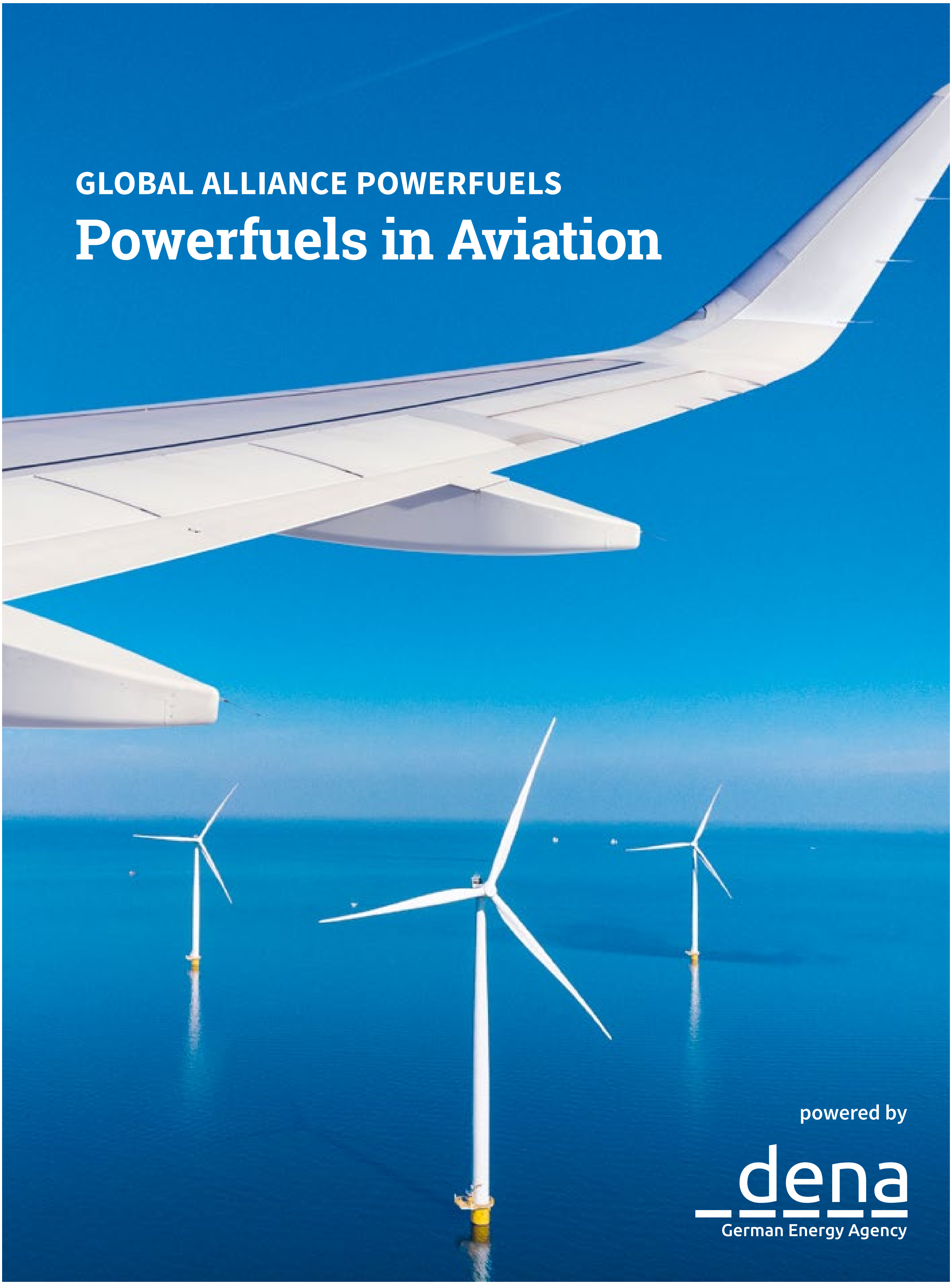
Global Alliance
Powerfuels



GLOBAL ALLIANCE POWERFUELS

Powerfuels in Aviation

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Content

1

Climate Targets and the Role of Sustainable Aviation Fuel (SAF)

CO_2 emissions from global aviation account for around 2.8% of global CO_2 emissions. The aviation industry has set itself the goal to halve emissions by 2050.

2

Powerfuels in comparison to biogenic SAF

To provide the necessary quantities of SAF, biofuels alone are not sufficient. The sustainable potentials to increase their production are limited. Powerfuels bridge the gap and offer sustainability benefits.

3

Cost of Powerfuels in Aviation

Currently, powerfuels costs are still high. However, they are expected to decrease strongly in the next decade. Significant emissions reduction can be achieved with moderate increases in ticket prices.

4

Accelerating Market Development

For reaching the target of 50% emissions reduction in 2050, a new policy framework is necessary, and action must start now.

5

Recommendations to foster powerfuels deployment

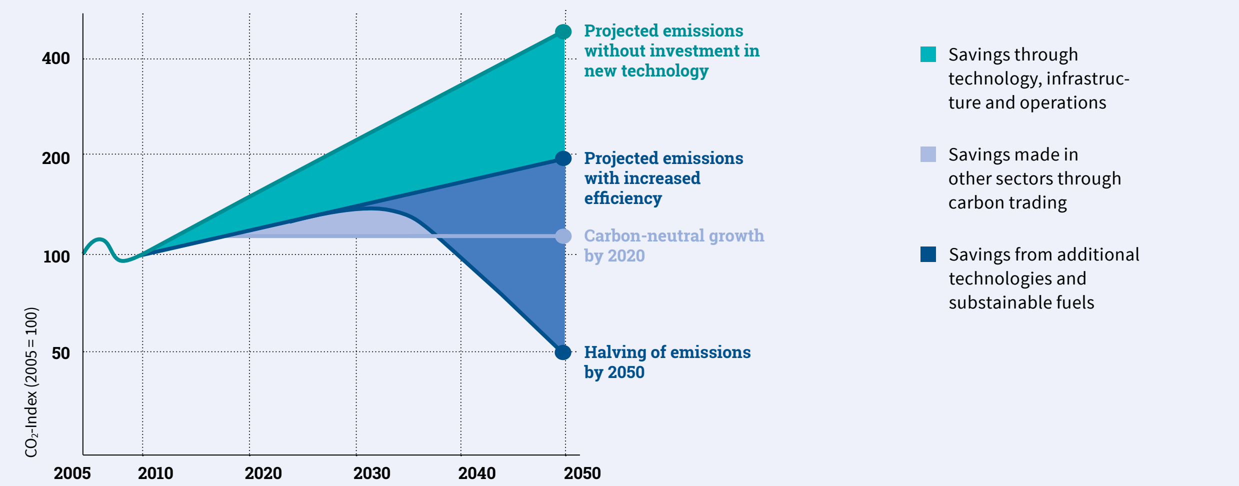
Existing measures are not sufficient to scale up SAF, as powerfuels are still at the beginning of their cost curve digression. Further action is necessary.

1. Climate Targets and the Role of Sustainable Aviation Fuel (SAF)

CO_2 emissions from global aviation account for around 2.8% of global CO_2 emissions [1] and about 12% of CO_2 emissions from the transport sector [2], while the total contribution to anthropogenic global warming is even larger[1]. If aviation were to be considered a country, its greenhouse gas (GHG) emissions would make it into the world's top 10. Thanks to technological innovation in the last decades, airplanes became more efficient, resulting in reduced specific GHG emissions. However, with projected growing demand for aviation, total GHG emissions is set to rise in the long term. Therefore, member states of the International Civil Aviation Authority (ICAO) have committed to keep total emissions constant from 2020 on. The entire aviation industry, organized as the Air Transport Action Group (ATAG), has set itself the aspirational goal to reduce CO_2 emissions by half by 2050, relative to 2005 levels.

Besides offsetting – shifting emissions into other sectors through certificates – sustainable aviation fuels (SAF) will play a key role in reaching these targets. They are able to reduce direct 'well-to-wake' CO_2 emissions up to 100% and particle mass emissions up to 70% compared to fossil fuels [45][2]. An essential requirement for any SAF is their drop-in capability – the ability to use existing infrastructure and engines to achieve CO_2 reductions in the existing fleet.

Although production has been growing strongly, SAF production currently accounts for less than 0.1% of total jet fuel demand. This is primarily due to higher costs than fossil fuels and the absence of other incentives for airlines and operators.



Source: based on IATA [44]

Figure 1: CO_2 emissions reduction roadmap. Based on IATA [44]

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[1] The total climate effect (or additional warming) of aviation beyond CO_2 (including nitrogen oxides (NOx), aerosols and their precursors (soot and sulphate), and increased cloudiness in the form of persistent linear contrails and aviation-induced cirrus cloudiness) in comparison to total global greenhouse gas emissions may, however, be much larger than this number. Calculated in CO_2 equivalents, it is estimated to be two times larger than the effect of only CO_2 emissions, totalling between 4-5% of global equilibrium surface temperature change (or anthropogenic radiative forcing, i.e. global warming). Exact estimation is difficult – the 90% likelihood ranges from 2-14% [22].

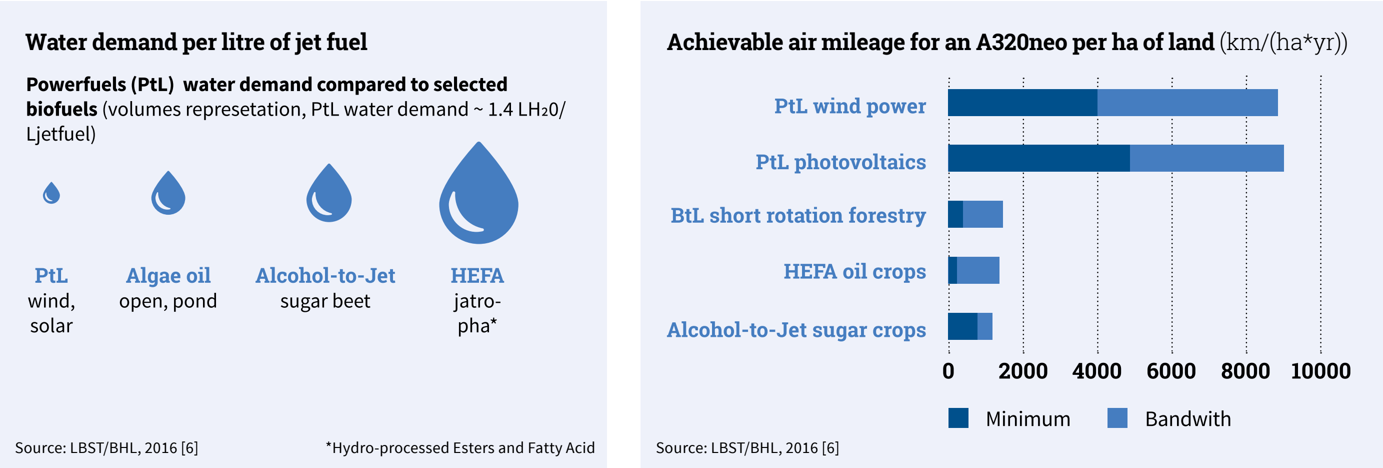
[2] Due to the non-CO_2 effects, current aviation propulsion systems will, however, not become neutral in their effect on global warming, even when using carbon-neutral fuels (see footnote 3), but these effects are reduced by using SAF [31].

2. Powerfuels in comparison to biogenic SAF

To provide the quantities of SAF needed for significant reductions in aviation emissions, biogenic SAF can play a large role. In 2018, global biofuels production reached 152 billion litres, out of which 0.015 billion were used in aviation [3]. With a global aviation fuel consumption of around 343 billion litres [1], however, existing biofuels production cannot be the only source of SAF. Significantly increasing the supply of biofuels further with crop-based biofuels can face sustainability challenges due to land use change, competition from food production and water issues. For waste-based fuels (municipal solid waste, agricultural residues), production potentials are limited.

As other sectors, such as industry, maritime and road transport are also looking to defossilise, electricity based powerfuels are a missing link for reaching climate targets. Powerfuels are gaseous or liquid fuels and feedstocks produced from renewable electricity. This includes, but is not limited to, hydrogen, synthetic gas and synthetic liquid fuels used in aviation (also known as Power-to-Liquid). According to the World Energy Council, the global demand for powerfuels could reach between 40% and 90% of final energy demand in global aviation [4], while the IEA estimates the demand for SAF to reach as high as 20%, corresponding to 75 billion litres, by 2040 [5].

Compared to biogenic SAF, powerfuels can offer additional benefits in their sustainability [6]. Land use is generally lower. Similarly, the water demand per litre of fuel is around 1.4 litres for powerfuels, while oil crops range between around 5,200 and 20,000 litres per litre of fuel [6].



Water demand per litre of jet fuel

Powerfuels (PtL) water demand compared to selected biofuels (volumes represetation, PtL water demand ~ 1.4 LH₂0/Ljetfuel)

Source: LBST/BHL, 2016 [6]

*Hydro-processed Esters and Fatty Acid

Achievable air mileage for an A320neo per ha of land (km/(ha*yr))

Source: LBST/BHL, 2016 [6]

Figure 2: Water demand per litre of jet fuel and achievable air mileage. [6]

Powerfuels are sustainable under two conditions: they are exclusively based on renewable power and close the carbon cycle. If these conditions are met, CO_2 savings of more than 80% are achieveable for power-based aviation fuels [7]. This is superior to most crop-based biofuels and similar to that of biofuels from residues and waste. Assuming additional deployment of renewable power plants that have been built using renewable energies, there is a perspective for nearly carbon-neutral powerfuel production [6].

Using powerfuels in current planes is already technically possible. In the ASTM (American Society for Testing and Materials) standards, powerfuels are already certified for use in aviation, blended with jet fuel up to 50%, using the Fischer-Tropsch (FT) production pathway[5]. However, the use of aviation powerfuels produced through the methanol route is currently not certified, nevertheless it is expected to have similar performance as FT route.

Source of Power	Source of Carbon
■ Power sources need to be renewable. The key condition is that renewable power used for SAF production does not crowd out the defossilisation of the power sector. Therefore, policy needs to safeguard that **dedicated power generation capacity** is used in addition to the defossilisation path of the power sector. ■ **Excess renewable power** constitutes an alternative. It is unlikely to be the only power source, because production processes need continuous and stable power supply. They can, however, contribute flexibilities to the power system.	■ The ideal and scalable solution is **direct air capture** (DAC) of CO_2. This is currently the costliest method, but even using this method, the electricity used in the electrolysis is decisive for overall costs. ■ In first industrial projects, excess CO_2 from biogenic sources could be used[4]. ■ Equally, **industrial point sources** of CO_2, such as the cement industry, may be used. However, the key condition is that the emitting process cannot be replaced by non-emitting processes in the medium term.

Table 1: Source of power and carbon for powerfuels.

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[4] For example, ethanol fermentation, biogas, or sewage treatment plants. The current KLM/SkyNRG project follows this approach [20].

[5] Moreover, alternative production pathways that also contain aromatics (required to preserve the tightness of seals and valves) are expected to be certified soon; hence, from a technical perspective, the way is paved for 100% powerfuels that would be fully drop-in ready. However, to further reduce the non-CO_2 climate impact of aviation [26] in the long run, shift to no-aromatics fuels is able to bring large benefits [27] and should be pursued.

3. Cost of Powerfuels in Aviation

Currently, powerfuels costs are still high and above the level of biofuels. Future cost estimates vary widely. However, they are expected to decrease strongly to around €1 per litre at locations with low-cost renewable power. The figure below compares cost estimates from a large range of recent literature[6]. The largest cost driver is renewable electricity, whose costs have been falling continuously and strongly over the past years.

Production costs of biofuels via the HEFA route, by comparison, are estimated to reach €0.88 per litre [7], although current market prices can be several times this value. More sustainable biofuels with feedstock availability in large quantities are significantly more expensive, and further significant cost decreases are unlikely, as acquiring feedstock makes up the largest part of biofuel costs.

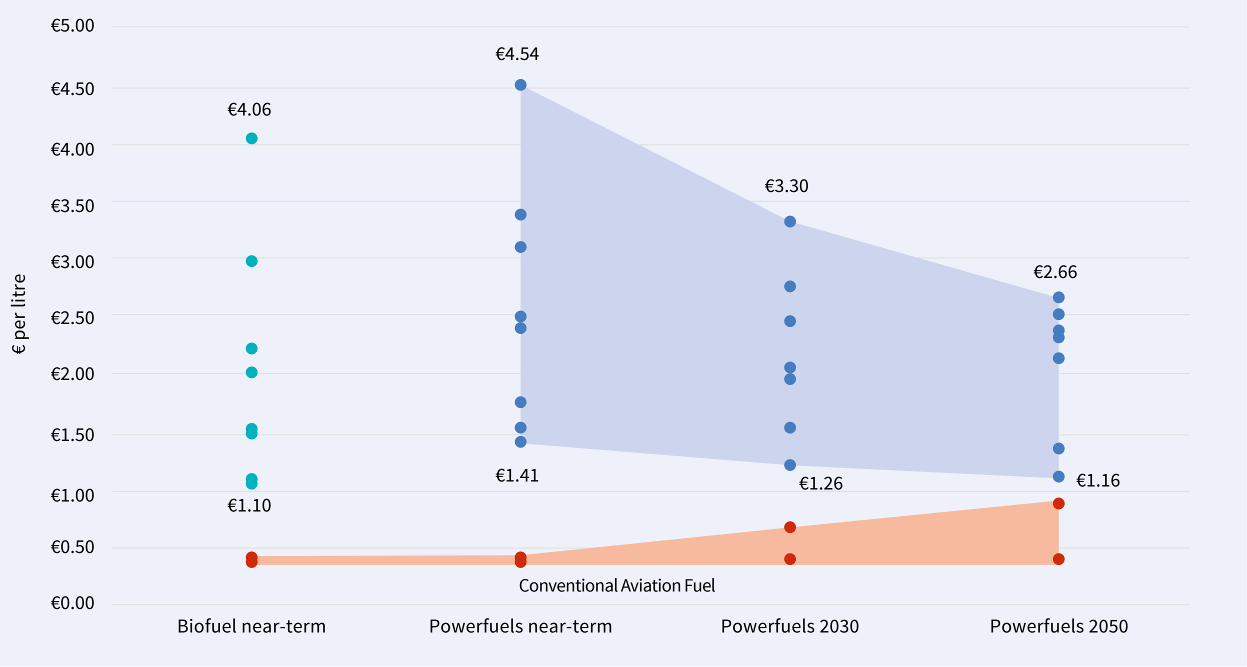

Figure 3: Cost estimates for biofuel and powerfuel SAF in the literature (€/litre) compared with Conventional Aviation Fuel (CAF).[7]

One of the main challenges for SAF is the higher price compared to conventional jet-fuel. Nonetheless, significant drop-in of SAF can be achieved with moderate increases in ticket prices, assuming that costs are passed on to the consumer. Airlines will pass this cost on to their passengers, as the industry operates in a competitive environment and profit margins are low (on average 3.9% of revenue in 2018 [8]), which does not permit them to absorb any additional costs. Therefore, airlines will not be able to use powerfuels at their own initiative except at very low percentages.

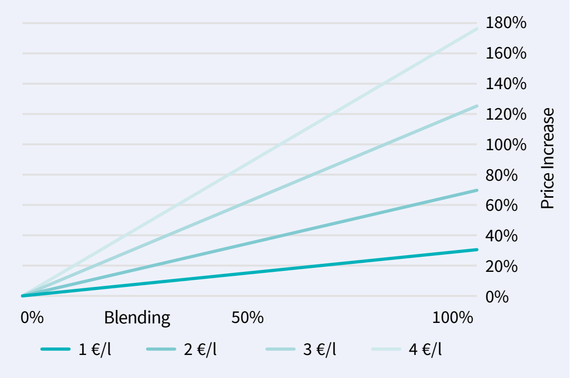

Figure 4: Ticket price increases for different powerfuel cost estimates.

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[6] Literature estimations for the cost of powerfuels vary widely in their assumptions on plant size, yearly full load hours and cost of renewable electricity.

[7] A large range of recent studies on powerfuel cost has been surveyed [6] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38]. Near-term CAF prices are based on the Jet Fuel Price Monitor from IATA. Estimations for CAF in 2030 and 2050 are based on IEA and World Bank scenarios

In 2018, fuel accounted for around 23.5% of airline operating expenses [9]. Using this number, the approximate effects on ticket prices for various cost estimates of powerfuels and blending rates can be estimated. To put these numbers in realistic examples, consider a typical intracontinental flight in Europe from Berlin to Mallorca (Spain) of around 1,700 km for a price of €145 (the IATA average in 2018). The median near-term estimation for powerfuels costs is 2.4€/litre (see figure 3), implying a price increase of around €15 for a 10% blend.

Similarly, an intercontinental flight from Berlin to Beijing with a distance of 7,500 km is assumed to cost €525 (the IATA average for this category). A 10% blend in this case would translate to €53 of additional costs. In both scenarios, as a rule of thumb, ticket prices rise roughly in proportion to the used blend (a 10% blend increases the ticket price by 10%).

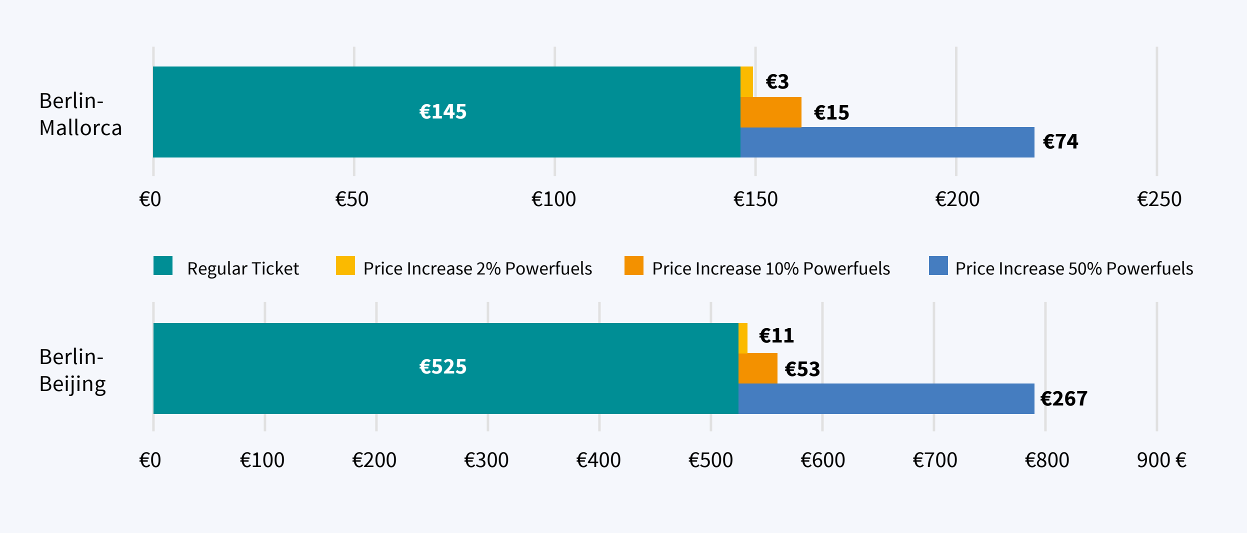

Figure 5: Ticket price increase by blending conventional aviation fuel with different proportions of powerfuels.

As powerfuels require additional renewable power generation capacity, it is important to understand the quantities involved. For example, a weekly return flight at a medium distance such as London-Barcelona with a 50% blend of powerfuels needs about 360 tonnes of powerfuels per year, which requires approximately one wind turbine of 3MW of installed renewable capacity in an offshore wind location[8]. For an individual flight, the necessary power generation capacities would be manageable. Considering the size of the entire aviation sector however, necessary total renewable capacities to achieve the climate goals are considerably larger [10].

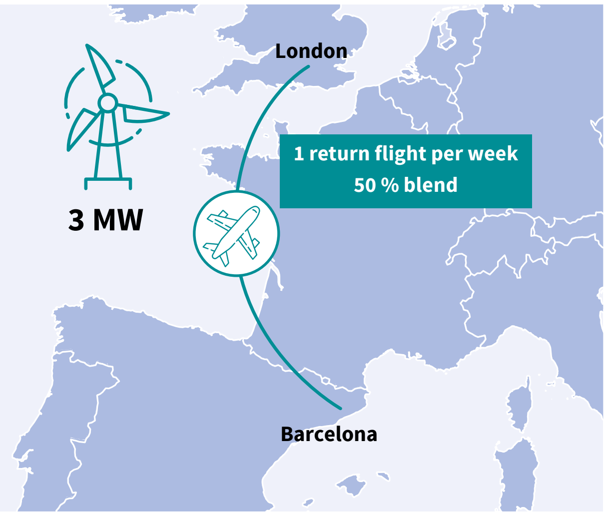

Figure 6: Renewable generation capacity requirements of powerfuels for a weekly return flight from London to Barcelona.

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[8] For daily flights, etc. the figure may be multiplied accordingly. This example uses an Airbus A320 (180 passengers, 92.9% load factor, 1,139km flight distance and specific fuel consumption of 3.5l per 100 passenger-km) for the calculation. The renewable asset is a wind turbine in a location with 3,750 full load hours, a realistic estimate, for example, for the North Sea. An efficiency of 42% for the conversion of electrical energy to powerfuels is assumed [6]. However, the authors calculate the efficiency for a facility with a much larger production capacity of 100 kt of liquid hydrocarbons per year.

4. Accelerating Market Development

For further development of power-based SAF, appropriate incentives need to be in place. All SAF are more expensive than jet fuel, and will continue to be so, if there will be no fundamental change in the regulatory framework. A new policy framework is necessary to reach the target of 50% emissions reduction by 2050 and further develop SAF. Existing national and international policy frameworks do not create sufficient incentives to use SAF as a means to achieve net GHG emission reductions in aviation. The following national and international agreements and targets can be seen merely as a first step for further actions.

- International aviation, just like maritime transport, is not covered in the Paris Agreement. The **Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)** is the corresponding market-based instrument in which ICAO member states commit to CO_2 neutral growth in aviation from 2020 on. States are responsible to enforce the targets against aircraft operators. Operators buy emissions from the carbon market (from mechanisms, programmes and projects) and 'cancel' them [11]. By primarily relying on offsetting, CORSIA focuses on offsetting emissions by financing emission reduction projects in other sectors. However, as long as offsetting projects are readily available at lower cost than SAF, this instrument will not be sufficient to create net emission reduction in aviation itself and to start market development of powerfuels. However, it is a good framework, and SAF could be promoted from within, e.g. through sub-quotas.

- Contrary to other transport fuels in most markets, kerosene on international flights remains tax free (since the Chicago Convention 1944[10]). However, some states impose **kerosene taxes** for domestic flights. They range from 1ct/litre in the US to 2ct/litre in Saudi-Arabia, 8ct/litre in Canada and 14ct/litre in Japan [17]. Furthermore, several countries impose fixed **ticket taxes** on domestic and/or international departures. The UK rate ranges from €14 for short haul economy to €190 for long-haul business class. By comparison, the German tax ranges between €7.38 for short-haul and €41.99 for long-haul flights. Starting in 2020, France will implement an additional CO_2 tax on any flights taking off from France. The tax ranges from €1.50 to €18 per flight, depending on distance and flight class[11].

  Finally, VAT or **sales tax** is applied in many countries for domestic ticket sales. Generally, this tax revenue is collected by national treasuries. While these sizeable tax receipts currently do not provide any incentives for SAF development, they could be used in the future to foster the market development of SAF, e.g. through public procurement.

- Since 2012, aviation has been included in the **European Union Emission Trading Scheme (EU-ETS)**, which means that for flights within the European Union, airlines have to acquire certificates[9]. Prices of certificates, although rising, are close to €30 per tonne. Compared with approximate abatement costs between €500 and €1,500 per tonne, alternative instruments need to be put in place to achieve a scale-up of both biogenic and power-based SAF. The **European Union Renewable Energy Directive II (EU RED II)** allows counting SAF with a factor of 1.2 towards the target of 14% renewable fuels in 2030. However, due to large multipliers in other areas with lower abatement costs (a factor of four for EV; and a factor of two for advanced biofuels) [14] this instrument is unlikely to significantly contribute to SAF deployment. Nonetheless, the delegated acts on electricity sources and methodology for assessing GHG emissions savings should be designed to allow competitiveness of powerfuels.

- Some countries proposed **national quotas**, for example, Sweden proposed national quotas at their airports to gradually increase the use of (biogenic) SAF, starting with 0.8% in 2021 to 27% in 2030 [12]. Similarly, Norway announced a minimum requirement of 0.5% of advanced biofuels (to be produced from waste and residues) starting in 2020 [13]. When these measures are fully implemented, they will create a predictable and binding path to SAF deployment. However, it should also include powerfuels.

- The **California Low-Carbon Fuel Standard (LCFS) Programme** aims to reduce carbon intensity of fuels by 10% in 2020 compared to 2010. Since 1 January 2019, renewable aviation fuels generate tradeable LCFS credits [15], which are currently valued at around 180$/tonne [16]. Compared to other carbon markets such as EU-ETS, this is fairly high and might create incentives for powerfuels, if prices continue to rise.

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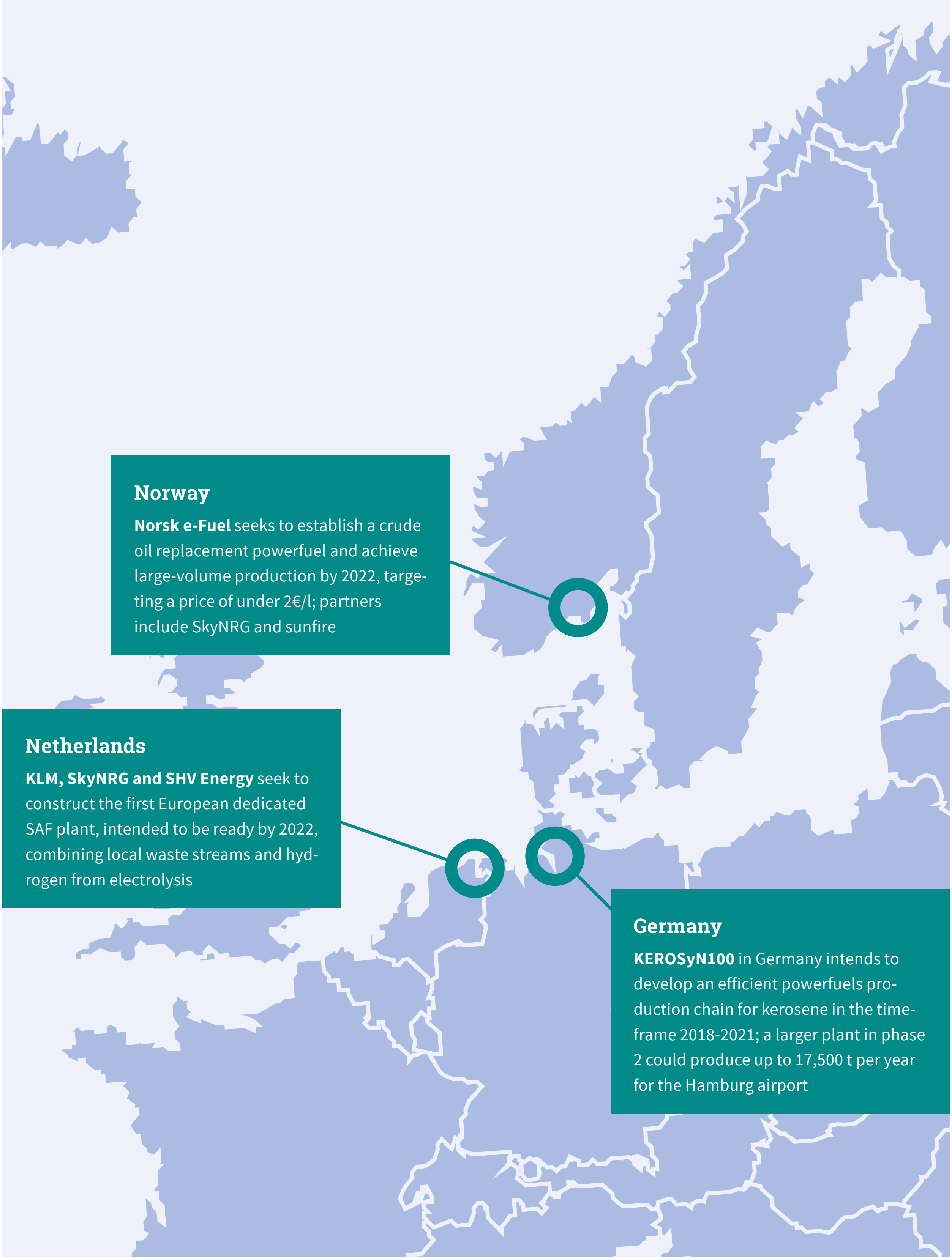
[9] However, a substantial but decreasing part of the required certificates is still granted for free [43].

[10] A study by CE Delft [40] notes that fuel taxation on international flights may therefore face legal challenges; per-flight taxes depending on take-off weight and distance (as opposed to per-ticket) are proposed as an alternative solution.

[11] Except transit connections flights to Corsica and the French oversea territories [41].



Norway

Norsk e-Fuel seeks to establish a crude oil replacement powerfuel and achieve large-volume production by 2022, targeting a price of under 2€/l; partners include SkyNRG and sunfire

Netherlands

KLM, SkyNRG and SHV Energy seek to construct the first European dedicated SAF plant, intended to be ready by 2022, combining local waste streams and hydrogen from electrolysis

Germany

KEROSyN100 in Germany intends to develop an efficient powerfuels production chain for kerosene in the timeframe 2018-2021; a larger plant in phase 2 could produce up to 17,500 t per year for the Hamburg airport

Figure 7: European powerfuel SAF projects. [18] [19] [20]

5. Recommendations to foster powerfuels deployment

As shown above, existing measures are not sufficient to scale up SAF, as powerfuels are still at the beginning of their cost curve digression. Further action may include the following:

- As a first step, powerfuels should be explicitly mentioned and considered in the ICAO Global Framework for Aviation Alternative Fuels and the IATA Sustainable Alternative Aviation Fuels Strategy – so far both of them have been primarily targeting biofuels.
- Powerfuels should be treated equally to advanced biofuels, whose GHG savings and sustainability balances are in many cases comparable to powerfuels. In the longer run, a comprehensive framework with robust criteria for SAF sustainability should be created and implemented with effective monitoring, verification and reporting schemes.
- Beyond any regulation, airlines should be encouraged to create the opportunity for private and business customers to purchase powerfuels voluntarily. Finnair has already created such an offer. Further, aircraft operators can pursue their climate goals through fuel purchase agreements. Airports and fuel suppliers should offer powerfuels to all airlines through their regular fuel infrastructure.
- CORSIA and other national and regional instruments should acknowledge powerfuels emissions abatement potential. **Powerfuels should also feature prominently in the ICAO agenda** over the next years to achieve a breakthrough decision at the third ICAO Conference on Aviation Alternative Fuels (CAAF/3), scheduled to occur before 2025 [12]. In addition, powerfuels should be **included as part of CORSIA eligible fuels**.
- ICAO member states should define an **increasing SAF/powerfuels blending quota for all airlines**, starting with at least 2% in 2025. If such blending quotas (e.g. 2% or 10% in the medium term, see price effects above) will be implemented on regional or national level in a solo-effort, tankering[13] and losing market share for local airlines and airports needs to find consideration in designing any such policy. To counter these effects, an ideal solution would be a coalition of member states implementing this measure.
- Several countries have introduced national aviation taxation or levies on tickets or fuels (see above). Such instruments and **its revenues may be used in the future to guarantee offtake through public procurement/tenders** to enable large scale powerfuel production and use it in aviation. Alternatively, airlines could receive incentives for using SAF, offsetting the cost difference to conventional aviation fuels (CAF).
- Beyond measures to reduce the cost difference between CAF and SAF, financial derisking measures for first project investments (e.g. grants, loan guarantees) can improve project development.
- Next to the already existing FT-route, certification of the methanol production pathway within the ASTM standards should be pursued.

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[12] CAAF/3 aims to update the 2050 ICAO Vision to include a quantified proportion of conventional aviation fuels (CAF) to be substituted with SAF by 2050 as well as the carbon reductions achieved by SAF.

[13] Research by DGCA [43] suggests that a price increase of 2% would lead to almost zero tankering; while a 10% price increase would be associated with a 20% substitution of fuel.

6. Figures

7. Tables

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