseline consists of the crude oil–linked kerosene price and the corresponding CO_2 price over time up to 2050.

SAF Scenario 1: EU Quota Pathway
This scenario represents the announced ReFuelEU directive quotas proposal,[43] which will likely be in place as of 2025. The mandates include an overall required minimum SAF share as well as a sub-quota for PtL SAF (Status July 2021). The ramp-up in this scenario represents the minimum legal requirements.

Minimum required SAF share

	2025	2030	2035	2040	2050
SAF share	2%	5%	20%	32%	63%
PtL share*	/	0.7%	5%	8%	28%

SAF Scenario 2: IEA Net Zero Pathway
This scenario is based upon the underlying requirements of the IEA Net Zero scenario by 2050.[44] Thereby, the SAF shares that are needed to reach such a goal were deduced, including a PtL sub-quota. The ramp-up in this scenario represents the SAF share required to meet the 1.5°C climate target.

Minimum required SAF share

	2025	2030	2035	2040	2050
SAF share	2%	15%	32%	50%	75%
PtL share*	/	2%	7.5%	15%	30%

* PtL share of SAF

Besides the baseline scenario, we chose two SAF ramp-up scenarios.

We chose the EU Quota Pathway as Scenario 1 because it represents the currently drafted minimum legally required SAF blending quotas.

We selected the IEA Net Zero Pathway as Scenario 2 because it is the most widely accepted normative cross-industry scenario describing a pathway to reach the Paris Agreement climate targets. It is important to note that this scenario offers a holistic view, maximizing efficiency in all economic sectors. Consequently, emissions are first reduced in sectors where a high impact can be achieved at lower cost. Because the aviation industry is considered a hard-to-abate sector, this scenario does not predict a 100% decarbonization of the industry until 2050. Moreover, it includes the installation of carbon capture measures. If we assess only the decarbonization of the aviation industry, a SAF ramp-up scenario towards a global 100% SAF usage by 2050 is conceivable. To address this consideration, we performed a sensitivity analysis, described towards the end of the study, setting the IEA Net Zero Pathway to lead to a 100% scenario.

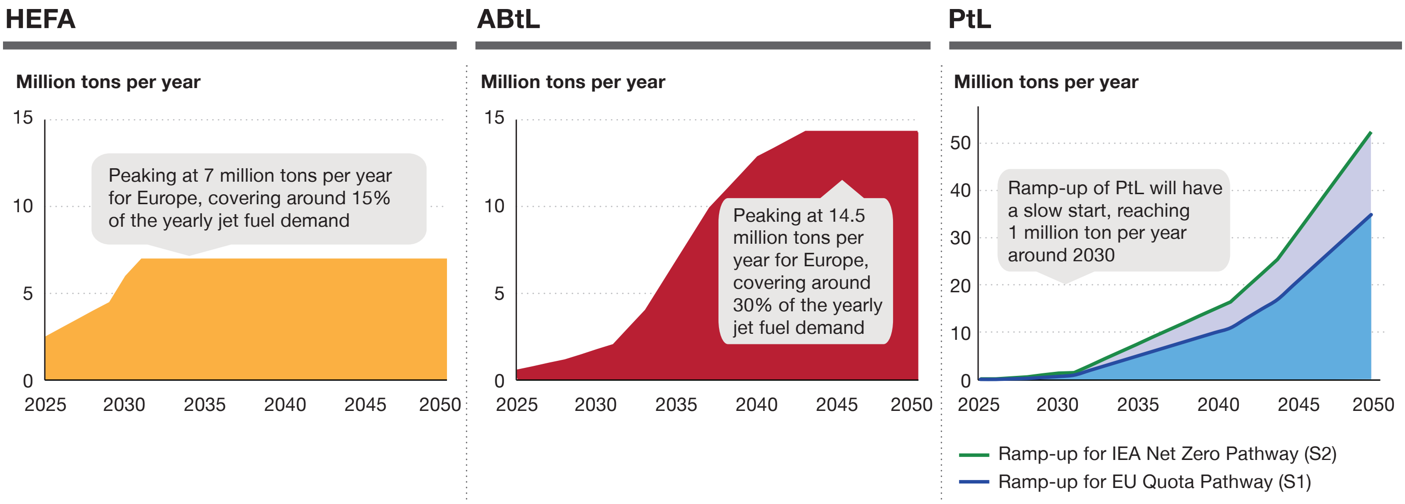
By means of a meta-analysis based upon existing SAF publications,[45] several expert interviews, and internal expertise, we estimated the cost development for each SAF type over time in the chosen scenario. We took a range of prices into consideration to reflect

The SAF blending quotas suggested by the European Commission in the ReFuelEU Aviation draft regulation are currently not sufficient to reach the 1.5°C target according to the IEA Net Zero Pathway.

the variety of predicted SAF costs, which are caused by differing feedstock sources and production processes within each SAF type. Since both fossil kerosene but also SAF feedstock prices can be subject to (strong) fluctuations due to market developments and external impacts, we have based our long-term prediction on a consensus model of the available SAF production cost forecasts.

For both SAF scenarios, we developed a realistic ramp-up pathway of the different SAF types while considering production capacity limitations. For all pathways, we assumed a global production of feedstocks and international trade. However, not all these feedstocks will be available for the European aviation sector, limiting the total quantity. For HEFA and ABtL the limited feedstock availability and demand competition with other sectors that aim to fulfill their net zero ambitions constrains the production capacity. For PtL, there is no limiting factor per se. However, PtL production is considered the most expensive SAF conversion pathway. Overall, for both SAF scenarios, the following maximum production capacities per SAF type were assumed[46] (*see Exhibit 8*).

EXHIBIT 8
Ramp-up curves per SAF conversion pathway



Source: Strategy& analysis

Due to the necessary investments, the more complex production processes, and the feedstock requirements, the production of SAF is currently more expensive than conventional fossil kerosene. This will remain the case for the various types of SAF, at least in the short and medium term.

Volatility of SAF prices

As for fossil kerosene, SAF prices are also constantly fluctuating and are influenced, e.g. by current feedstock costs, technology maturity, margins and geopolitical developments. Within our analysis we calculated the SAF prices based on production costs and a 10% markup including e.g. administrative or transportation costs.

HEFA	HEFA is currently the most advanced and cost-effective pathway for SAF production. No significant capital expenditure reductions can be expected for HEFA. Economies of scale and learning effects may help to reduce investment costs, but steeply rising prices for biogenic feedstocks have recently driven HEFA production costs to record levels. This shows the sensitivity of HEFA production costs to market fluctuations.
ABtL	In 2025, ABtL is expected to be 25% more expensive than HEFA because this pathway is not widely used for SAF production yet. Due to the development of economies of scale, a more accelerated cost reduction is expected. This can reduce the price difference with HEFA by up to 7% until 2050. However, by 2050, according to our model, cost parity with conventional jet fuel will still not be reached.
PtL	PtL is currently the most expensive way to produce SAF, especially because of high costs for green hydrogen. However, substantial cost reductions can be expected for renewable electricity in the future. First, renewable power generation costs (accounting for 60%–80% of green hydrogen costs) are expected to fall over time, dropping green hydrogen costs to US$1–2/kg in regions around the world with optimal conditions (e.g., Chile) compared with US$6–8/kg in Europe today.[1] Second, economies of scale and learning effects are expected to lead to a significant reduction of investment costs.

1 PwC (2022): The green hydrogen economy. Predicting the decarbonisation agenda of tomorrow. Retrieved from: https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html
Source: Strategy& analysis

Sector competition

Not only aviation, but all industrial sectors are significantly challenged to reduce GHG emissions. Besides familiar measures, such as the expansion of renewable energies and efficiency improvements, these sectors must rely on feedstocks suitable for SAF production. For example, there is a great demand for biomass in the construction sector (particularly wood as a substitute for concrete), or for heat generation in the manufacturing industry. Biofuels based on lipids, ethanol, or methanol can be used in shipping and road transport. Moreover, the renewable hydrogen required for PtL production is also needed in steel and fertilizer production. For the aviation sector to achieve its goals through SAF, it will be necessary to commit to early offtake agreements and investments, as well as to offer producers planning security.

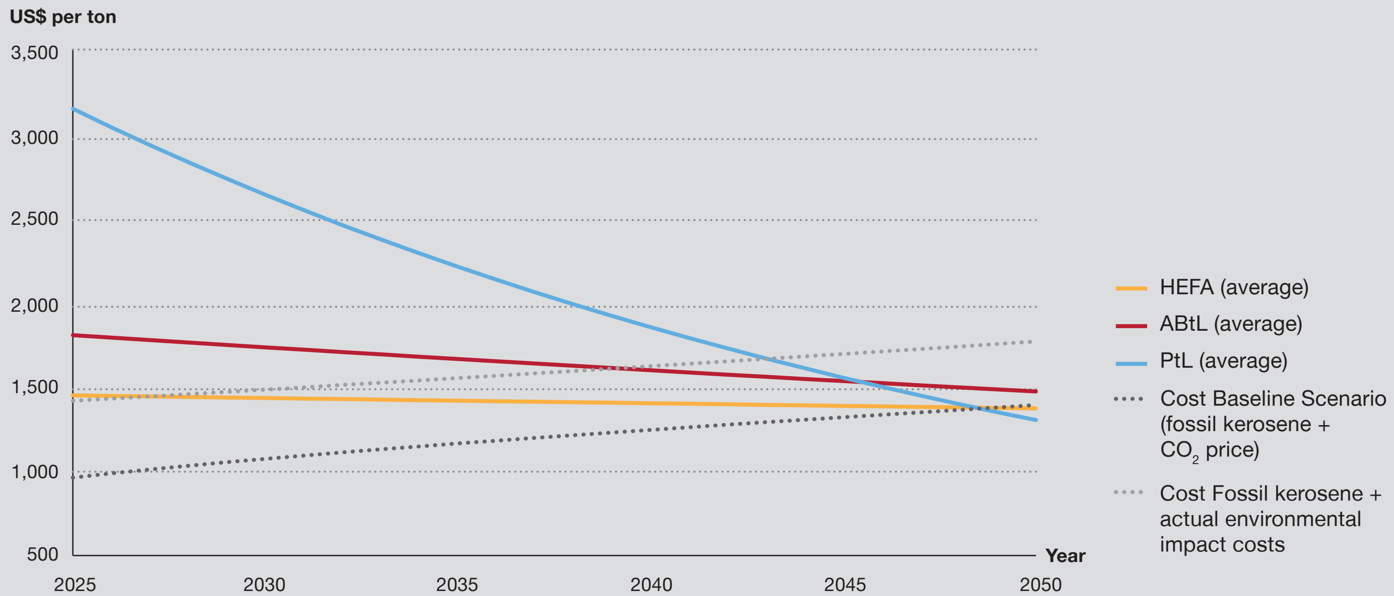
However, energy transitions in other transport sectors may also reduce the demand for SAF. The private automotive sector in Germany is a representative example. Due to the replacement of internal combustion engines (ICE) with electric vehicles (EV), this sector will require less biofuel to meet its decarbonization targets (one-sixth of the current fuel demand by 2030). As a bio-refinery can – within boundaries - adjust the share of each fuel type it makes, a producer can use the excess SAF plant capacities for the aviation industry instead.

When will SAF reach price parity with fossil-based jet fuel?

It is noticeable that the cost of SAF production for all three pathways converges to very similar levels by 2050. Assuming increasing CO_2 prices for kerosene over time, they may even reach cost parity with conventional jet fuel (*see Exhibit 9*). Due to the uncertainties contained in the forecasts, it can be assumed that there will be strong competition among the SAF conversion pathways. This can potentially lead to further cost reductions. However, we expect SAF to remain more expensive than fossil kerosene until 2040. Without fiscal measures (such as CO_2 prices or subsidies), price parity will not be achieved until 2050.

EXHIBIT 9

SAF price development until 2050 (unblended)



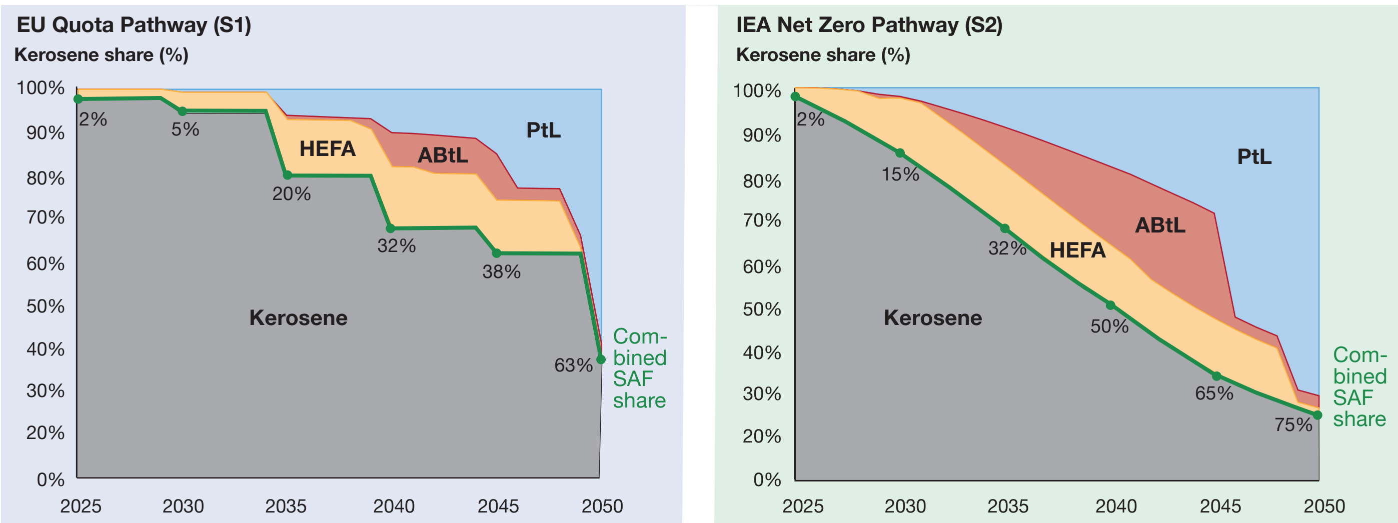
Source: Strategy& analysis

A different picture emerges once the estimated cost of the actual environmental damage caused by emitting one ton of CO_2 is taken as a basis[47]. Adding the actual cost of environmental impact to the price of jet fuel, SAF would reach cost parity well in advance (*as shown in Exhibit 9*). For this estimation, we used a CO_2 price of US$230 for 2025 and increased it to US$281 by 2050. In this situation, HEFA would reach cost parity in 2027. Due to cost degression and initially high costs, ABtL and PtL will reach this break-even point much later, approximately in 2040. Although the discussion of the actual environmental damage is highly interesting, for the subsequent analyses, we use the baseline scenario with more realistic CO_2 prices.

Using data on feedstock availability, the actual SAF demand, and the costs of the different SAF types, we calculated the SAF type shares in each year and scenario. We estimated the share of each SAF type over time by always using the maximum available capacity of the cheapest SAF type. The underlying assumption is that both, producers, and off takers are optimizing their costs by choosing the cheapest available SAF type. When, for instance, PtL becomes cheaper than HEFA or ABtL, PtL will be increasingly used, and the considered quantities of HEFA and ABtL are decreased in the model. To counteract this potential development, HEFA and ABtL producers might have to lower their prices or shift their production volumes to other industries (e.g., marine shipping or chemicals) to stay competitive and use their built-up capacities. The resulting SAF pathways over time for each scenario are shown in *Exhibit 10*.

EXHIBIT 10

Blending ratios for the EU Quota Pathway (S1) and the IEA Net Zero Pathway (S2)

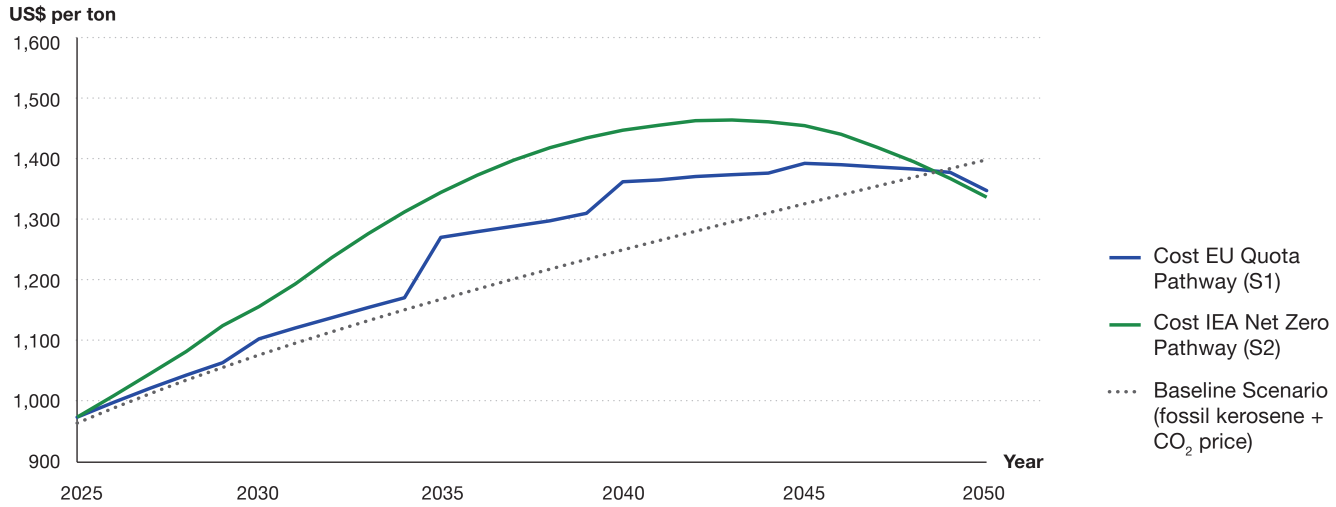


Source: Strategy& analysis

With the cost ranges of each SAF type and the corresponding shares, we calculated the overall cost of a representative ton of jet fuel mixture (representing a blend of the different SAF types and fossil kerosene) and compared these cost levels against the baseline scenario cost level (fossil kerosene and CO_2 price) (*see Exhibit 11*) to calculate the cost markup.

EXHIBIT 11

Cost development of Scenarios 1 and 2 in comparison with baseline scenario up to 2050



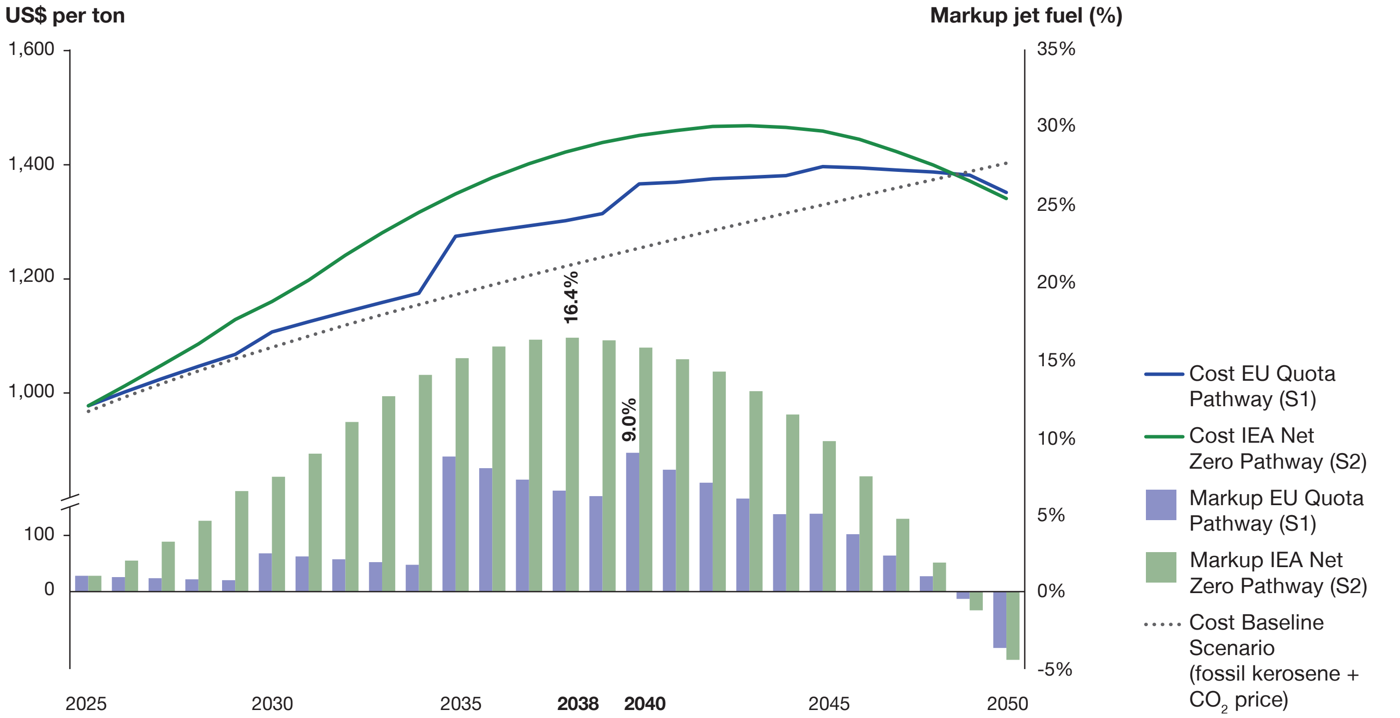
Source: Strategy& analysis

The cost markup for airlines and beyond

Using the different ramp-up scenarios, we modeled the SAF cost development and calculated the expected actual cost implications of SAFs for typical European airlines and their customers (*see Exhibit 12*).

EXHIBIT 12

Integrative cost comparison of SAF, conventional fuel, and markup for the different scenarios



Source: Strategy& analysis

The use of SAF will result in additional fuel costs up to 16%

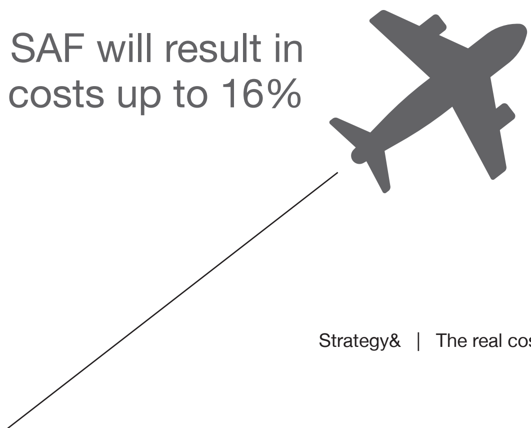


Exhibit 12, page 31 shows the development of the cost markup for one ton of kerosene from 2025 to 2050. This cost markup results from a comparison of the SAF costs in the respective scenarios with a baseline scenario considering kerosene price and a CO_2 price. Assuming a SAF mix based on the minimum legal requirements, the highest markup is reached in 2040 with around 9% per ton of fuel. When following the IEA Net Zero Pathway, Scenario 2, this maximum markup is reached in 2038 with about 16%. This peak results from an increased usage of PtL due to its technological availability and the need to meet the high SAF demands. However, because the technology is still maturing, economies of learning and scale cannot be fully applied yet. After 2040, the cost of jet fuel, including the share of SAF assumed for each scenario, will decrease, due to two main factors. First, the cost for PtL will become significantly lower. Second, CO_2 prices are assumed to be constantly rising, because they can be considered as an important steering instrument for GHG emission reduction and are already established in several countries around the world. Higher CO_2 prices will lead to a remarkable cost increase for fossil kerosene. Consequently, the cost gap with SAF will be closed.

The calculated cost markup has different implications for the typical short-, medium-, and long-haul routes. The relative cost markup is expected to be higher for long-haul than for short-haul flights (*see Exhibit 13, page 33*). This is because long-haul flights experience a higher share of fuel costs compared with the overall operational costs than shorter flights do. As a result, the relative cost increase per flight is more than double for long-haul flights in comparison with short-haul flights in Scenario 1. In Scenario 2, the relative cost increase is almost three times as high.

9%

relative cost markup per ton fuel in 2040

16%

relative cost markup per ton fuel in 2038

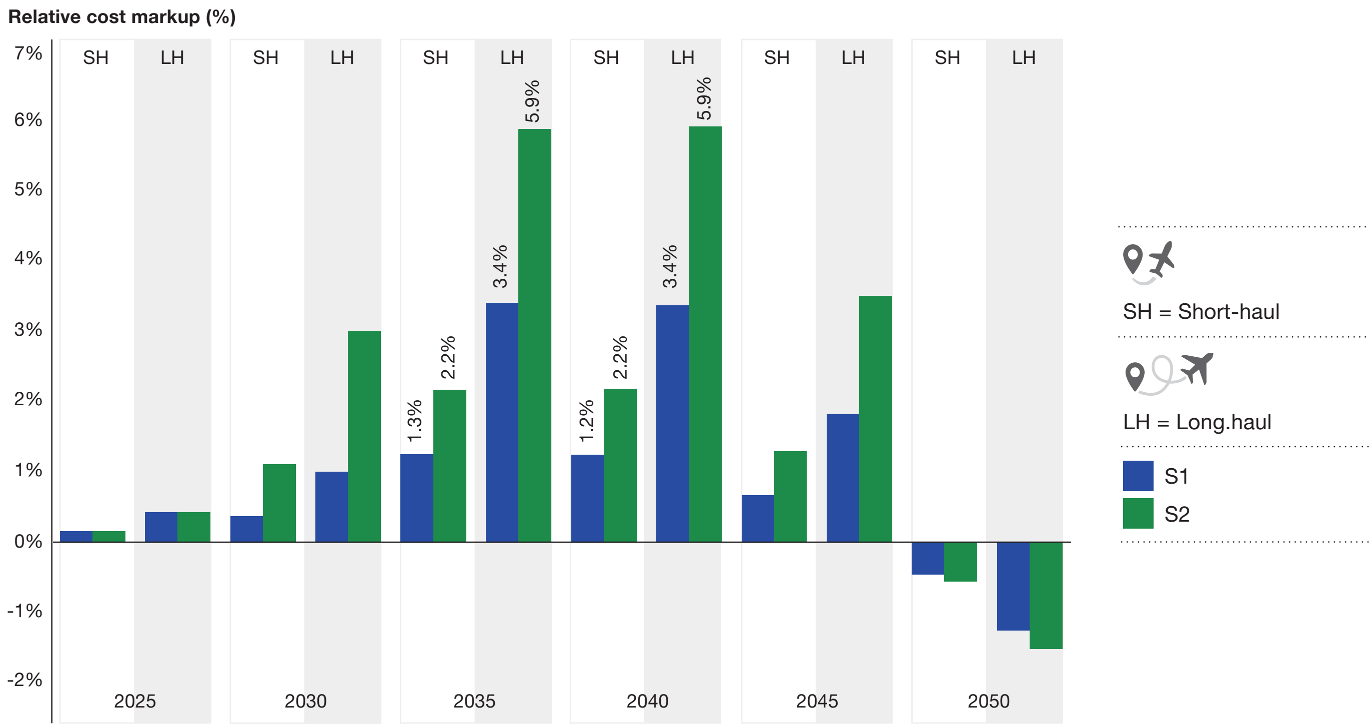
The largest relative cost markup increase is expected in the long-haul segment

When we take a closer look at the cost markup for long-haul flights in the EU Quota Pathway (Scenario 1), we see that the cost increase peaks at around US$4,900 per flight for an FSNC in the mid-2030s. If these costs were shared equally among all passengers independent of booking class and willingness to pay, this would result in a maximum cost markup of around US$20 (+3.5% compared to baseline scenario) per passenger. When we compare these results to the cost markup in the IEA Net Zero Pathway (Scenario 2), it becomes evident that in both scenarios the cost markup remains manageable for the airline. In Scenario 2, the total cost markup per flight reaches its maximum at around US$9,000 in the late 2030s. With the same distribution assumption as for Scenario 1, this would result in a cost increase peaking at just under US$36 (+6% compared to baseline scenario) per passenger.

Moreover, we observe a higher impact on the overall profitability for long-haul than for short-haul flights. While in Scenario 2 long-haul flights experience a profitability reduction of up to 29% (16% in Scenario 1), short-haul flights will have to manage a reduction of only up to 14% (8% in Scenario 1). Notably, the medium-haul profitability is most affected (with up to 40% in Scenario 2). This is due to middling profitability in comparison to long-haul flights and a more significant fuel cost share in comparison with short-haul flights. Overall, even while considering an equal distribution of SAF costs, the cost increases over the different route types remain manageable, if the right incentives are in place.

EXHIBIT 13

Estimated relative total cost increase in flights for FSNCs by route type compared with baseline scenario



Source: Strategy& analysis

The two archetypal airline business types are also affected differently by the application of a SAF blending mandate. Given its higher fuel cost share and the most price-sensitive passengers, the LCC business model is more affected by the SAF cost markup (*see Exhibit 14*), even though it serves on average mostly short-range routes.

EXHIBIT 14

Estimated relative cost increase in short-haul flights by business model, compared with baseline scenario

Source: Strategy& analysis

Low-Cost Carrier (LCCs) will be more impacted by the cost markup than Full-Service-Network Carrier (FSNCs)

As the fuel cost share of LCCs is almost double the fuel cost share of FSNCs, the LCCs' relative cost increase is expected to be more than two times higher than for FSNCs', meaning that their average operating profit margin will be halved. But when looking at the absolute cost markups for each airline cluster, the different baselines must be considered. On average, the absolute SAF cost markup of an LCC is expected to be only half the markup of an FSNC. However, the costs per passenger for the total fuel burned per flight, are generally already lower for an LCC compared to an FSNC. Since LCCs have a higher seat capacity and load factors in general, the additional costs are distributed among more passengers resulting in lower cost markups per passenger. Overall, a full-service network carrier is expected to face total additional costs of US$3 billion (if following Scenario 1) or US$8 billion (for Scenario 2) due to SAF cost markups between 2025 and 2035. A low-cost carrier would face total additional costs of US$225 million (if following Scenario 1) or US$610 million (for Scenario 2).

LCCs' relative cost increase is expected to be more than two times higher than for FSNCs'

Overall, this development adversely affects the core of the LCC business model – being able to offer cheaper flights. Moreover, potential considerations to establish LCC long-haul flights need to be rethought. LCCs have fewer possibilities to distribute additional costs towards more profitable long-haul routes the way FSNCs do. If regulators enforce the broad use of SAF, LCCs might struggle more to retain their price-sensitive customers.

One common argument is that higher fuel quotas and CO_2 prices can threaten the competitive position of European airlines. Competitive losses could particularly occur on long-haul routes, where other countries' airlines are operating free of blending mandates and free, or nearly so, of an obligation to pay CO_2 costs. Compared with these airlines, European airlines' SAF cost markup would be higher than in our model, because the comparison baseline would not consider any CO_2 prices.

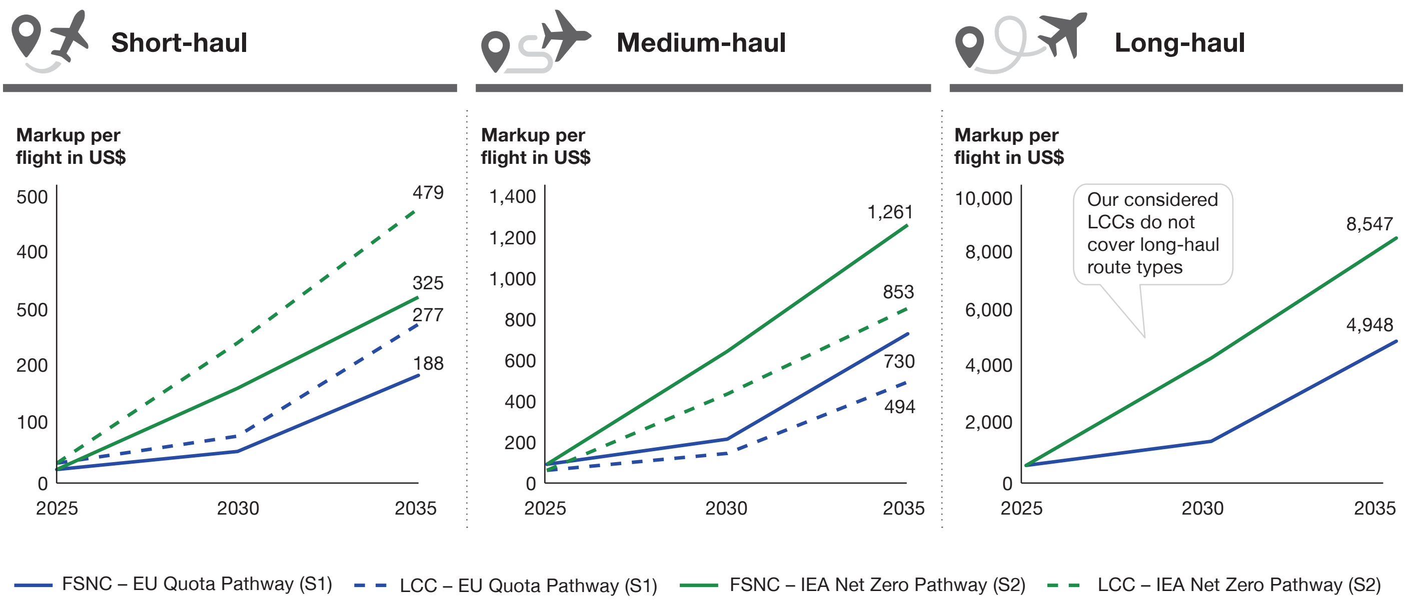
To reduce the risk of a competitive disadvantage for European airlines, regulations on blending quotas need to be thoughtfully designed. One approach, which is currently discussed, focuses on integrating a mechanism that levies the SAF blending quota on the complete itinerary, equally affecting non-European airlines as it is irrespective of legs throughout the itinerary. Other proposed solutions of the aviation industry are international blending quotas on UN level.[48] However, depending on the range of the cost markup, it can be discussed if passengers would switch to a non-European airline to avoid relatively small price increases, knowing it would mean an additional layover. Finally, we assume that CO_2 prices are an important instrument to achieve climate targets. Thus, it is important to consider a scenario including CO_2 prices charged on fossil kerosene. Airlines that make an active decision to use SAF can not only achieve their legally imposed GHG emissions reduction targets, but also feel empowered to reach new green-minded target groups.

Cost distribution mechanisms

As described earlier, the use of SAF will result in a cost markup for airlines compared with a baseline scenario considering only kerosene and CO_2 prices. The absolute cost markup per flight differs for the two scenarios, the airline business model, and the route type (*see Exhibit 15, page 36*) for average cost increase per flight).

EXHIBIT 15

Expected total cost markup of a typical representative flight depending on SAF scenario, business model, and route type



Source: Strategy& analysis

Having a look on the total cost markup per flight the question arises how this affects the ticket and belly cargo prices. The answer depends on the cost distribution mechanism the airline decides to apply. Below, three different mechanisms are calculated and discussed. Here, we assumed that the cost markup is forwarded directly to the customer without reducing the profit margin. The reference year for the calculation is 2035, and we have applied a SAF share of 20% for Scenario 1, or of 32% for Scenario 2.

Ticket price increases resulting from SAF are expected to remain manageable and differ by the applied distribution mechanism

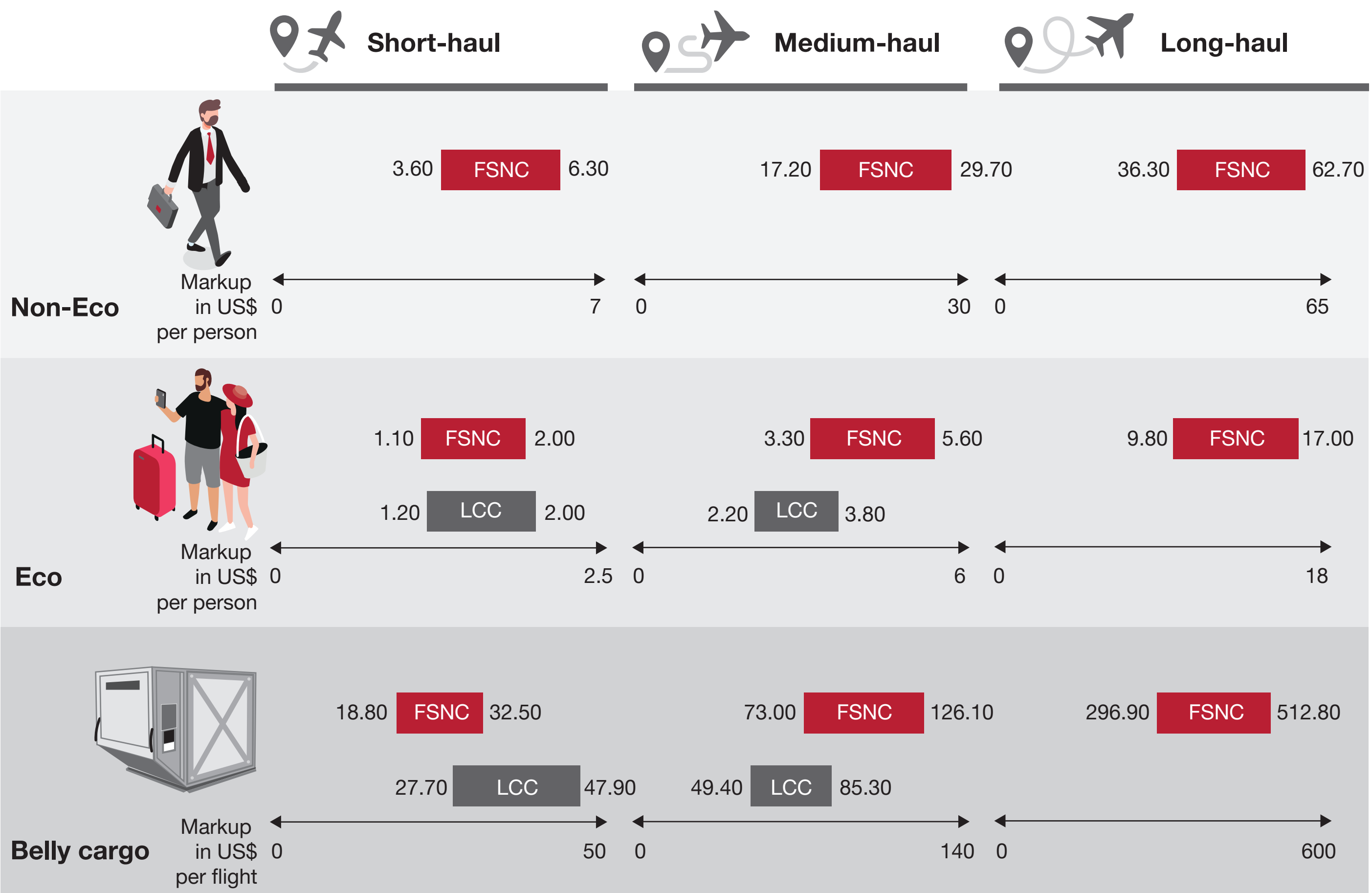
Revenue-based distribution

The first approach is to distribute the cost among passengers and cargo based on their revenue share. The underlying assumption is that non-economy class passengers (first class, business class, and premium economy class) are willing to pay more for their tickets than economy-class passengers. Applying this approach, we see that the ticket price for a non-economy-class passenger would increase by US$3.60 (in Scenario 1) or US$6.30 (in Scenario 2) on an FSNC short-haul flight and by US$36.30 or US$62.70 on an FSNC long-haul flight. The same logic applies to the economy-class passenger. Here the ticket price would increase by US$1.10 or US$2.00 on a FSNC short-haul flight and by US$9.80 or US$17.00 on a FSNC long-haul flight.

The price markup for the belly cargo follows a slightly different approach. Here the total price markup per flight instead of the ticket price per passenger was calculated. Considering the FSNC business model again, the price markup would range between US$18.80 and US$32.50 on an FSNC short-haul flight and between US$296.90 and US$512.80 on an FSNC long-haul flight *(see Exhibit 16)*. If a long-haul flight transported 20 tons of cargo, this would result in a price markup of US$14.80 to US$25.60 per ton.

EXHIBIT 16

Estimated price markup per business model, route type, and customer class, assuming a distribution based on revenue share



Source: Strategy& analysis

Corporate customer distribution

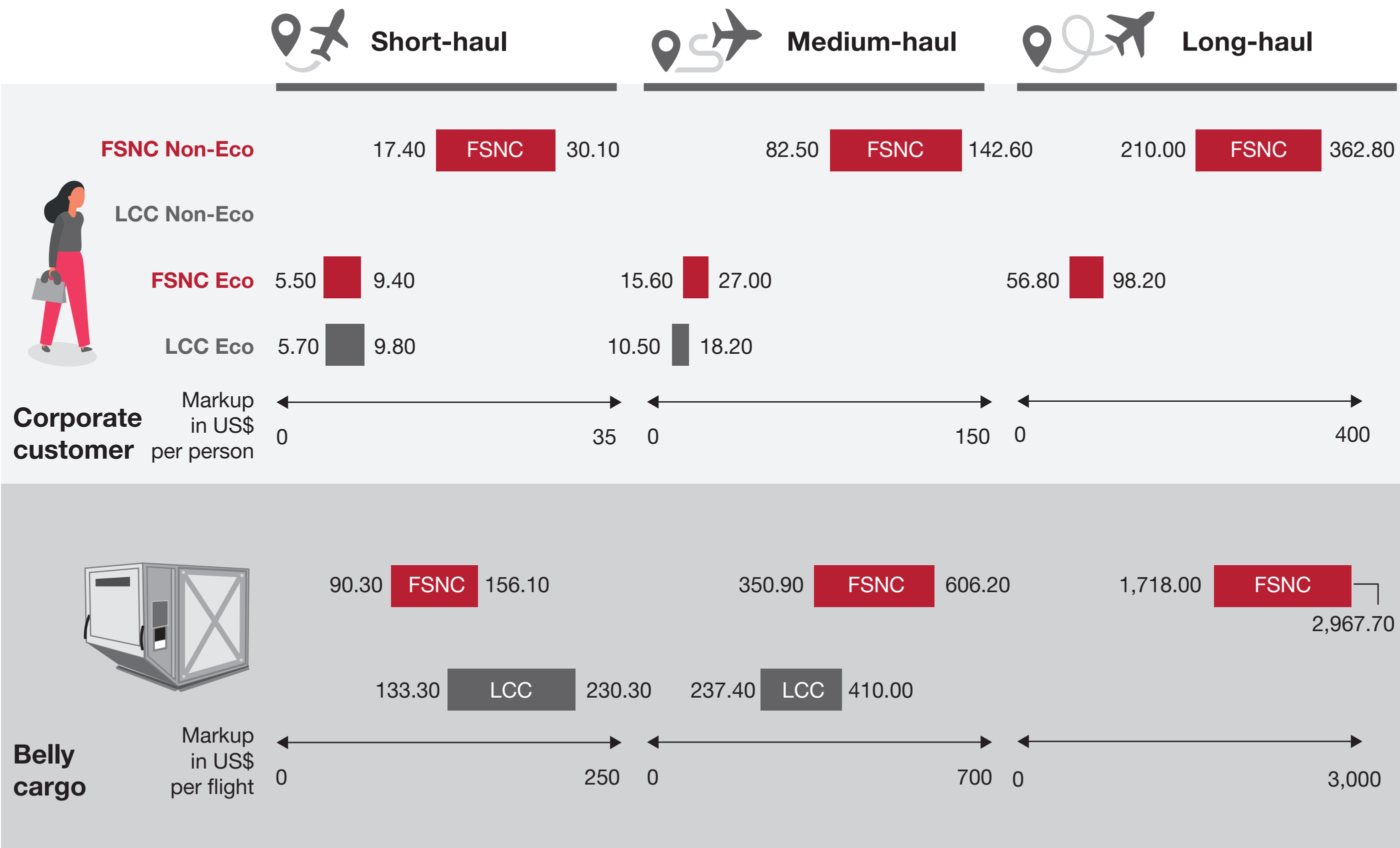
The second approach aims to distribute the whole cost markup to corporate clients, meaning business travelers and cargo clients. Passengers who travel for private reasons will not be charged any extra. Here, the underlying assumption is that companies will have to reduce their GHG emissions. Business travel represents a part of current GHG emissions and is a focal point of public pressure. Thus, corporate customers will have a higher willingness to pay extra for their tickets.

In this discussion, we assume that corporate customers pay 100% of the extra markup. Taking a long-haul FSNC flight as an example again, the price markup for corporate clients differs between non-economy and economy class. The non-economy class markup varies between US$210.00 and US$362.80 depending on the considered scenario; the price markup for the economy class is between US$56.80 and US$98.20. This higher price markup compared with the revenue distribution is explained by the fact that the additional costs per flight are distributed among a smaller group (assumption: 12% of passengers travel for business reasons).

For the belly cargo, we again looked at the whole cargo with a potential price markup of US$1,718.00 to US$2,967.70 per flight (*see Exhibit 17*). If we again assume that a long-haul flight transports 20 tons of cargo, this would be a markup of US$85.90 to US$148.40 per ton.

EXHIBIT 17

Full distribution of cost markup to corporate customers per business model and route type



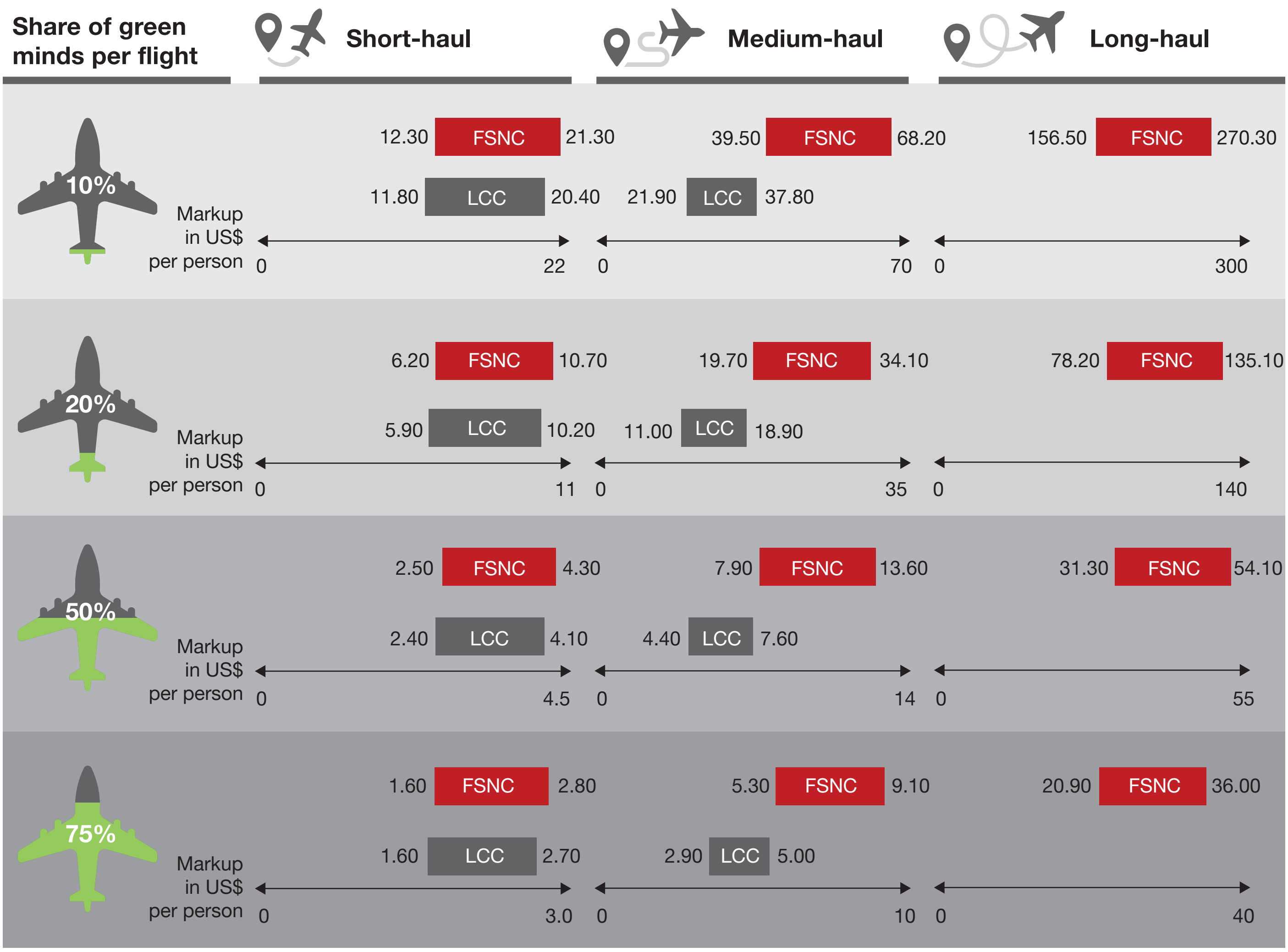
Source: Strategy& analysis

Green minds distribution

The third approach aims to distribute the costs to people with a "green mind," i.e., passengers who actively decide to pay a price markup at the point of sale to travel in a more environmentally friendly way (*see Exhibit 18*). Here, the additional costs are shared only among these green minds, and the remaining people are not charged any extra markup. To evaluate the potential cost distribution, we took a closer look at how the distribution would change if the share of green minds rose (10%, 20%, 50% to 75%). We again considered our example of a long-haul FSNC flight. If the share of green minds is 10%, then the additional markup would be between US$156.50 and US$270.30 per passenger in 2035. However, if the share rises to 75%, then one person would have to pay an extra amount of only US$20.90 to US$36.00. Another example is the LCC short-haul flight. If we assume that only 10% are green minds, the markup would vary between US$11.80 and US$20.40 per passenger. However, if we assume 75% green minds, this markup would drop to only US$1.60 to US$2.70 per passenger.

EXHIBIT 18

Full distribution of cost markup to green minds per business model and route type



Source: Strategy& analysis

Generally, the cost markup for ticket prices can be expected to remain manageable, even in an IEA Net Zero Pathway. Thus, it is reasonable to discuss further increases in the legally required SAF blending mandates as the industry works toward an ambition compliant with the IEA Net Zero Pathway target, or even goes further.

Cost markup allocation

Besides the distribution mechanisms themselves, where should the price premium be allocated? One option is to raise the ticket price itself. The markup would be clearly visible at the beginning of the buying process. Another option is to charge additional services with a price premium. Here the assumption is that the ticket price is the main reason for a customer to decide on an airline, while additional costs such as baggage fees or in-flight meals are of only secondary importance. If only the additional services became more expensive, the customer might be less influenced in his or her buying decision than by a more expensive basic ticket price.

Another option is to charge the cost markup only on selected routes. FSNCs have a highly complex route network. Here, additional costs can be shifted from one route to another. Highly competitive routes would not be charged any premium, while non-competitive routes would be charged a higher markup. Moreover, as corporate customers aim to reduce their GHG emissions, another option would be to charge frequent business routes the extra. To select the routes for price markup, route competition and core customer groups can be decision criteria.

Incentivization to increase willingness to pay

Lastly, the question remains how people who are unwilling to pay any premium could be incentivized to do so. One approach could be to set up a green frequent flyer program. This would mean that people who pay the SAF price markup can collect green miles, giving them a green flyer status and access to additional services such as a “green minds lounge.”

A second approach would be to adapt existing frequent flyer programs so that the collected miles could be used for fueling SAF.

A third approach would be the exchange of booked services for SAF fueling. Here, passengers who have already bought a flight with traditional extras such as luggage or an in-flight meal can exchange these services to fuel SAF.

Finally, and especially appealing for corporate clients, airlines could create a certification program for GHG emissions reduction. Each flight would generate a compensation certificate for travelers, which could be handed out for their records.

Air Cargo – A deep dive

Most of our study has focused on the passenger transport segment of the air traffic market. However, as of 2022, about 30% of all revenues are generated in the cargo segment (it was 14% in 2019).[49] Air cargo, due to both its market size and its inherent dynamics, is of high interest and relevance in the application of SAF fuels. It can be an opaque segment, so we will explore air cargo through the lens of a deep dive.

The air cargo market has undergone a remarkable evolution during the pandemic. The traditional “unloved second child” of many airlines, this business has unexpectedly flourished in the last few years while passenger transport collapsed. Overall cargo shipping volumes have suffered slightly during the pandemic, but perhaps counterintuitively, revenues have soared. With the grounding of many aircraft due to the lack of passengers, belly cargo capacities have vanished from the market. Airfreight forwarders had to rely more heavily on dedicated cargo planes, leading to cost increases of between 100% and 200% per transported kilo and much improved cargo-space utilization (roughly an 80% increase in utilization levels). For the foreseeable future, as geopolitical upheaval continues and same-day-delivery demand rises, we anticipate that these advantageous pricing conditions will prevail.

Air-transported goods are often characterized by high urgency or high price-to-weight ratios. This often correlates with relatively high market prices of such goods. Customers of such products tend to be very interested in the GHG emissions aspect of the supply chain. Many of the companies that serve these customers have begun setting science-based targets (SBT, Scope 3), driving the demand for GHG neutralization and offsetting opportunities along their supply chains. The leading airfreight forwarding companies are all located in Europe[50] and therefore in the center of our

EXHIBIT 19

European SAF cargo programs[1] and trial routes[2]

Cargo SAF Programs

It enables shippers and forwarders to operate flights with a percentage of SAF. Customers determine their level of engagement, ensuring that their entire investment boosts SAF production.

Example

Cargo SAF Program

AIR FRANCE KLM MARTINAIR

Since December 2020
29 Official partners
(five Chinese)

Kühne + Nagel
Airpharm
Ziegler
Best Global Logistics
Bolloré Logistics
Fast Forward Freight
DB Schenker France
Jobmate
Total Touch Fresh Cargo
…

Skyline Express
Airflo
Aramex
Globelink
Bansard International
VCK Logistics
Samer&Co. Shipping
Grupo Ferva Delivery
Enviroteiner
…

Cargo Route SAF Supplied

Since April 2021 Lufthansa Cargo and DB Schenker run a weekly cargo flight to China operating on SAF and matching SAF requirements.

This cooperation has saved 31,000 tons of CO_2e since starting their cooperation in November 2020.

1 Air France KLM Group (2020): Air France KLM Martinair Cargo Launches World's First SAF Programme for the Airfreight Industry: Retrieved from: https://www.airfranceklm.com/en/air-france-klm-martinair-cargo-launches-worlds-first-saf-programme-airfreight-industry,
DB Schenker (2020): Together for climate protection: Lufthansa Cargo and DB Schenker start first CO2-neutral freight flights. Retrieved from: https://www.dbschenker.com/lu-en/about/press/corporate-news/co2-neutral-freight-flights-670370
2 argus (2021): Lufthansa to run weekly SAF cargo route to China. Retrieved from: https://www.argusmedia.com/en/news/2201590-lufthansa-to-run-weekly-saf-cargo-route-to-china
Source: Strategy& analysis

study scope. For example, DHL Express alone has contracted 13% of all SAF offtake agreements in 2022.[51] Numerous examples of existing European SAF cargo programs and trial routes are shown in *Exhibit 19, page 41*.

Thus, the air cargo market is of high interest from the SAF utilization perspective. First, the increased cost of blended SAF under current market conditions represents only a small increase in comparison with the overall fluctuations that are witnessed in a low-supply market. Second, the demand side favors GHG emissions reduction measures and is expected to represent a considerable willingness to pay, if appropriate book and claim mechanics are in place.

Cargo SAF price calculation and conclusions

To estimate the concrete cost impact of a full application of 100% SAF for air cargo, we first analyzed the total amount of kerosene burned for cargo.

We calculated the kerosene amount of the European air freight market based on the assumption that it accounts for around 22%[52] of the globally transported cargo ton kilometers (about 160,000 million CTK)[53] in 2021. Thus, the European air freight market generated approximately 36,000 million CTK in 2020. The average prices for air cargo have risen to about US$5.20/kg. Based on the average kerosene consumption of 216g/CTK[54], the European air freight market accounts for a total of 8.2 million tons of kerosene that could be replaced by SAF. In the European context, this is a substantial amount, representing about 1% of yearly (2019) overall GHG emissions.

Next, we calculated the markup of SAF if air cargo companies were to run their flights with 100% SAF. Airlines usually operate with a fuel surcharge in their cargo pricing. Owing to recent volatility in the oil market these prices have risen from about US$1.20/kg to US$1.40/kg.[55] These surcharges are independent of route origin or length. They are currently expected to rise above US$2.10 and then to drop.[56] According to our SAF cost analysis, a 100% substitution of SAF for kerosene would result in a markup of 68% (in 2025) per liter of fuel. This would increase the fuel surcharge of air cargo from its current US$1.40/kg to US$2.40/kg, which is close to some of the earlier stated price predictions. That means that the overall price per transported kilogram will increase from US$6.60/kg to US$7.60/kg, or by 15.1%.

Our calculations show that the air cargo segment not only is interesting for SAF from a pricing point of view but also has substantial potential for fuel substitution. It is therefore possible for air cargo to remain at the forefront of this transformation. From a pricing perspective, we observe higher volatility in overall cargo prices than what the 15.1% cost increase of SAF fuel would add. Considering that we see evidence that air cargo customers possess a high willingness to pay for GHG emissions reduction measures such as SAF, we conclude that the argument for an environmentally transformative air cargo industry is compelling.

The overall price per transported kilogram will increase from US$6.60/kg to US$7.60/kg, or by 15.1% when fueling 100% SAF.

Sensitivity analysis

The SAF market is still evolving. Thus, it is interesting to evaluate how the cost markup would change, if underlying assumptions would be adapted. Within our analysis, we made three main assumptions:

First, we assumed that the cost of fossil kerosene will increase, especially due to rising CO_2 prices in line with the IEA Sustainable Development Scenario. Although this is a reasonable assumption as policymakers around the globe are pushed to act, it is not a certainty.

Second, we assumed that the SAF share will develop according to either the EU Quota Pathway (Scenario 1) or the IEA Net Zero Pathway (Scenario 2). As even Scenario 2—although reaching the Paris Agreement goals—still assumes a 25% level of fossil kerosene use in 2050, some parties are pushing for 100% SAF use by airlines by 2050 to eliminate at least the direct fossil CO_2 emissions.

Third, we assumed that the cheapest SAF, based on the HEFA route, will be used as much as possible, even considering quantities of non-European origin. Although this is economically reasonable, there might be a chance that—due to, e.g., feedstock competition or regulatory changes—less HEFA feedstock will be available and more PtL will need to be added to meet the demand.

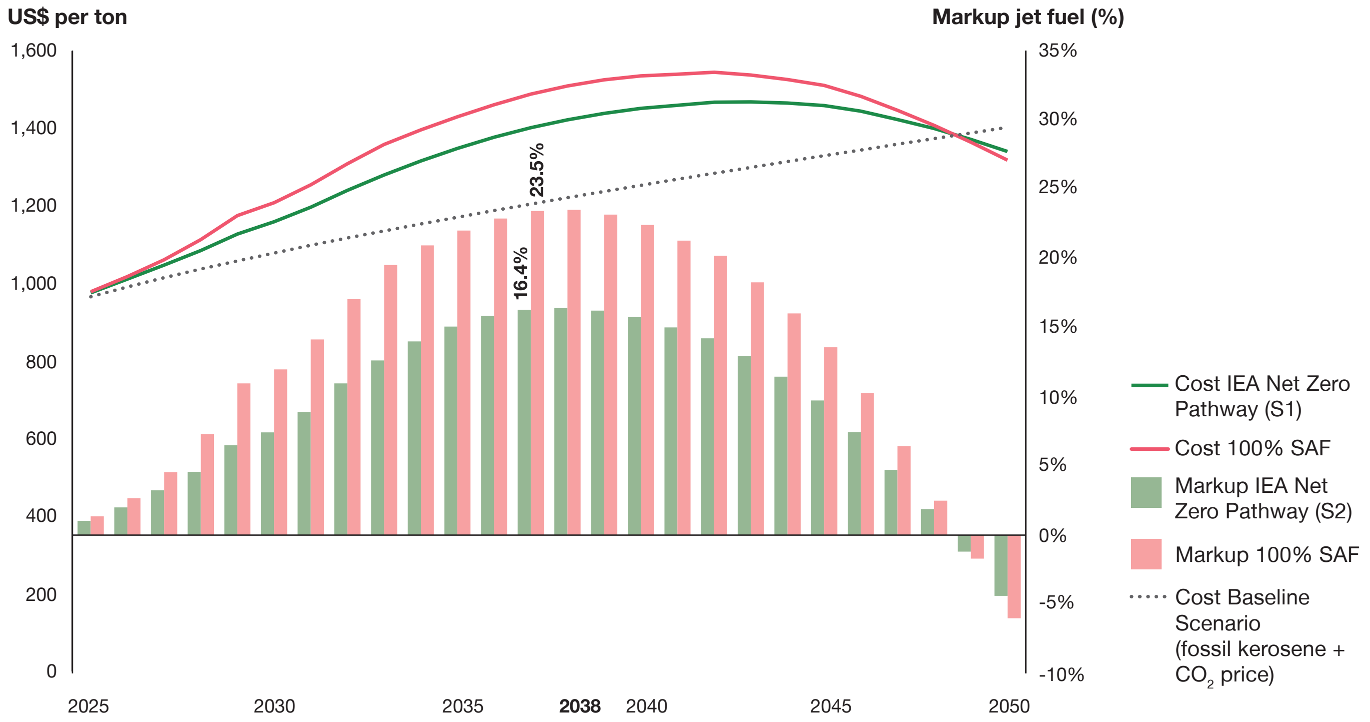
To understand the impact of unexpected but possible developments, we undertook a analysis with three changing variables:

100% SAF

The IEA Net Zero Pathway assumes that in aviation, due to its classification as a hard-to-abate-sector, a SAF share of 75% is needed in 2050. Other sectors may need to reduce their emissions dramatically or even achieve negative emissions. However, considering Europe's advancements in aviation and the high number of current SAF projects, it can be assumed that Europe will take on a pioneering role by striving for even higher SAF shares. Thus, it is also conceivable that the aviation sector will increase its GHG emissions reduction efforts by aiming to fly with 100% SAF. Here, we assume a 100% admixture in 2050 and that additionally required SAF volumes will be provided by PtL, once the feedstock potentials of HEFA and ABtL are exhausted. *Exhibit 20, page 44* shows that in the case of a 100% SAF scenario, the cost markup compared with fossil kerosene would peak at 23.5% in 2038 compared with 16.4% in the IEA Net Zero Pathway.

EXHIBIT 20

Comparison of IEA Net Zero Pathway with a 100% SAF scenario



	FSNC, short-haul–average cost markup	FSNC, short-haul–relative cost markup	FSNC, long-haul–average cost markup	FSNC, long-haul–relative cost markup
IEA Net Zero 2038	US$3/ passenger	2%	US$36/ passenger	6%
100% SAF 2038	US$5/ passenger	3%	US$51/ passenger	9%

Source: Strategy& analysis

Based on this analysis, we conclude that for a 100% SAF share, additional SAF fuel costs and costs per passenger will not rise significantly. This suggests that the EU can further extend its global pioneering role in climate protection by setting even higher SAF quotas.

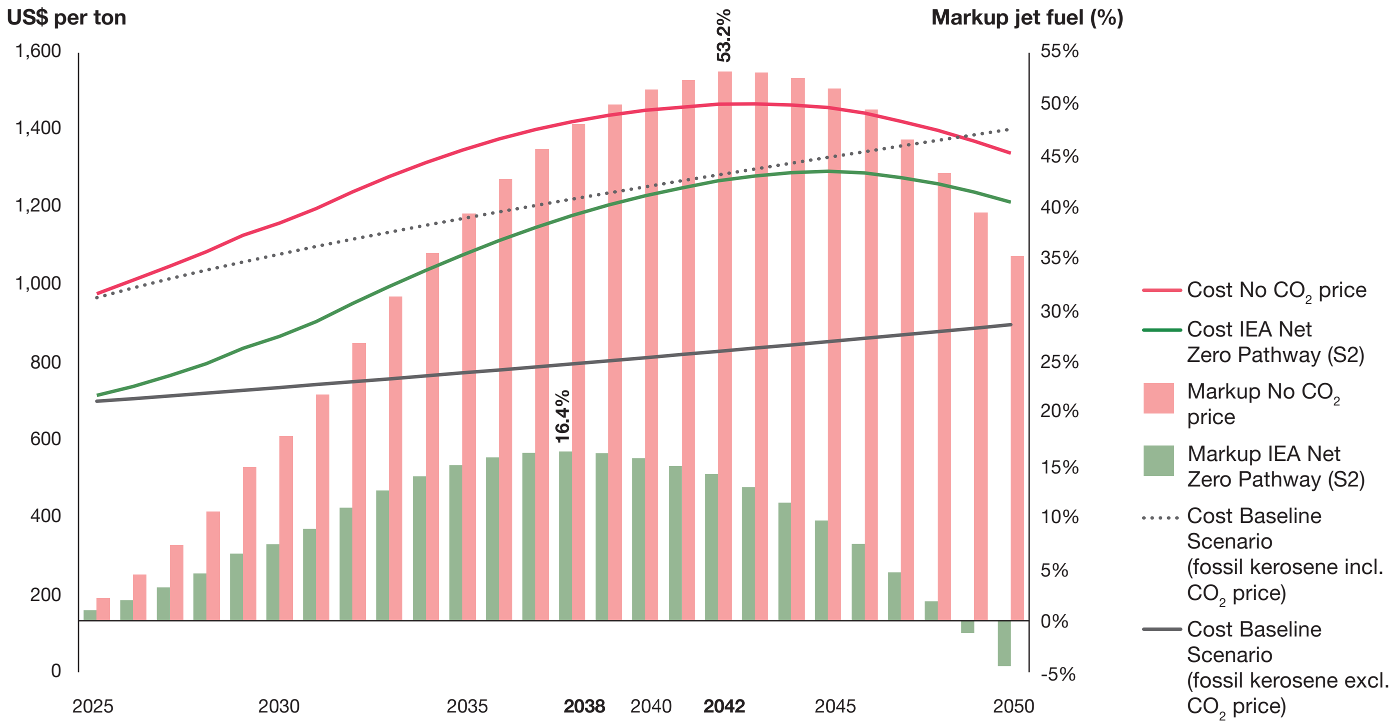
No CO_2 prices

We evaluated how the cost markup would change if no CO_2 prices were charged at all. *Exhibit 21, page 45* shows that in this case, both the kerosene baseline and the SAF cost line could change. As a result, the peak of the cost markup will be reached four years later and will increase significantly, by 53.2%, compared with 16.4% in the IEA Net Zero Pathway.

The sensitivity analysis shows that omitting the CO_2 price has the largest impact among our analyses on the cost markup created by SAF. This supports the importance of a (preferably global) CO_2 price to make climate-friendly alternatives to fossil fuels more competitive.

EXHIBIT 21

Comparison of IEA Net Zero Pathway with a scenario assuming no CO_2 prices



	FSNC, short-haul–average cost markup	FSNC, short-haul–relative cost markup	FSNC, long-haul–average cost markup	FSNC, long-haul–relative cost markup
IEA Net Zero 2038	US$3/ passenger	2%	US$36/ passenger	6%
No CO_2 price 2042	US$10/ passenger	7%	US$113/ passenger	20%

Source: Strategy& analysis

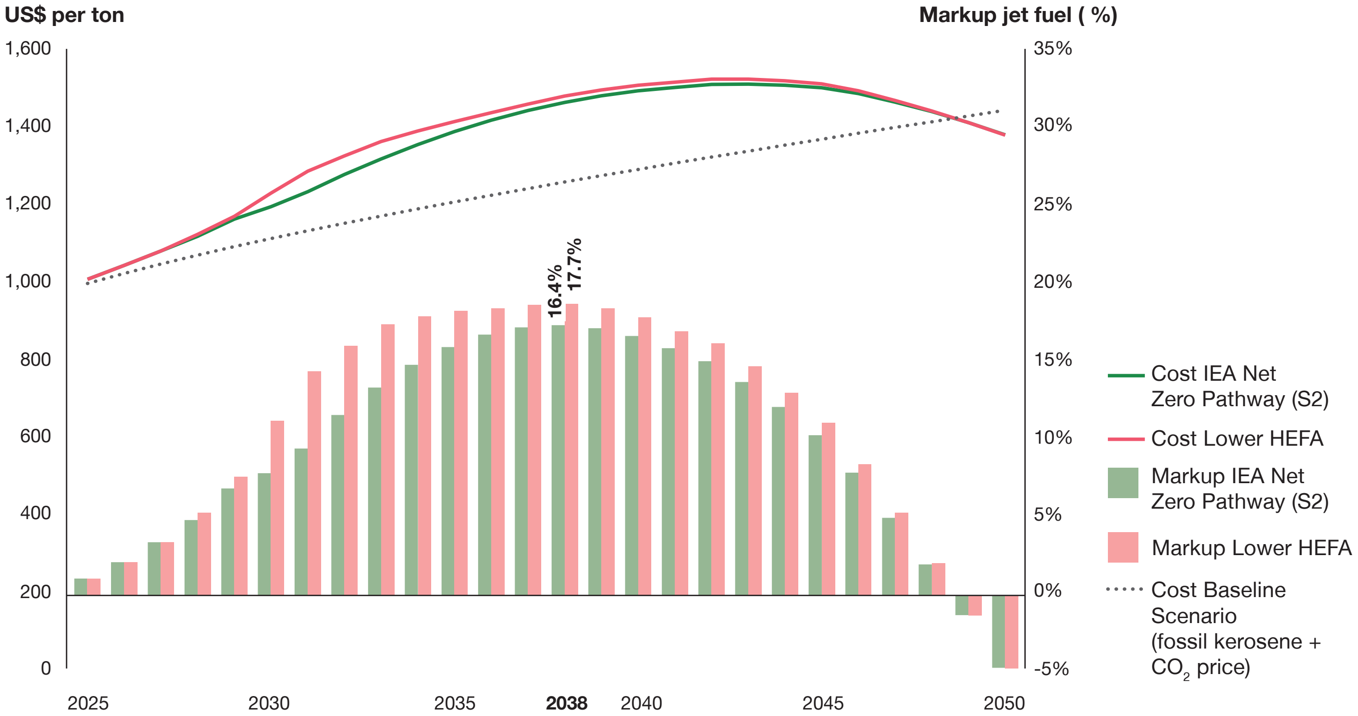
Moreover, such high cost markups underline the economic and environmental importance of continuously developing more fuel-efficient and hydrogen- or electric-powered aircraft.

Lower HEFA share

Finally, within our analysis we assumed that for Europe the available amount of SAF produced by the HEFA pathway is capped at 7 million tons per year. However, considering cross-sector competition, it is also interesting to evaluate how the cost markup would change if the amount were capped at 3.5 million tons produced via the HEFA pathway. *Exhibit 22, page 46* shows that the cost markup will not differ significantly from that of the IEA Net Zero Pathway. Within this evaluation, the lower HEFA-produced SAF quantities will be offset by additional ABtL and PtL quantities.

EXHIBIT 22

Comparison of IEA Net Zero Pathway with a scenario with a lower HEFA-produced share



	FSNC, short-haul–average cost markup	FSNC, short-haul–relative cost markup	FSNC, long-haul–average cost markup	FSNC, long-haul–relative cost markup
IEA Net Zero 2038	US$3/ passenger	2%	US$36/ passenger	6%
Lower HEFA share	US$4/ passenger	3%	US$39/ passenger	7%

Source: Strategy& analysis

Based on these results, we conclude that it makes absolute economic sense to exploit any available feedstock potential—if the defined sustainability requirements are met. Even when we consider reduced feedstock for the HEFA conversion pathway, the expected resulting cost markup from using more expensive pathways will not be significant.

SECTION 7

General uncertainties

The broad acceptance and utilization of SAF in aviation is possible and, as we have shown, also probably practicable for the industry. Several issues and challenges still need to be managed and overcome. Some of these challenges, however, are external and are manifested in uncertainties. These uncertainties need to be monitored for both positive and negative impacts on the industrialization and market acceptance of SAF.

Macroeconomic shocks

The aviation and fuel industries are highly affected by macroeconomic factors. Consequently, they are vulnerable to macroeconomic shocks, as recent global crises have shown. A prominent example is the ongoing COVID-19 pandemic. International travel restrictions and restrictive health measures led to one of the sharpest declines in demand in the history of the airline industry (a 66% decline in global RPKs [revenue passenger kilometers] in 2020[57]).

In reaction to this demand crisis and to compensate for financial losses, the industry has undertaken unprecedented cost-saving measures. In the future, similar crises might result in a reduction of costly R&D spending. Especially considering the not immediately obvious economic benefits of SAFs, cost-saving measures might inhibit their development and market introduction.

Nevertheless, recent years have shown that crises also bring new opportunities. We witnessed how airlines took the step of renewing their fleets to leverage the better fuel economics of newer aircraft models. This had positive implications for the environment in general and for the use of SAFs specifically, as newer aircraft can fly with much higher SAF blends.

Additional macroeconomic influences include global conflicts and the resulting political measures and restrictions. Conflicts and sanctions imposed on oil-supplying countries can lead to a shortage of jet fuel and a sharp rise in prices. For this reason, there is a growing need for energy and geographic diversification of production and feedstocks. This can be enabled by SAF whose feedstocks possibly originate from a greater variety of countries and regions.

As with the supply dependency considerations of typical oil states, there are also potential limitations on raw materials for SAF, e.g., due to crises in agricultural countries, which must be considered as a limitation of our study results. To ensure supply security, the expected production volumes, and storage might be hedged by longer term and diversified supply contracts.

Worldwide sustainability trends

The application of SAFs to air travel varies greatly, both in Europe and worldwide. Differences in prosperity, environmental attitudes, demographic structures, and public trust all play significant roles in limiting the local applications of the general conclusions of this study.

For instance, growing prosperity in developing countries is leading to market growth for the aviation industry. In this rebalancing of global aviation market revenues, developing countries attend to be particularly cost-conscious. In some regions, older aircraft models without adequate technical capability to fly with high SAF blends tend to be deployed first.

Furthermore, national political attitudes toward the reduction of GHG emissions differ. Some regions have a significantly smaller green-minded population demanding and actively supporting sustainable fuel alternatives. So, adoption will be slower in some regional markets than in others.

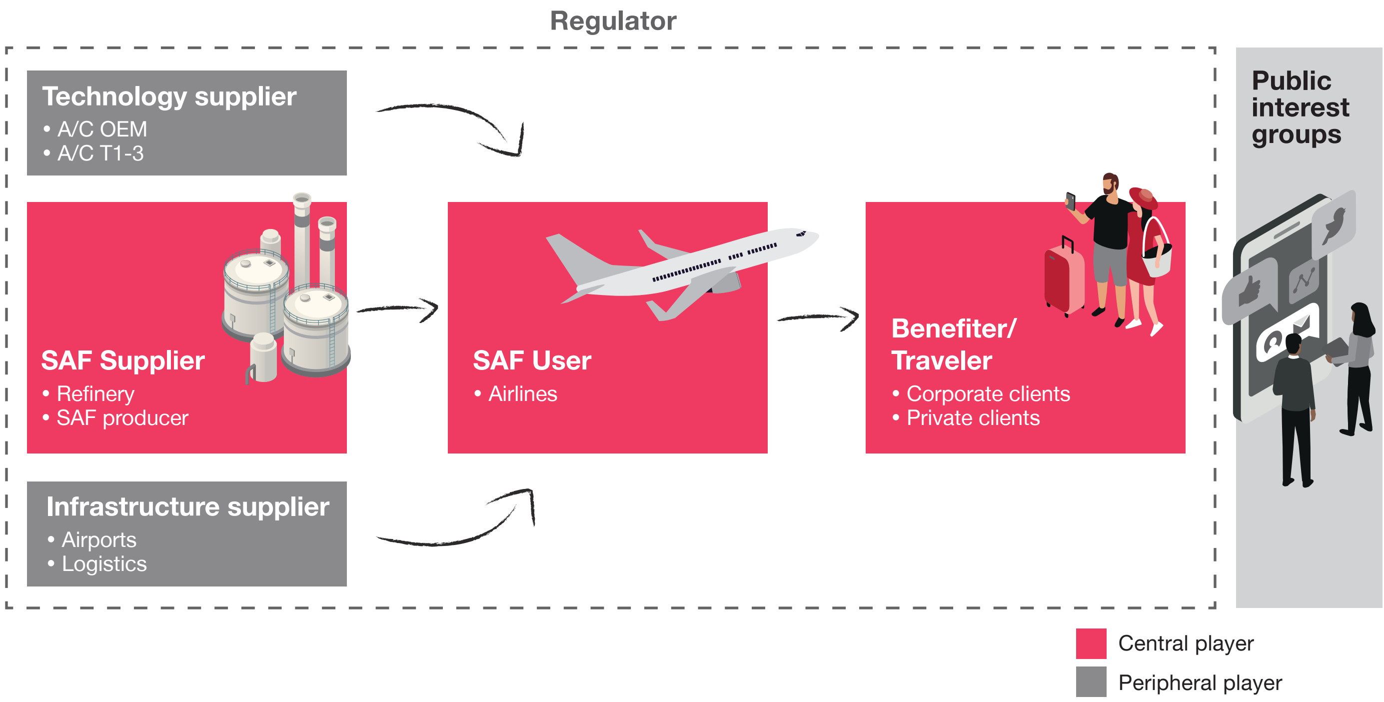
Another trend that can be observed is an increasing modal shift towards trains, especially for short-haul travel, to benefit the environment. If this trend continues, short-haul flights and particularly LCC short-haul flights will lose revenues. This could lead to either a more aggressive adoption of SAFs by the LCCs to counter the modal shift or LCCs having to modify their business model.

Finally, if SAF's benefits for the environment become so widely accepted that people again increase their appetite for air travel, the aviation industry might witness a rebound effect. The resulting total increase in flights could not be offset via GHG emissions savings from SAFs. The overall net emissions impact would increase.

Ecosystem player action list

Our study analyzes the economic effect that the mass utilization of SAF will have and provides evidence that the overall cost impact of SAF will remain manageable. However, the ecosystem players (*see Exhibit 23*) are all affected differently, resulting in a diverse set of challenges and opportunities that must be strategically addressed. We can foresee the following strategic actions for key players in the SAF ecosystem.

EXHIBIT 23
SAF ecosystem players



Source: Strategy& analysis

Fuel producers

Fuel producers are crucial for SAF's market ramp-up, as they already produce the kerosene for aviation and can also produce SAF on a large scale in the future.

Decide on your SAF strategy based on your portfolio	On the one hand, fuel producers must comply with European and national blending mandates to avoid penalties. On the other hand, the voluntary market offers them further options for selling SAF volumes. This gives these players the advantage of knowing that a certain purchase of SAF volumes is guaranteed. For this reason, fuel producers should develop a SAF strategy based on their portfolio. This can consist of producing initial SAF volumes via co-processing, converting parts of an existing refinery to SAF, or building completely new SAF refineries. In addition, they could purchase produced SAF volumes and bring them to market.
Develop a market for SAF fuels	The market for SAF will differ from the conventional kerosene market, and fuel producers should prepare for this early on. Kerosene production has an exchange-traded price for crude oil and well-established production processes, but the production processes and feedstock options for SAF are currently developed. Here, it is important to identify promising options at an early stage and to build up production capacities to establish a future-proof business model. Initially higher investment costs can be reduced through economies of scale, learning effects, and potential subsidies. Furthermore, it might be advisable to push for common regulations across Europe and initiate transparent pricing regimes so that produced fuel can be sold into a common market.
Build strategic alliances to ensure a fully functioning supply chain	The supply chains for SAF should be rethought and reshaped by the fuel producers so they can benefit from new business models. To secure the purchase of SAF volumes, it is crucial to conclude long-term contracts and build new strategic alliances. This also includes collaboration or mergers with innovation drivers that can complement the traditional companies with original procedures or processes.

"To meet the growing demand for SAF, the necessary production capacities must be drastically increased. Here, especially kerosene producers are relevant. By adding different types of SAF to their portfolio they are not only improving their own sustainability but also the resilience of their business model."

Dirk Niemeier, PwC Strategy& Germany,
Green Hydrogen and Alternative Fuels Leader

Airlines

Airlines are crucial for SAF's market ramp-up because they purchase the fuels for the flights they operate, use them in their aircraft, and market their utilization to passengers and cargo customers.

Decide on your decarbonization strategy and the role of SAF within it	Airlines must decide whether to use only the amount of SAF required by law or to take a frontrunner/early adopter position by using a higher percentage of SAF. The trend towards sustainability and climate-friendly travelling offers the opportunity to attract new passengers by using SAF. Customers might see that as a decisive differentiator from other airlines in today's competitive market. This can lead to an enormous gain in reputation for an early adopter airline. Moreover, it is likely that CO_2 pricing will be increased in the medium term, leading to higher prices for fossil kerosene. Using more SAF than is currently legally required can help airlines to implement measures early on that will be necessary in the future. However, there is a risk of losing market share on routes to destinations that can be served by non-European airlines that have no SAF blending mandates and whose fuel costs are lower. Consequently, it is crucial to conclude contracts for SAF volumes at an early stage so that cost increases can be managed.
Establish mechanisms to deal with the additional costs of SAF	Regardless of what quantities of SAF they use, airlines must decide whether and how to distribute the resulting additional costs. Due to the increasingly green-minded behavior of passengers and the expected resulting willingness to pay, the additional costs of SAF should be communicated to customers as transparently as possible. Here it is especially important to clarify what climate protection effect the usage of SAF offers. To involve customers in the best possible way, booking processes and the right strategic branding should be established at an early stage. With Paris Agreement–aligned measures, airlines can gain access to "green capital" from financial institutions improving their financial position. Generally, financial institutions can attach importance to the companies they finance in having credible climate strategies, so it is prudent to be prepared.

Aircraft original equipment manufacturers (OEMs)

Aircraft OEMs play an important role in SAF's market ramp-up because they contribute to making SAF safely usable in the existing aircraft fleets as well as in newly built aircraft.

Identify and develop business opportunities in an evolving SAF ecosystem

SAF enables a more sustainable operation of existing and future fuel-powered aircraft models. Thus, the promotion of SAF can be favorable for the development of a future-proof business model for aircraft OEMs. To enter the SAF market as a SAF trader can increase their presence in the aftersales market and generate a wide range of business opportunities. For example, aircraft OEMs can bundle their aircraft sales together with guaranteed SAF volumes or certificates, or they can offer SAF-powered flights in a subscription model. In addition, they should ensure that their overall strategy is consistent with the development of alternatives to SAF (hydrogen- or electric-powered flights). By engaging in this area, aircraft OEMs are also demonstrating that flying, and thus their business model, can have a climate-friendly future.

Regulators

Regulators are crucial for SAF market ramp-up because the regulatory framework they create has an enormous impact on SAF production and demand.

Establish a SAF certificate system

A certificate system which enables the decoupling of physical SAF quantities and crediting via book and claim, can have an important impact on the development of the SAF market. Regulators at all levels should advocate for this introduction so that SAF enters the market as cost-efficiently as possible for both producers and airlines and that willingness to pay for GHG reduction is used in the best possible way.

Set more ambitious SAF blending quotas that are net zero-aligned and do not distort competition

As shown in the study, the proposed EU fuel quotas are not sufficient to achieve a Paris Agreement–aligned climate target. To ensure the purchase of further SAF volumes, one option would be to increase the fuel blending mandates. We showed in the analysis that even following the IEA Net Zero Pathway the cost markup for airlines and airline passengers might not be as significant as one assumes. However, there can be the risk of a competitive disadvantage for European airlines. Here, it is important to design SAF blending quotas thoughtfully, e.g. by integrating a mechanism that levies the SAF blending quota on the complete itinerary, hindering competitive distortion.

Compensate the first-mover disadvantage

There is a danger that fuel-producing companies will refrain from investing as they fear that second-mover companies will benefit from lower capital expenditures. Therefore, they will be able to produce SAF at lower costs, which can result in a competitive advantage compared to first-mover companies. Governments have several ways to offset the first-mover disadvantages resulting from those initially higher investment costs. Options include investment or operational expenditure subsidies, carbon contracts for difference, or tax benefits. Moreover, as the analysis shows, CO_2 prices are important measures to support the SAF market development.

Capital providers

Capital providers are crucial for SAF market ramp-up because the steering of financial flows to Paris Agreement–aligned business activities has a major impact on which projects and companies are financed.

Bundle and support airline investments for SAF ramp-up	Capital providers must disclose what proportion of their investments and loans are sustainable, which is leading them to aggressively increase ESG requirements for the companies they finance. In addition, the European Central Bank requires banks to consider ESG risks in their risk models. The production and use of SAF offers new green assets that can be financed by financial institutions, which is why they can also find a future-proof business field here.

Corporate and cargo customers

Corporate customers are crucial for SAF market ramp-up as they must decide on their willingness to pay for sustainable flying, which ultimately finances SAF.

Embed SAF in corporate and ESG strategy	The use of SAF-powered flights for business travel or the transport of goods can be a distinguishing feature for companies and offer competitive advantages. To this end, corporate brands should position themselves on ESG and communicate this transparently. A clear climate strategy can attract new customers and employees, as well as financing.
Explore options to reimburse or forward SAF costs	Airline customers should also make it clear to their customers what climate protection effect is associated with the additional costs caused by SAF. Customers can then be given the option of using SAF quantities by making a voluntary additional payment, or the company can purchase certain SAF quantities and pass along those charges.

Private customers

Private customers are crucial for SAF's market ramp-up because they account for the largest share of airline customers (88%) and will also have to carry the end costs for SAF.

It can be assumed that private airline customers will increase their awareness towards sustainable travel and, thus, their willingness to pay for green flying (see "Green minds distribution" section). SAF can give them an option for flying with lower emissions in the future. In addition, it is to be expected that other price influences, such as rising kerosene costs, will generally have a significantly stronger impact on ticket prices than the increasing use of SAF.

CONCLUSION

Embedded in the interplay of reduction measures and aviation technologies, sustainable aviation fuels play an integral role in reducing GHG emissions in aviation. Although all key players in the industry are aware of the great environmental benefits of SAF, higher production cost lead to insecurities about potential financial implications and hinder implementation.

Our study shows that even high SAF fuel shares are not expected to lead to significantly higher costs than a continued reliance on fossil-based kerosene. In times of accelerating climate change we must realize that SAF offers a tremendous chance to enable flying in the future, and it's our responsibility to act. Besides building awareness for our own environmental and social responsibility, we must also understand that the world we are living in is changing. Regulations, financial markets, and customer needs will adapt and put even more pressure on the need for environmentally friendly behavior. With CO_2 prices being an important instrument, kerosene in general is likely to become more expensive; thus, the cost markup for SAF remains comparatively low. This will make SAF and the functioning of the evolving ecosystem around it even more important. With all the opportunities and challenges that will arise, it is on us all to shape this evolving ecosystem, to stake out our ground in it, and to create a more environmentally friendly future for aviation.

GLOSSARY

Advanced Biomass to Liquids (ABtL): A SAF conversion pathway comprising the transformation of biomass into biofuels using the technological processes of Fischer-Tropsch (FT) and alcohol to jet (AtJ).

Belly Cargo: An aviation term used to describe the freight stored underneath the main deck of the aircraft.

Cargo Ton Kilometers (CTK): One CTK is one metric ton of revenue load, carried one kilometer (including unaccompanied baggage and mail). The sum of all CTK for every segment flown by every aircraft over a specific period is the CTK of an airline over that period.

Cellulosic Cover Crops: Grasses, legumes, or small grains that are grown between regular cash crop growing seasons to reduce soil erosion, improve soil organic matter, and conserve soil moisture by increasing the amount of residue on the soil surface.

Cost of Available Seat Kilometer (CASK): An indicator designed to measure the efficiency of an airline. It expresses the unit cost to operate every single available seat per kilometer. The lower the CASK, the more profitable and efficient the airline.

Cracking: A process in petroleum refining by which heavy hydrocarbon molecules are broken up into lighter molecules.

Ethanol: An organic chemical compound produced by the fermentation of sugars or via petrochemical processes. Also called ethyl alcohol, grain alcohol, or alcohol, it is a fuel source.

Full-Service Network Carrier (FSNC): An airline business model that focuses on network profitability and often operates in a hub-and-spoke system. Having different aircraft types in their fleet, FSNCs offer a worldwide network of regularly scheduled services in cooperation with other network carriers based on service standards.

Hydroprocessed Esters and Fatty Acids (HEFA): A conversion pathway that processes vegetable oils, waste, and residue lipids with hydrogen to create SAF.

Hydrotreating: A range of catalytic processes including hydrotreating and hydrocracking for removal of sulfur, oxygen, nitrogen, and metals.

Indirect Land Use Change (ILUC): A negative effect that increasing demand for biofuel feedstock can have on agriculture. This can lead to land expansion and deforestation elsewhere, with a subsequent increase in emissions.

Isobutanol: A chemical used for producing antioxidants, paint solvents, flavors, and synthetic rubber. It can also be used as a fuel additive to improve fuel quality.

Isomerization: Process in which a molecule is transformed into another molecule with a different chemical length structure.

Lignocellulosic Biomass: Plant or plant-based material that is not used for food or feed and mainly includes agricultural residues, energy crops, and forestry residues.

Low-Cost Carrier (LCC): An airline business model that focuses on route profitability and often operates with point-to-point networks. Usually operating only one aircraft type, LCCs often offer short- to medium-haul flights at lower ticket prices thanks to minimizing operating costs and reducing the services included in the ticket fare.

Methanol: A wood alcohol with the simplest chemical alcohol structure. It is used as a solvent, motor fuel, ethanol denaturant, and feedstock for manufacturing other chemicals. Methanol is miscible with water and with almost every other organic solvent. It is colorless, volatile, flammable, and poisonous.

Oligomerization: Conversion of a monomer (a molecule that can be bonded to other identical molecules) or a mixture of monomers into an oligomer (a molecule that consists of a few similar or identical repeating units).

Offtake Agreement: It refers to an arrangement where a buyer and a manufacturer decide to trade specific portions of the products that the manufacturer will produce in the future. Offtake agreements are used for project financing acquisition and to ensure a positive revenue stream throughout a project.

PAX: Abbreviation for passengers transported by an airline.

Power to Liquids (PtL): A SAF conversion pathway that converts green hydrogen and green CO_2 into jet fuel and other hydrocarbon products with either the Fischer-Tropsch (FT) synthesis or the methanol synthesis.

Revenue Passenger Kilometer (RPK): An indicator used by the aviation industry referring to the revenue generated by a passenger who is carried one kilometer. One RPK means that one passenger is carried one kilometer, and it is calculated as the number of revenue passengers multiplied by the total distance traveled.

Scope 1 to 3: The Greenhouse Gas (GHG) Protocol categorizes greenhouse gas emissions emitted by a company into three 'Scopes'. Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the generation of purchased energy for the company's activities. Scope 3 includes all other indirect emissions that occur in a company's value chain (upstream and downstream).[58]

Seat Load Factor (SLF): An indicator used in the airline industry that measures the percentage of available seating capacity occupied by passengers. A high SLF indicates that an airline has sold most of its available seats, a sign of a high occupancy efficiency.

Short-, medium-, and long-haul: A categorization of commercial flights based on their length. Short-haul routes are shorter than 1,000 km, long-haul are longer than 5,000 km, and medium-haul are in between.

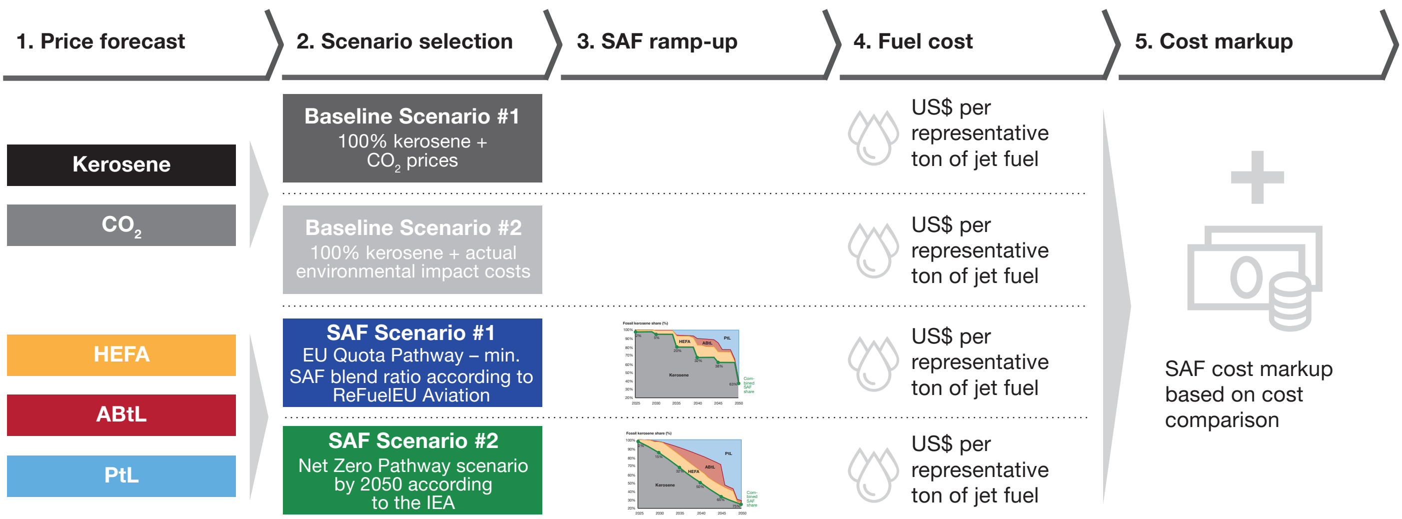
Sustainable Aviation Fuel (SAF): A non-conventional (non-fossil-derived) aviation fuel that is produced from sustainable feedstocks and has almost identical chemical and physical characteristics to conventional jet fuel. It can be safely mixed with conventional jet fuel to varying degrees.

Syngas: Mixture comprising carbon monoxide, carbon dioxide, and hydrogen.

Methodology

To evaluate the impact of different SAF ramp-up scenarios for the European aviation sector up to the year 2050, we conducted a comprehensive scenario analysis (*see Exhibit 24*).

EXHIBIT 24
Study methodology steps



Source: Strategy& analysis

1. Price Forecast

To calculate the cost markup of SAF-blended jet fuel in comparison to fossil-based jet fuel, we needed to identify the underlying cost structures. We used a meta-analysis approach to determine the price forecast for fossil-based kerosene, for the CO_2 price per ton, and the costs for the different SAF conversion pathways. The underlying assumptions were set using a multi-stakeholder input based on existing SAF publications,[59] several expert interviews, and internal expertise.

2. Scenario Selection

We identified the baseline scenario. Here we assumed that only fossil-based fuel and no SAF was used. We also assumed that in the future, CO_2 prices would be charged on fossil fuel. Thus, the baseline cost consists of the cost of fossil-based kerosene and CO_2 prices. Besides this first baseline scenario, which was applied for the markup calculations, a second baseline scenario was determined. This scenario considered the kerosene costs and the actual environmental impact costs and was used to calculate the time point when cost parity would be achieved.

After evaluating the baseline scenarios, we chose two SAF scenarios: Scenario 1 ("the EU Quota Pathway") represented the minimum required SAF scenario. This means that the amount of SAF was determined by the stipulated minimum SAF blend ratio according to the draft of the ReFuelEU Aviation directive.[60] Scenario 2, conversely, represented the maximum required SAF scenario. Here the amount of SAF was determined by what was required to achieve the IEA Net Zero Pathway by 2050.[61] The underlying total kerosene demand, which is the same for each scenario, was deduced from the annual flight demand growth rate forecast of 1.2% for the European domestic and outbound market.[62] Combined with a yearly 0.7% in efficiency gains[63], a CAGR of 0.5% was applied on a 2019 fuel demand baseline.

Remark: Initially, we intended to evaluate a third SAF scenario taking airline announcements into consideration. As a basis, the report of Destination 2050[64] was chosen. However, during the analysis it became apparent that in case of a greater jet fuel demand than forecasted by the Destination 2050 team, more SAF would be required. Consequently, the resulting SAF share would be below the ReFuelEU Aviation mandates. Thus, this scenario was not included in the further detailed analysis.

3. SAF ramp-up

Based on the respective SAF scenarios, we developed a realistic ramp-up for each SAF pathway up to 2050. Here, we considered the respective cost range and capacity limits of HEFA and ABtL in order to set realistic assumptions for the ramp-up.

4. Fuel cost

In the next step, we used these ramp-up scenarios as the basis for calculating the cost of a representative ton of SAF-blended kerosene. This ton was calculated for both scenarios for the time span to 2050.

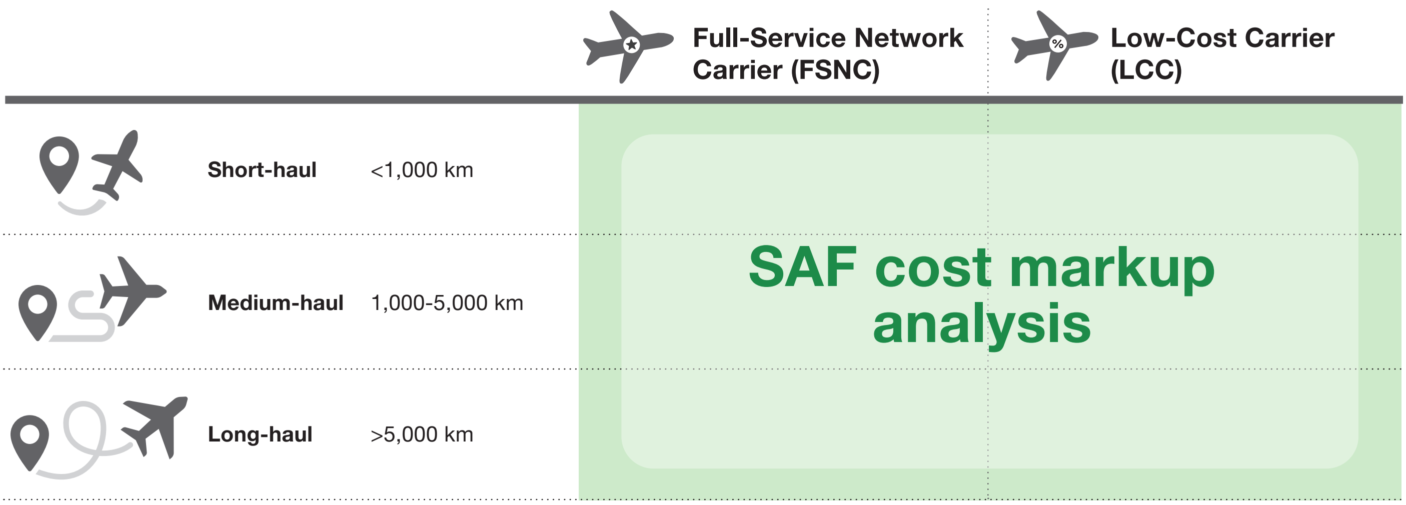
5. Cost markup

Finally, the resulting fuel costs of both scenarios were compared with the baseline scenario. The difference constituted the resulting cost markup of SAF-blended kerosene.

After calculating the cost markup of fuel for the airlines, we wanted to interpret the cost markup and its impact for airlines. To do so, we made a differentiation between three airline clusters and route types (*Exhibit 25, page 59*). For the analysis, we considered both FSNCs and LCCs, with each cluster consisting of a set of typical European airlines. Furthermore, to obtain a detailed insight into the cost impact for these airlines, we considered different range segments on which these airlines operate—short-, medium-, and long-haul flights. We analyzed each cluster and range segment by distinct cost and performance characteristics, such as mean fuel burn and fuel cost per flight, load factor, or profit margins per passenger. For each combination of the 3x3 matrix shown in Figure (*Exhibit 25, page 59*), different parameters[65] (e.g., PAX per flight, seat load factor, fuel burn per PAX, fuel cost per flight, CASK, profit margin) were calculated.

Based on this analysis, we could calculate the specific cost markup for per flight. This allowed detailed statements about the integration of SAFs for different business models and route segments.

EXHIBIT 25
Airline clusters and route categorization



Source: Bauhaus Luftfahrt e.V.

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