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Private jets: can the super rich supercharge zero-emission aviation?

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The findings and views put forward in this publication are the sole responsibility of the authors listed above. The same applies to any potential factual errors or methodological flaws.

Executive Summary

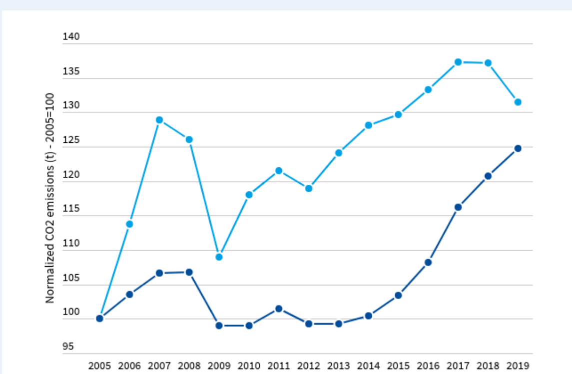
Aviation's climate impact is disproportionate and growing fast. But it is caused by a very small group of people. Just 1% of people cause 50% of global aviation emissions, from all types of air travel[1]. This report exposes the outsized role played by the super rich hopping on private jets for super short distances.

European private jet CO_2 emissions have soared in recent years, with a 31% increase between 2005 and 2019, faster than commercial aviation emissions. Covid-19 put a temporary halt to that growth, but compared to commercial aviation, it was able to bounce back much quicker. Whilst most Europeans were still grounded, by August of 2020, the peak time of year for private jet travel, the sector had fully recovered.

Private jets have a disproportionate impact on the environment. In just one hour, a single private jet can emit two tonnes of CO2. The average person in the EU emits 8.2 tCO2eq over the course of an entire year.

The average private jet owner has a wealth of €1.3bn and France and the UK dominate the private jet market - flights departing from these states each emit more CO2 than 20 other European countries combined. In 2019, one tenth of all flights departing from France were with private jets, half of which travelled less than 500km.

In fact, private jets are twice as likely to be used for very short trips (< 500 km) within Europe as compared to flights in commercial aviation. These distances correspond to the operational range where planes are the least efficient, thereby increasing the climate impact of such flights.

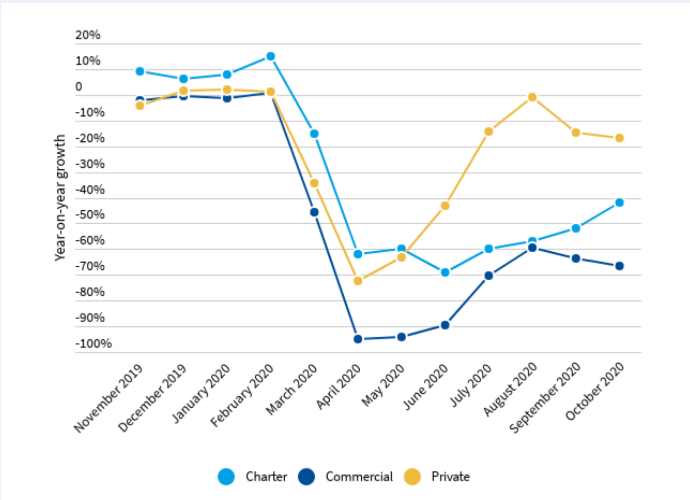


The private jet sector urgently needs a path to decarbonising. Our report finds that private jets are 5 to 14 times more polluting than commercial planes (per passenger), and 50 times more polluting than trains, a gap which will grow as private jet users

[1] Gössling, Stefan, and Andreas Humpe. 2020. "The Global Scale, Distribution and Growth of Aviation: Implications for Climate Change." *Global Environmental Change: Human and Policy Dimensions* 65 (November): 102194.
Addendum: This sentence was amended on 20 September 2022 to clarify the figures.

move towards aircraft which are bigger and more polluting than their commercial alternatives. High speeds train connections exist on 70/80% of the top 10 most popular private jet routes.

The report also found that private jets are untaxed in most European nations. Private jets are exempt from the EU ETS, Europe's carbon pricing scheme. There is no tax on kerosene, not even for domestic flights, and Switzerland is the only European nation to have recently introduced a tax on such flights.



Two factors can boost the sector's role in decarbonising. The first is wealth - the average private jet owner has a wealth of €1.3bn - meaning they have the resources to fund important decarbonising technologies for the sector, such as new fuels and aircraft. This wealth should be put on the table for that purpose, with multiple means possible for the wealthy to fund the deployment of Sustainable Advanced Fuels (SAF) and new zero-emissions (ZE) aircraft.

The second factor is that the short haul usage of these jets can become a positive, as such short flights are ideally suited to ZE aircraft. Hydrogen and electric aircraft will, at the start, only carry a small number of passengers short distances - perfect for the world of private jets. Commercial aviation can be step two for such aircraft, but step one should be mandatory use in the private jet sector.

The use of private jets is receiving increasing critical attention, and this report confirms that such critical attention is justified. Whether the sector rises to the challenge posed by such criticism will determine what future it has in Europe and globally.

Recommendations:

1) By 2030, regulators should only permit the use of hydrogen or electric aircraft powered with green hydrogen and electricity for private jet flights under 1,000km within Europe. Large private jet companies should be obligated to enter into PPA agreements with e-kerosene suppliers for all flights.

2) Until a ban is in place in 2030, a ticket and fuel tax should be imposed on fossil-fuel private jets, scaled with flight distance and aircraft weight, to account for their disproportionate climate impact. We suggest levying a ticket tax on all private flights departing from Europe, at rates similar to those implemented by Switzerland, i.e. at least €3000. This would raise several hundreds of million euros, which should be ring fenced to help fund the development of the new aviation technologies.
3) Pending the development of these new technologies, companies and individuals should commit to substantial reduction in private jet use.

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1 Introduction

With aviation already among the most carbon intensive modes of transport, for it's CO_2 and non-CO_2 effects [1], it's clear that the private jet section of this travel is, without peers, the most carbon intensive activity that anyone can engage in. In just one hour, a single private jet can emit two tonnes of CO_2[2]. The average person in the EU emits 8.2 tCO_2eq over the course of an entire year [2]. Despite this unparalleled climate impact, and despite some recent focus, the private jet sector's climate impact remains in some ways underreported and, certainly, under regulated.

This report attempts to redress some of this imbalance, by bringing a greater focus on the emissions profile of this sector, and further information on who flies and why. Our analysis shows that, far from jets being used for the purpose of facilitating business (as is often claimed), they are increasingly and sometimes overwhelmingly used for short-haul private travel, further bolstering the case for their reduced use and increased regulation. As a result, for this report we use the phrase "private jets", rather than "business aviation" as the sector prefers.

This report details what such regulation should look like. The private jet sector faces a different regulatory environment: from looser reporting regulations and different tax status to fewer climate obligations. This report doesn't aim to examine each and everyone one of these, but does attempt to examine some of the major ones, and how they can be amended to ensure the sector makes a more appropriate climate contribution including through pioneering new technologies.

The climate crisis is forcing all sectors to examine how they have operated to date, and whether their operations and regulations need change. This is especially true of a carbon intensive sector such as private jets. It is even more urgent given the significant uptake in private jet use as a result of COVID-19, a trend this report highlights.

2 The world of private jets: what are they, who uses them, and how much do they pollute ?

2.1 Models and characteristics of private jets

Most people have an idea of what a typical private jet looks like - a downsized version of a commercial plane, with a luxurious interior - but few know the range of possibilities to choose from when buying a jet. Private aircraft are classified as light jet, midsize jet, large jet or

[2] Emissions of a Cessna Citation Excel on a London-Paris flight of about 55 minutes, calculated with EEA/EuroControl master emission calculator, available on: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-1/view

turboprop, based on their size and engine type. Fig. 1 shows an aircraft for each of these categories .

The Cessna Citation Excel (Fig. 1a), the most flown private jet in Europe, is a 16 metre long light jet and can be customized to fit up to eight passengers. At full capacity, it has a range of 2700 km, and cannot perform long-haul flights. The Beechcraft King Air 200 (Fig. 1 b) is the second most flown private aircraft in Europe and is powered by a turboprop engine. It typically accommodates six passengers and has a shorter range of 1900 km. If one has the means, they can buy a midsize jet such as the Bombardier Challenger 300 (Fig. 1 c)), which is 20 metre long and transports eight to ten passengers comfortably. With bigger size comes longer range, and this plane has a seats full range of 5400 km, which is still insufficient for most transatlantic flights. Finally, the heavy jet Gulfstream G550 (Fig. 1 d)) allows its owner to enjoy long-haul flights with many guests, with its 19 seat capacity and 12,500 km range. The list price for such an aircraft is about €50 million. This explains why there is a real market for second-hand private jets, where the price of this airplane is reduced to €13 million on average [3].

Figure 1: Four private aircraft models. a) Cessna Citation Excel b) Beechcraft King Air c) Bombardier Challenger 300 d) Gulfstream G550.[3]

[3] Photos:

2.2 Private flying, luxury travel

It is a fact that even commercial aviation is a pleasure that is mostly enjoyed by the richest part of the global population, though the extent of this imbalance is often underappreciated. The pollution of this means of transportation is so disproportionate that it represents 41% of the total CO_2 footprint of the richest 1% of the EU population [2].

However private jet use is another level of exclusive travel, and one which comes at great cost for the environment. Those with the means can fly on a private jet using on-demand charter, memberships, fractional ownership or full ownership. On-demand charter consists in booking a private jet for a given flight, with prices depending on the aircraft model and flight duration. Jet card memberships, which allow to purchase flight time in bulk and save costs when travelling regularly, start at around €5,000/hour and are therefore not accessible to the common public[4]. Fractional ownership, i.e. owning part of a private jet and sharing it with others, is another option. Buying a personal jet is a luxury few can afford, the investment and maintenance costs making it worth it only for the multi-millionaires who fly a lot. This explains that **private jet owners have an average net worth of €1.3bn** [4]**.**

2.3 Real reasons to use a private jet

According to the industry, there are two ways in which private jets provide economic benefits that commercial aviation cannot provide, and could thus justify their higher pollution [5]:

- They allow VIPs to save precious work time
- They increase connectivity between airports that are not served by commercial aviation

A recent survey performed by *Business Jet Traveller* confirms time savings and access to extra airports to be the main reasons why people fly private [6]. From this, however, it is not clear what proportion of the time saved is work time, nor how many of the extra airports actually serve an area without other airports. The analysis we performed shows that both arguments for private aviation remain unconvincing.

- Gerry Stegmeier — http://www.airliners.net/photo/Cessna-560XL-Citation/1708106/L, GFDL 1.2, https://commons.wikimedia.org/w/index.php?curid=18912915
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[4]Example of pricing: https://jetcards.org/pricing

First of all, our analysis of private jet traffic data provided by the European Business Aviation Association (EBAA) shows that a sizable share of private flights are taken for private purposes (leisure and other) rather than business. We identified a clear peak of private aviation traffic during the summer months, and airports in sunny locations realize the majority of their revenue at that moment. Consumer surveys confirm that business is not the only reason why people fly private. **In a recent survey by *Private Jet Card Comparisons* found that among their subscribers, perhaps influenced by Covid-19, 46% of them were planning to use private jets in the next six months to transport family members, 45% were planning to visit a second home, and only 35% will use them to conduct business**[5] [7]. These numbers clearly demonstrate that the time saved by flying private is not necessarily of the utmost importance, and thus can not always be used as an excuse for the resulting disproportionate climate impact.

A second fact that puts the purported time savings argument in perspective is that, according to the EBAA itself, **long-haul flights greater than four hours might actually be slower when using private jets,** because of their lower speed [5]. As per our analysis, such flights account for at least **40% of private aviation emissions in Europe.** The time savings justifying a big portion of the pollution of private jets thus deserve to be questioned.

On connectivity, private aviation argues that it serves many city or area pairs not connected by direct commercial flights, providing “efficient vital connectivity between regions of different socio-economic status“, which illustrates their “indispensable role in the European economy” [5]. The problem is that these “beneficial” flights once again represent a minority. More precisely, **an alternative direct commercial flight exists for 72% of private aviation flights,** a figure confirmed by the EBAA[6] [5].

2.4 Disproportionate pollution

Flying by private jet is the least fuel efficient means of transportation, a position that will only worsen as other transport modes accelerate their decarbonisation. The automotive sector, for example, has seen a trebling of electric car sales in 2020 compared to 2019 [8]. As society tries to tackle climate change, it is obvious that private flying should be questioned, as it transports few passengers at a very high environmental cost. To measure the exact impact of private aviation, we compared the CO_2 consumption per passenger of private jets and commercial airliners, for the most used models in Europe in 2019. For this analysis, we made the following assumptions:

[5] Some of the respondents subscribers will use private jets for several of these reasons.
[6] Direct commercial routes between airports within 100km radius from airports reached by private flight. EBAA’s figure is 73% .

- Flight length was set to 500km, the median distance of intra-EU private flights (as per our calculation).
- Passenger load factors for private jets were set based on an industry report, which shows that 41% of private flights are empty legs, and for those that are not, the average occupancy is 4.7 passengers per flight [9].
- Passenger load factors for commercial planes were set to 80%, a conservative figure because in recent years, load factors of commercial aviation surpassed this 80% level[7].

The complete methodology for this analysis is described in Appendix 1. Its results are shown in Fig. 2. As can be seen, **private jets are 5 to 14 times more polluting than commercial planes.** Moreover, industry data shows that relatively efficient aircraft such as the Pilatus PC-12 are the exception rather than the norm, and that all the other popular models pollute much more. As a result, **private jets are on average 10 times more carbon intensive than commercial flights**.

Flying a small number of people in fuel inefficient aircraft, which frequently fly empty, will always incur a substantial climate penalty relative to commercial aviation, where thin margins and competition have helped drive relative efficiency gains over the years. These findings underline the challenge that the private jet sector will have to survive in a low-carbon world.

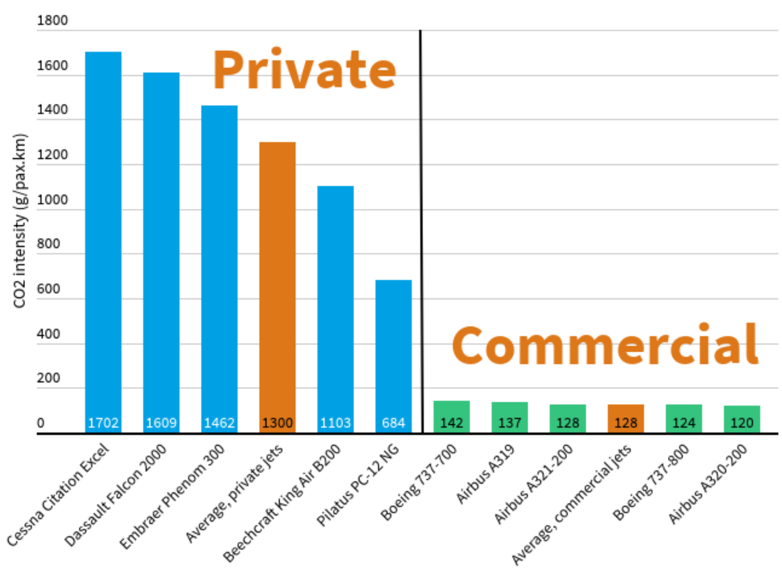

Figure 2: Private aircrafts models are much more polluting than commercial models

[7] Date from Eurocontrol STATFOR platform (pre-COVID): https://www.eurocontrol.int/dashboard/statfor-interactive-dashboard

3 Analysis of European private aviation traffic

3.1 Intra-EU flights, short-haul city hops

A characteristic that aggravates the inefficiency of private flying is that so many flights are taken for short distances. We analysed data from the EBAA and found out that **private jets are twice as likely to be used for very short trips (< 500 km) within Europe as compared to flights in commercial aviation**. This propensity for people who can afford it to hop on a private jet as soon as a trip is more than a couple hours away is very troubling, particularly in regards to the current climate crisis.

In the same way as commercial aviation, European private jet use is characterized by a higher number of intra-EU flights but higher extra-EU emissions. Indeed, extra-EU flights are mainly long-haul flights and thus more polluting. Note that in the following of this report, “EU” in “intra-EU” or “extra-EU” will actually refer to EU27+UK, as the UK was still part of the EU when emission data used in this report was compiled. **Our analysis shows that 70% of EU private jet flights are intra-EU, representing 39% of emissions,** a figure slightly higher than the corresponding intra-EU emissions share of commercial aviation (34%).

As mentioned above, a feature of private flying is that an impressive share of the flights are taken for particularly short distances. As shown in Fig. 3, **close to 50% of all intra-EU private flights cover distances of less than 500 km.** In comparison, commercial flights shorter than 500km represent less than one quarter of intra-EU flights [10]. **These distances correspond to the operational range where planes are the least efficient**, due to the higher consumption of take-off and landing phases compared to cruise. Fig. 3 shows the consumption of the most popular private jet, the Cessna Citation Excel, decreases as the flight length increases. By using them on short-haul routes, flyers are making the least efficient use possible of private jets.

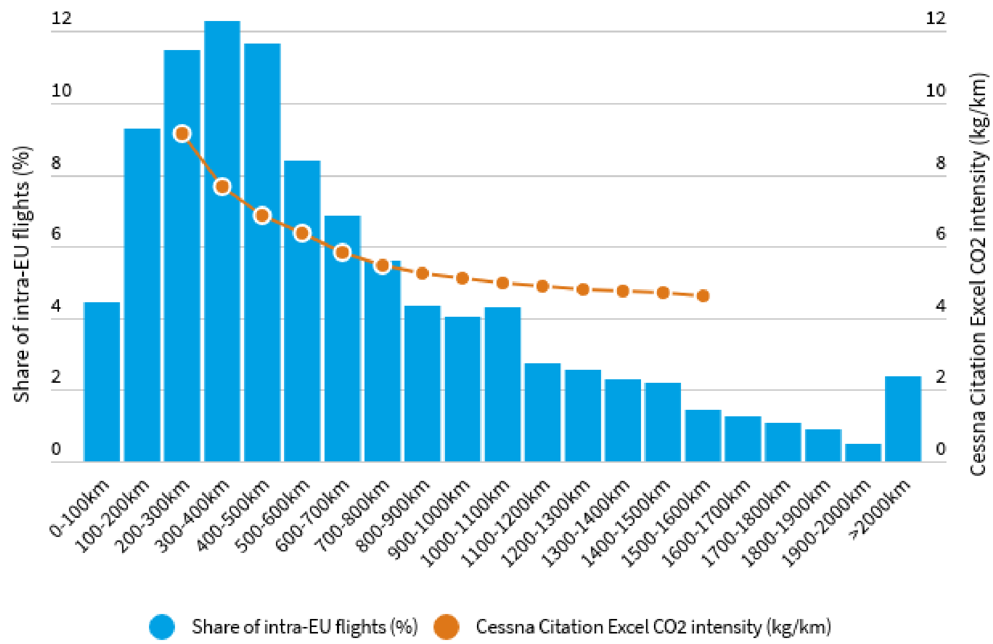

Figure 3: Most business aviation flights are taken for the most inefficient distances

The above analysis also implies that it would be easier to reduce intra-EU emissions of private aviation than of commercial aviation by replacing or decarbonising these short flights. **The total potential savings for flights of less than 500km represents 28% of private jet intra-EU emissions.** There are two means of eliminating the climate impact of such flights: either switching to zero carbon alternative modes of transport (e-vehicles or rail) or deploying new, zero-carbon technology (new aircraft and fuels).

In Fig. 4, we show a comparison of the CO_2 intensity of private jets and other modes of travel that could be used instead. For road transport, we assumed that a private jet can be compared to a high-end 7-seater ICE van because, as mentioned previously, private jets transport 4.7 people on average. Therefore, options exist today that could reduce the carbon intensity of a passenger by more than an order of magnitude. Looking ahead, were this van to be electric, the tank-to-wheel emissions shown in Fig. 4 would be zero. As renewable electricity sources increase, well-to-tank emissions will also tend to be zero. In Section 6, we discuss how private jet emissions could be reduced.

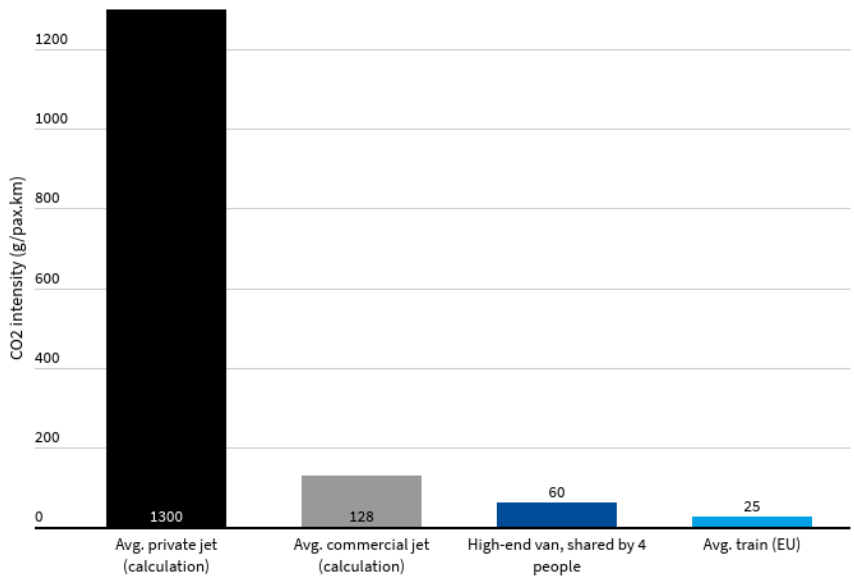

Figure 4: Comparison of the CO2 intensity of private jets and other modes of overland travel (direct emissions only)

To get an idea of the potential for replacing short private flights, we compiled the ten most polluting private flight routes below 500km and calculated the additional time it would take to travel between the same cities using other modes of travel, where possible. The scope was enlarged to include Switzerland, which is an important country for private aviation. The results are displayed in Table 1 and the methodology is detailed in Appendix 1. Most of these routes can be travelled using a less polluting option, adding less than 3 hours to the journey. We took a conservative approach for journeys connecting an airport around London, assuming the city to reach is the city where the airport is situated and not the City of London. Had we not made this assumption, the travel from the airport to the centre of town would actually have a duration closer to that of the private flight.

Ranking	City pair (airport pair)	Distance (km)	CO_2 [t][8]	Alternative travel mode	Additional travel time
1	Geneva - Paris (Geneva International - Paris Le Bourget)	409	6923	Train	2h22

[8] Refer to the methodology section for a discussion of the absolute emissions calculated in this report.

2	Farnborough (London) - Paris (Farnborough - Paris Le Bourget)	344	4393	Train	3h44
3	Roma - Milano (Roma Ciampino - Milano Linate)	485	4037	Train	1h11
4	Luton - Paris (London Luton - Paris Le Bourget)	379	3835	Train	3h17
5	Geneva - Nice (Geneva International - Nice Côte d'Azur)	299	3551	Commercial plane	2h20
6	Madrid - Barcelona (Barcelona - Madrid Barajas)	483	2682	Train	1h31
7	Zurich - Paris (Paris Le Bourget - Zurich)	482	2004	Train	3h5
8	Geneva - Zurich (Zurich - Geneva International)	230	1631	Train	2h8
9	Zurich - Nice (Zurich - Nice Côte d'Azur)	434	1561	Commercial plane	2h16
10	Biggin Hill (London) - Paris (Paris Le Bourget - London Biggin Hill)	313	1524	/	/

Table 1: Top 10 most polluting private jet routes below 500 km in Europe and their alternatives for transport

As can be seen in Table 1, travelling by train (usually high-speed rail (HSR)) is often the fastest option when travelling between big cities. It is also the least polluting one, as trains in the EU emit on average 25 gCO_2/pax.km [10], 50 times less than private jets (Fig. 4). HSR can be more expensive than a car trip in some cases, but that cost increase should be easily absorbed by millionaires choosing to travel greener considering the high cost of flying on a private jet.

A final observation on the intra-EU private jet traffic is that flights are mainly concentrated along the UK-France-Switzerland-Italy axis. The map in Fig. 5, showing the 10 most polluting routes in Europe (without cutoff distance), helps to realize this. Remarkably, these routes connect only 7 different airports. The fact that private jets mostly fly between a few countries in Europe will be discussed in section 3.4.

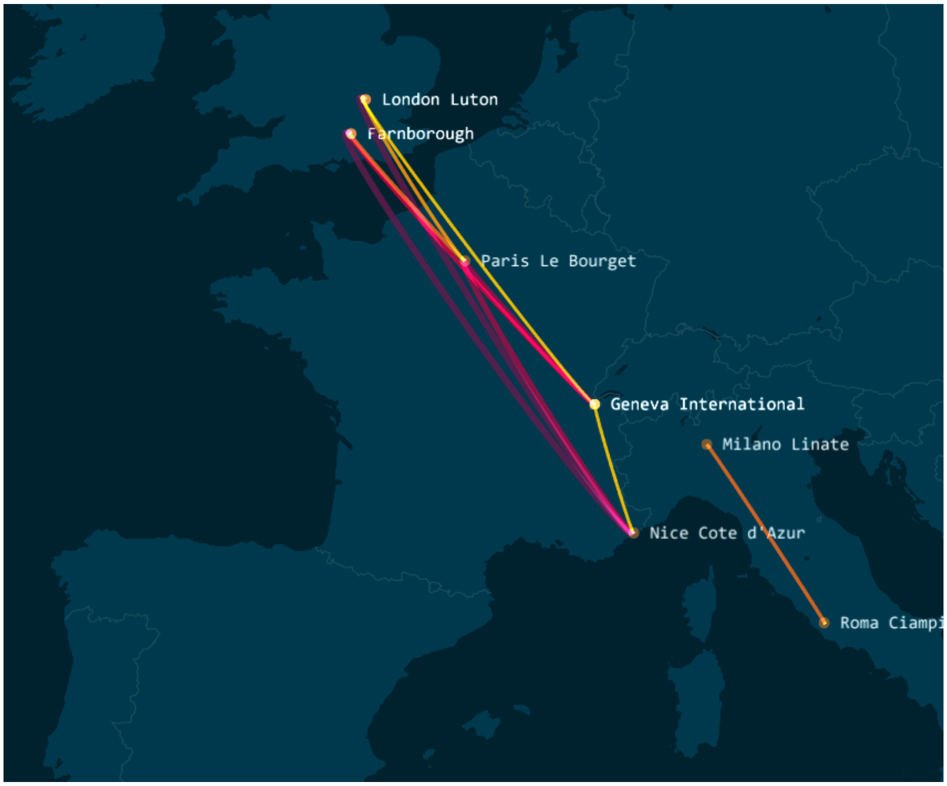

Figure 5: Map of 10 most polluting routes for private aviation within the EU. The darker red the arc, the more polluting the route.

3.2 Extra-EU flights, unavoidable?

Unlike intra-EU travel, extra-EU private jet flights, which represent 61% of emissions, have fewer decarbonisation pathways. Rail is not an alternative, and options for new aircraft become more limited the longer the journey. However for **62% of extra-EU private jet trips, commercial alternatives do exist,** and offer an immediate means to reduce emissions.

Depending on the length of the flight, different paths to decarbonisation exist: they are discussed further in section 6.

3.3 Most polluting routes: dominated by the UK, France and holiday destinations

The case for replacing private flights with direct commercial alternatives is further strengthened by the ranking of most emitting routes shown in Table 2. All these routes have commercial alternatives available. Three additional observations can be drawn from this table. Firstly, this ranking is a mix of long routes and very short routes (with many flights per year), a specificity of private aviation. **Secondly, all of these flights depart from or arrive to the UK or France**. Indeed, the following section will show that these countries are, by far, the biggest private jet users in Europe. Finally, Nice is the airport that is the most represented in this top 10. This further confirms that private jets are being used by wealthy people to enjoy the sun and splendour of Nice, instead of conducting business.

Ranking	Airport 1	Airport 2	Distance (km)	Flights	CO_2 [t]	Commercial alternative (ICAO codes)
1	London Luton	Teterboro New YorK	5532	565	16629	LHR-JFK
2	Moscow Vnukovo	Nice Côte d'Azur	2508	1548	16197	SVO-NCE
3	Paris Le Bourget	Teterboro New York	5829	386	11662	CDG-JFK
4	Teterboro New York	Farnborough London	5526	289	8384	JFK-LHR
5	Nice Côte d'Azur	Farnborough London	1036	1390	7472	NCE-LHR
6	London Luton	Nice Côte d'Azur	1072	1340	6959	LHR-NCE
7	Geneva International	Paris Le Bourget	409	3044	6923	GVA-CDG
8	Paris Le Bourget	Nice Côte d'Azur	694	2007	6896	CDG-NCE

9	Hong Kong International	London Luton	9595	113	6407	HKG-LHR
10	Farnborough London	Moscow Vnukovo	2531	426	5397	LHR-SVO

Table 2: Top 10 most polluting routes for private aviation in Europe and their commercial flight alternative

3.4 The unequal distribution of private aviation traffic in European countries

Being a means of transportation for the extremely rich, it is not surprising that access to private flying mirrors the unequal distribution of wealth across Europe. We analysed the emissions of private flights in Europe (EU27 + UK, Switzerland, Norway and Iceland). The ranking of the 10 highest polluters is shown in Table 3. **The UK and France dominate the ranking and together represent almost 40% of emissions from private jets in Europe**. The following countries in the ranking, Italy, Germany and Spain, individually pollute two times less than the UK, although their population is comparable or higher than this country.

Ranking	Country	Departing CO2 [t][9]	Share of CO_2
1	United Kingdom	425499	19.2%
2	France	365630	16.5%
3	Italy	227653	10.2%
4	Germany	220948	9.9%
5	Spain	203538	9.2%
6	Switzerland	161763	7.3%
7	Greece	69877	3.1%
8	Austria	55157	2.5%
9	Portugal	50874	2.3%
10	Ireland	50560	2.3%

[9] For details regarding emission allocation, see Appendix 1.

Table 3: Top 10 European polluters with private aviation (scope:EU27+UK+CH+NO+IS)

It is particularly striking to compare the emissions of the top polluters with those of other countries. **Private jet flights departing from the UK and France each emit more CO_2 than 20 other European countries combined,** a fact represented in Fig. 6**.** Taken together, the three highest polluters (The UK, Italy and France) emit as much as all the other countries in the analysis.

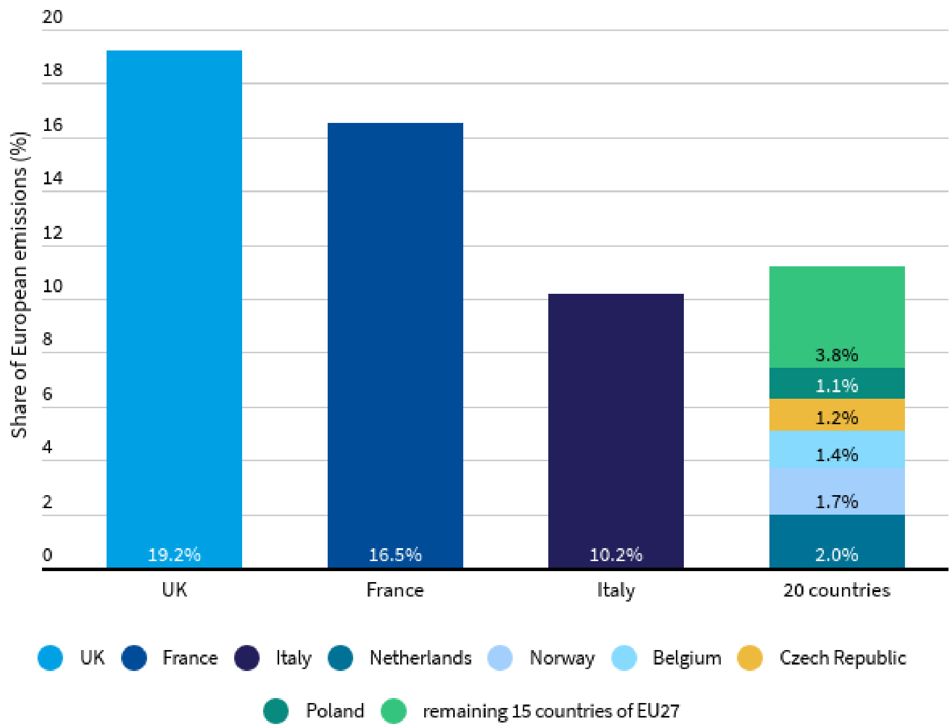

Figure 6: French emissions comparable to the total emissions of 21 other European countries

3.5 Private jets in France: the reign of short flights

The role of France in the growth of private aviation in Europe is obvious, this country being the leader in terms of flights. **In 2019, one tenth of all flights departing from France were with private jets**[10]. They emitted almost 400kt of CO2, as much as 180,000 combustion engine cars a year. Moreover, French flights are even more skewed towards short flights than the European average. **Half of all private flights in France in 2019 travelled less than 500km, 80% stayed**

[10] Based on data from EuroControl STATFOR platform: https://www.eurocontrol.int/dashboard/statfor-interactive-dashboard

within Europe. This for a country which is more than adequately connected by train and commercial aviation.

Our analysis finds that most of the flights in France connect to two airports, Paris le Bourget and Nice Côte d'Azur, which are also the two most popular private jet airports in Europe. Paris is known as a very popular touristic and business destination, whereas Nice is the most popular European airport for private flyers in summer. The importance of these airports is such that close to 60% of the country's emissions from private jets are related to these airports, and that 44 of the 45 most popular routes in France connect with Paris or Nice.

All this additional evidence should incentivise French politicians to legislate to reduce private flying in France. **France's tax rate for private jet fuel is between 35% and 40% lower than for gasoline**, depending on the fuel used [11]. Wealthy people who fly thus enjoy a tax benefit compared to the common population travelling by car and train. Recently, the citizen convention for climate has proposed to align the two tax rates [11], and this proposal only seems logical when considering the figures mentioned above.

3.6 Private jets in the UK: the access point for international private flyers in Europe

Whereas France leads the European ranking in terms of flights, the UK comes first in terms of emissions. Like France, most of the UK's flights (78%) are short hops within Europe. In terms of emissions, the situation is more balanced, intra and extra-EU trips each accounting for about half of the emissions. This is because many highly polluting routes connect one of the airports around London to extra-EU destinations such as New York (Teterboro), Hong kong or Moscow. In particular, the London-New York segment pollutes twice as much as the next segment in the ranking. Knowing that there are many, potentially faster commercial flights available for that route, there are no justifiable reasons for such flights. Similarly to France, a majority of the emissions (53%) can be attributed to only two of the UK's airports, London Luton and Farnborough. It is even more striking because those airports are very close to each other, a sign of the concentration of wealth around London.

3.7 The seasonal nature of private flying: evidence of a leisure-driven sector

An important conclusion of our analysis of private jet traffic in Europe is that it displays a clear peak in traffic during the summer months (Fig. 7). **In Europe, private jet departures are up by 50% in July compared to January, and total traffic by 65%.** The French traffic is even more skewed around summer months - it almost doubles. Finally, as the most popular holiday destination for jetsetters, Nice sees its traffic triple with the arrival of the sunny months.

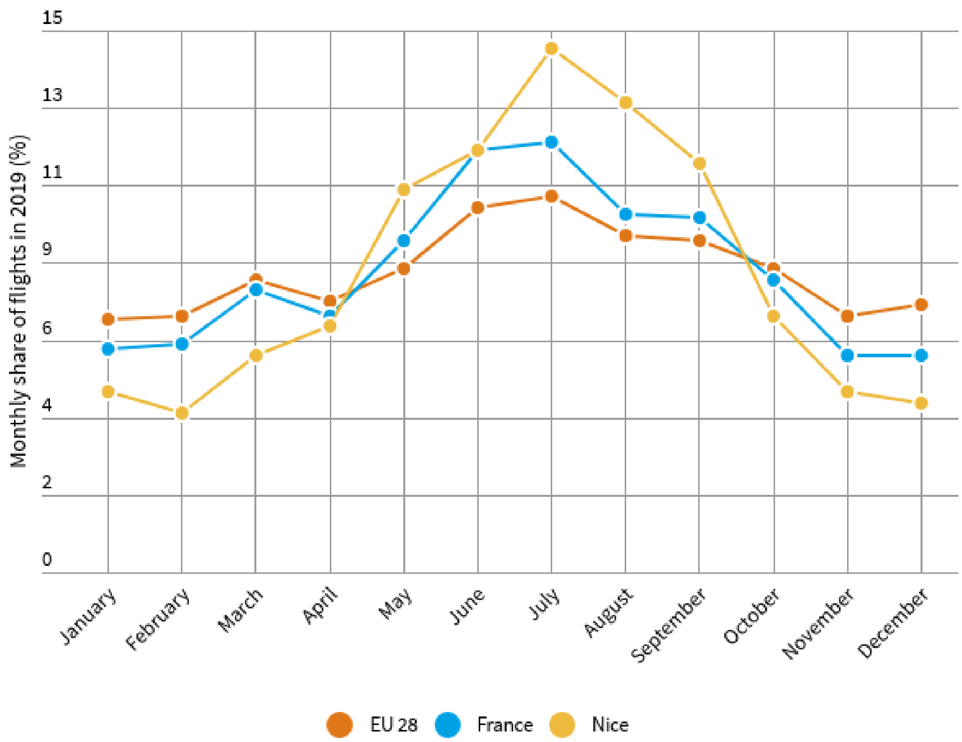

Figure 7: Private aviation traffic is heavily skewed towards the holiday months[11]

There are more than a few airports that count on wealthy people's propensity to fly during the summer months to generate the bulk of their annual revenue. Fig. 8 shows the airports with the highest asymmetry between July and January traffic. Activity in those airports more than doubles in summer compared to winter time. Olbia (IT) and Ibiza (ES) airports for example, are used almost exclusively in summer and the impact of this is not negligible: together they account for as much traffic as Nice in July. The ten holiday airports of Fig. 8 represent one third of all private flights in July, and one tenth when considering yearly traffic.

[11] Based on data from EuroControl STATFOR platform: https://www.eurocontrol.int/dashboard/statfor-interactive-dashboard, departures only.

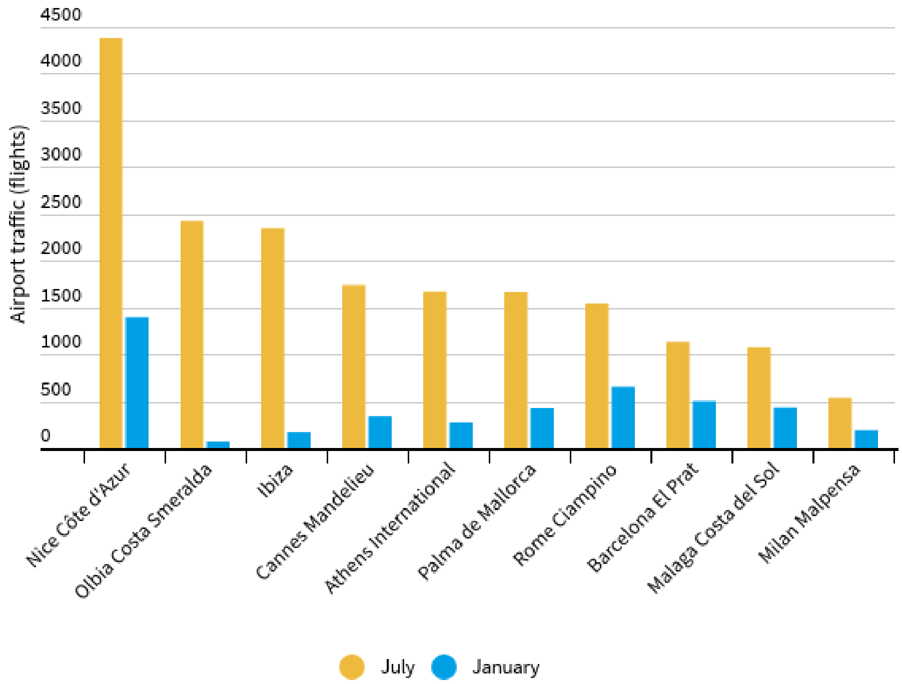

Figure 8: Some airports are deserted by private aviation in winter, but very popular in summer

This analysis shows that contrary to the claims of the industry, private aviation is not only used to save time when doing business, but also for rich people to get more quickly to their second homes and holiday destination. Unfortunately, this means that holiday habits of the richest undermine the efforts made by ordinary people to cut their emissions. **Alone, the 1,000 flights between Paris and Nice during the year pollute as much as 40,000 families taking the same holiday with a new combustion engine car.**

4 The growth issue

4.1 Growth in recent years

It is well-known that aviation's emissions have grown substantially in recent years. Remarkably, data provided by the EBAA shows that European private aviation's emissions have soared even faster than commercial aviation. Except for the last economic crisis (2008), private aviation has seen a constant increase in traffic between 2005 and 2019. The emissions of the sector grew by 31%, compared to 25% for European commercial aviation (Fig. 9). If this worrying trend continues, private aviation's emissions in 2050 will be double those of 2010. It must be noted, however, that private aviation suffered a dip in traffic in 2019, mainly due to the Brexit situation [12]. Clearly, the future relationship agreement between the EU and the UK , and on what terms it includes aviation, will influence the sector in the years to come.

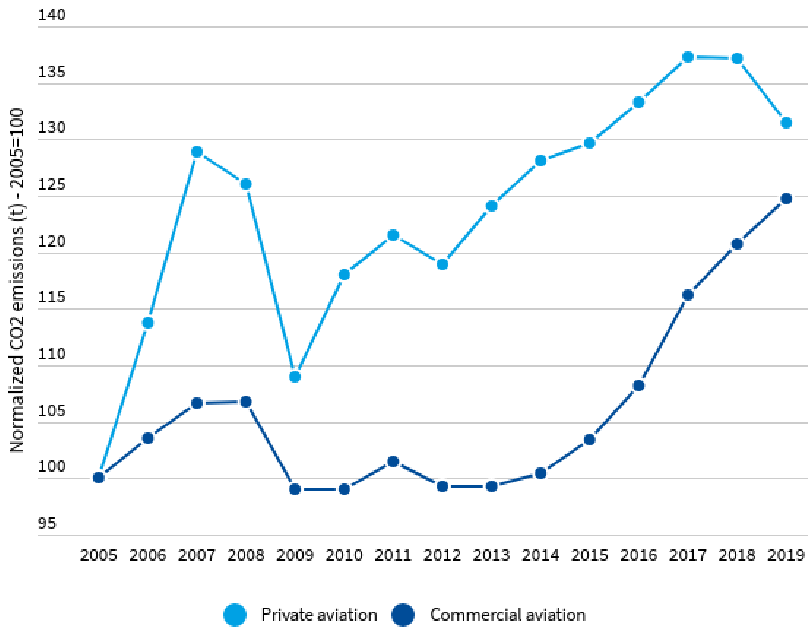

Figure 9: Private aviation emissions are growing faster than commercial aviation (EBAA and UNFCCC data)

It is correct to say that private aviation emissions represent a relatively small share of aviation emissions (around 2%), but at a time when all man-made emissions should be decreasing (and quickly), private aviation is sending just as bad a signal as commercial aviation for the future of our climate. The continuous increase in emissions in the last years, and the inaction of the sector to rein these in, are just as problematic as in the commercial sector.

The main driver of private flying is the rise in the number of high-net-worth individuals, according to leading market research company *Research and Markets [13]*. Besides this, schemes such as flight sharing (pre-COVID-19) and empty leg booking services have recently enabled more people to enjoy the commodity of private planes for a relatively small price. Fares below €500 for Geneva-London trips have been reported [14]. Although filling up planes is better than flying them empty, the danger, and the goal of the industry, is to accustom wealthy people and companies to use this more luxurious, more polluting means of transportation. With this, the industry hopes to lock in new customers and increase flight demand. In the long term, it is likely that the COVID-19 pandemic, and the fear of future pandemics, will encourage more customers to book their own flight rather than use flight sharing schemes.

4.3 Why the COVID-19 pandemic could benefit private aviation

If there is one sector of the aviation industry that could recover stronger from the COVID-19 pandemic, it is private aviation. Compared to all other air passenger markets, private aviation is faring the best during the pandemic, with a reduced drop during lockdown and a more swift recovery afterwards. Its traffic levels in Europe in August 2020 reached parity with 2019 levels despite the ongoing pandemic (Fig. 10). This is to be compared with the 60% drop suffered by the commercial aviation sector compared to the same period last year.

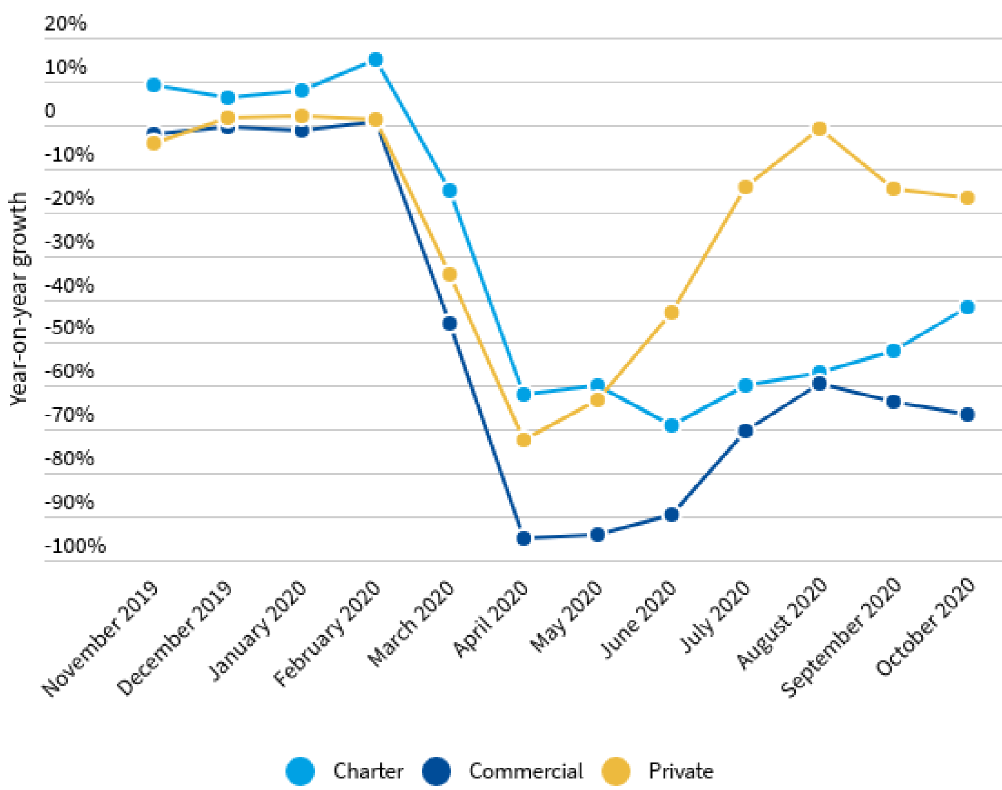

Figure 10: Private aviation fared much better than other sectors during the COVID-19 pandemic[12]

There are several reasons for private aviation's quick recovery and likely future growth. Firstly, VIPs typically have more means to bend the rules ordinary people must follow, such as the crew

[12] Based on data from EuroControl STATFOR platform: https://www.eurocontrol.int/dashboard/statfor-interactive-dashboard, total traffic EU27+UK.

filming the next installment of the Matrix movie series being allowed to fly to Berlin in June 2020 despite the travel ban [15]. Wealthy Americans also used their contacts in Europe to issue letters claiming they were coming on official business trips, hiding the fact they were actually going on holiday [16]. Owning a private jet also helps non-Europeans enter the continent by transiting through a country with a wider country acceptance list, such as Ireland or the UK.

Secondly, COVID-19 has convinced new customers to turn to private flying [17]. The major private jet operator GlobeAir reported a 11.3% increase in sales in July 2020 compared to 2019 [18]. Fear of COVID-19 contagion and lack of alternatives from commercial airlines are the main reasons for this increase. While airlines are trying to convince passengers that flying commercial is relatively riskless, private jet companies have much to gain to convince people who want to fly that private aviation is much safer [19]. It is clear that this argument has already convinced new and regular customers alike, and will appeal to companies as well [17].

Thirdly, the fact that the typical private jet user has a high-risk profile for COVID-19[13] can only increase the demand, as they grow eager to fly again. In a recent study in the US, **51% of the respondents said they would increase their use of private jets, whereas only 21% said they would fly less** [17]. As the study points out, people who previously split their trips between commercial airlines and private jets will now use private jets exclusively, increasing their already high carbon footprint.

Finally, in the aftermath of the pandemic, some industry experts suggest that commercial flying will become more expensive [20], which means there will be less of a financial incentive to fly commercial rather than private. It will take time before commercial aviation returns to its pre-COVID-19 level of service, if it ever does.

For all these reasons, it is likely that private flying and its resulting emissions will grow in the future, unless measures are taken to rein in such growth. As the pandemic recedes, the most cautious private flyers will get back to their old polluting habits, and together with the newly convinced customers, they could drive up private jet aviation pollution to unprecedented levels.

4.4 Market developments currently on the wrong trajectory for the climate

One would expect that in 2020, technological and market developments are going towards a more efficient, less polluting private jet. The current reality is quite different, however. Indeed, **market research company *Research and Markets* foresees a 50% growth of the private jet**

[13] As mentioned in Section 2, the average age of private jet users is over 60.

market between 2020 and 2030, with the large jet segment to lead the way. The main reason for this seems to be the additional luxury they provide [21]. Our analysis[14] shows that heavy jets, e.g. Dassault Falcon 2000, Bombardier Global Express/6000, Bombardier Challenger 600 Series, have a higher consumption per passenger than other segments. Most of these jets are also ultra-long-range, allowing its user to take more long-haul, highly polluting flights.

INFO BOX: Supersonic jet development

An additional future burden is the development of supersonic private jets that would consume 5 to 7 times more than current models [22], a catastrophe if aviation is to reduce its emissions to comply with the Paris Agreement. These jets would serve a tiny elite, and would reduce flying time by half [23] - a time saving far outweighed by the significant increase in emissions. Given these figures, European states should retain existing bans on supersonic travel and should refuse to certify any supersonic aircraft which has a worse climate impact than subsonic aircraft - a de facto ban.

5 It's not only about carbon: particulate matter pollution

Alongside the growing impact of private jets on the climate, there are two other important problems with private jets that should be tackled by lawmakers, i.e. particulate matter and noise.

A recent publication in *Environmental Science & Technology* highlighted the fact that **a single private jet (Dassault Falcon 900EX) emits more non-volatile particulate matter (nvPM) than a Boeing 737** [24]. These particles have been associated with respiratory and cardiopulmonary health impacts as well as climate impact such as absorbing solar radiation and affecting cloud formation. This is why the United Nations aviation agency, the International Civil Aviation Organisation, has adopted an nvPM standard, enforcing a limit on emissions to all engines with a thrust above 26.7kN, from 2020 onwards . However, the cut-off point on engine thrust means that most private jet engines remain unregulated. According to the tests in the study, the Dassault Falcon 900EX is predicted to emit twice as much nvPM during a 2-hour fight as a Boeing 737. **Reported per passenger, nvPM mass emissions are 72 times higher for private jets**. Taking into account that private flights represent about 8% of all European flights [5], it is clear that their nvPM emissions can have a serious impact on people's health and will undermine the efforts made by the rest of the aviation sector.

[14] Based on EEA/EuroControl master emission calculator, available here: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-1/view

Surprisingly, these were the first reported nvPM emissions of a private jet engine with a standardized measurement system, although private jets have been emitting these health-threatening particles in the skies for many years. It is thus essential that proper measurements are performed for all private jet engines, and that proper regulation is enforced, with standards adopted at European-level if need be.

A further under appreciated impact from private jet use is the non-CO2 climate impact. Non-CO2 climate impact refers to the additional warming caused by emissions other than CO2 resulting from flights, such as NOx and nvPM. A recent study for the European Commission found that nvPM emissions are directly linked to contrail cloud formation (white stripes in the sky coming out of planes) which is one of the biggest non-CO2 effects of aviation [25]. Research now shows that non-CO2 effects contribute twice as much to global warming as aircraft CO2 emissions [26], bringing into further focus the enormous climate impact of flying. The study did not distinguish between commercial and private aviation, so we are unable to say if the latter has a greater or reduced non-CO2 impact, however it confirmed that a decrease in soot particle reduces contrail lifetime and size. This means private jets should urgently reduce their extremely high nvPM emissions in order to address these damaging non-CO2 effects.

6 Mitigating this impact

It is clear that private jet use creates a disproportionate impact on the climate, and for questionable social and economic benefits.

However every sector should at least be given the opportunity to decarbonise. The same is true for the private jet sector, and the benefit of such an approach is that the deployment of mitigation measures to this sector could be used as a launch pad for deployment to the commercial aviation sector. Some of these mitigation measures are considered below, along with recommendation for deployment.

6.1 The need for a fuel tax

The first step in any effort to rein in this sector's emissions would be to ensure that it is paying an effective carbon price - either through kerosene taxation, or through carbon markets like the EU Emission Trading System (EU ETS). Most private jets fall below the threshold for inclusion in EU ETS, and one solution would be to lower that threshold to bring a greater number of aircraft into the scheme. However this would substantially increase administrative complexity for regulators and raise only minimal revenue.

An alternative would be to introduce, or increase, jet fuel taxation. The legal framework to introduce such taxation is however unclear. Existing restrictions on taxing jet fuel for commercial aviation stem from Air Service Agreements negotiated between states - in some cases such restrictions may extend to private aviation, but preliminary research by T&E suggests that this differs on a case-by-case basis. Therefore member states and the European Commission should set about removing such restrictions: for both commercial and private aviation. Where such restrictions do not exist today, thanks to regulators removing fuel tax exemptions between the EU and third countries [27], then taxation of jet fuel for private aviation should proceed.

One jurisdiction where taxation of private jet fuel is permitted, at least for domestic flights, is France. However, private jet fuel is subject to a lower tax regime than fuel for road vehicles. **In this case, the tax rate should be increased to at least equalise with road transport.**

In addition to fuel taxes, these flights should be subject to flight taxes to better reflect their climate impact. Tax revenues could be used to subsidise low-carbon fuels and technologies, as has been proposed in France by the Citizens Convention [28] and as has recently been adopted in Switzerland [29]. In France the proposal aimed at imposing a tax of 360€ for private flights below 2000 km and 1200€ for longer flights. Applying a tax proportionately to flight distances would be more representative of their climate impact, however. We calculated that such a measure would raise more than €325 million if applied to all flights departing from the EU(+UK)[15]. For the same reason, the size of aircraft should be taken into account, as in the flight tax legislation approved by Switzerland. Higher rates were proposed in that country than in the French Citizens Convention, i.e. between CHF 500 (€462) and CHF 3,000 (€2,775) depending on private jet weight and flight distance. An absence of data permits us from estimating revenue to be raised from this proposal. However it is clear from the sum of €325 million that making private aviation pay a price for its climate impact will provide welcome funds for decarbonising aviation. And such sums exceed what could be raised by extending EU ETS to the sector.

Such taxation will not entirely deter such flights - users are far too wealthy to be bothered by the relatively minor increase in price. However ensuring the wealthiest polluters pay the price for their disproportionate impact on the climate is socially fair especially as the aviation industry is today severely undertaxed compared to other modes of transport. Better pricing private jets pollution should be one of the first stepping stones towards promoting and bringing to the market cleaner aviation technologies, like more efficient aircrafts and clean fuels. These taxes alone won't be enough to decarbonise the sector, but they can assist in raising revenue for governments to invest in climate mitigation and adaptation.

[15] Using Citizen Convention's rate of 1200€/2000km and a minimum tax of 360€/flight.

6.2 Sustainable Advanced Fuels (SAF) for aviation

In addition to pricing, the private jet sector could contribute to greater use of sustainable advanced fuels (SAF). SAFs have the potential to substantially reduce the climate impact of aviation, including non-CO2 effects, especially when those SAFs are e-kerosene (known as power-to-liquid, PtL) produced from additional renewable electricity and captured CO_2. Such fuels are detailed more in our policy paper [30]. In our below recommendations, SAFs refer to this type of fuel.

A barrier to the deployment of such fuels is their high price relative to untaxed fossil kerosene. However the private jet sector is less price sensitive, in some parts not price sensitive at all, and therefore is better placed to absorb this price differential.

The EU's forthcoming ReFuelEU initiative, to legislate for the development of SAFs, will likely cover all aviation fuel sales in Europe, and therefore cover fuel sold for private jet use. One idea would be for the users of private jets to face a greater SAF use obligation under this or a related legislative initiative.

However this faces a number of hurdles. Firstly, T&E's recommendation is, for reasons detailed in the above paper, to impose a blending obligation on the fuel supplier, not the user (commercial or private). Secondly, it is expected that SAFs will be mixed into the global aviation fuel supply at the airport, making it hard if not impossible to impose a greater obligation on one type of user over another. Finally, differing mandates would entail greater administrative complexity.

As mentioned above, an alternative is to use revenues raised from taxation (per flight or on fuel purchases, as considered above) to fund the development and deployment of such fuels. This would help bring down their costs, facilitating their deployment more broadly in the aviation sector. Once SAFs are more widely available, private jet users could then face a higher binding obligation. In the meantime, private jet users should be encouraged, perhaps through exemptions from the above taxes, to enter into direct purchase agreements for such fuels. In particular, large private jet companies should be required to enter into the equivalent of power purchase agreements (PPA) to purchase e-kerosene. This could be facilitated through the deployment of such fuels at major airports used by private jets, and could be reflected in revised tax regimes.

Our analysis shows that **if the 50 most popular airports for private jets are equipped with SAFs, 50% of the European emissions for the sector can be covered**. In case all private flights departing from these airports would be supplied with SAF, 510kt of e-kerosene would be required, which corresponds to less than 1% of the total kerosene used by EU aviation in 2019. That's achievable, as our research has indicated that up to 2% of EU aviation fuel demand in 2030 could be met through e-kerosene.

However caution is needed to ensure that the legislative obligation on the sectors, commercial and private jets, combined with an increased use by private jets, does not result in demand exceeding supply, and therefore creating a risk of SAFs will low-environmental integrity being used. Using tax revenue from the sector to bolster supply can help reduce this risk.

Table 4 details the cost implications for such use in 2030 and 2040: **a 50%-50% e-kerosene/kerosene blend in 2030, and 100% e-kerosene in 2040, should both result in a price increase below 10%**. The assumptions for this calculation are further detailed in Appendix 1 and are, among others, based on the recent study commissioned by T&E to investigate renewable electricity needs to decarbonise the European transport [31]. In order to have conservative estimates on the cost increase, we did not choose the most optimistic technological and cost pathways.

Aircraft chartered	Capacity (passengers)	Charter rate Paris (LBG) - Geneva (GVA) (USD) - 2020	Price increase with 50% PtL - 2030	Price increase with 100% PtL - 2040
C56X - Cessna Citation Excel	7	7,800	2%-6%	4%-9%
GLEX - Global 6000	14	17,700	3%-6%	4%-10%
GLF5 - Gulfstream G550	18	63,400	1%-2%	1%-3%

Table 4: Charter rates of exemplary aircraft for a Paris-Geneva flight in 2020, and estimation of the corresponding increase in price by using e-kerosene in 2030 and 2040.

6.3 Aircraft design for greener flying

A number of manufactures have announced new, zero-emission aircraft including aircraft powered by hydrogen and battery electric. All designs currently publicly available propose, at least initially, aircraft suitable for short-haul carrying a small number of passengers, therefore ideal for the private jet market. **SRIA Clean Aviation Report has stated that private jets could conceivably shift to zero-emission aircraft by 2030** [32].

Thanks to their smaller energy requirements, private jets are better suited to electrification than commercial planes. This technology will bring highly-efficient powertrains and enable a complete redesign of the airframe for better aerodynamic efficiency while eliminating engine noise. It also solves non-CO_2 issues. The first electric private jet could be flying very soon, company Eviation having announced they are aiming for FAA certification of a nine-seater by 2022 (Fig. 11), while many others are in the race and electrification of 20-seat aircraft is expected to be introduced by 2025 [33].

Figure 11: Eviation's electric aircraft, Alice. Photo: Dassault Systemes.

While Airbus has announced a commercial plane powered by hydrogen combustion for the 2030s [34], company ZeroAvia is already flying a prototype of a smaller aircraft using hydrogen fuel cell technology. In September 2020 it achieved the world's first hydrogen fuel cell powered flight of a commercial-size aircraft, a Piper M-class six-seat plane (Fig. 12) [35]. The company is planning to commercialize 10-20 seaters from 2023. Hydrogen fuel cell propulsion will allow for longer ranges than electric propulsion but isn't completely devoid of climate impact as it emits water vapour and doesn't completely cancel contrail formation. It is estimated that the technology will reduce climate impact by 75% to 90% compared to conventional jet fuel [36].

Figure 12: ZeroAvia's hydrogen fuel cell aircraft, to be commercialized in 2023. Photo: ZeroAvia.

Another technology that should be available shortly is hybrid-electric propulsion. Ampere successfully completed a test flight back in June 2019, using the six-seater Cessna 337, and plans to begin commercialisation in 2021 [33]. Other companies follow closely to bring the aerodynamic and noise benefits of this technology to market. However, fuel efficiency improvements of such aircraft are rather limited (12% for small planes [33]) and hybrid electric planes should thus use SAF to make a true progress towards zero-emission aviation.

The private aviation market could therefore provide an important boost to new aircraft technologies, by ensuring they are used in this sector once developed. To ensure this occurs, regulators should set an end-date for the use of small, traditional jet engine aircraft, in Europe of 2030. From 2030 onwards, any private jet flights in Europe under 1,000 km will have to occur using these new aircraft.

In December 2020 the European Commission launched its Strategy for Smart and Sustainable Mobility (SSMS) which committed to making "scheduled collective travel" under 500km carbon neutral by 2030. This report, and ongoing design developments, demonstrates that such a target should not be limited to scheduled collective travel, but instead should be expanded to include unscheduled private travel by private jet. There's no clear reason why they should be exempt.

7 Conclusion & Recommendations

Private jet use will face increasing scrutiny as the climate crisis accelerates and other sectors decarbonise. In its current state, few arguments can be made to defend its continued existence, given its disproportionate use for leisure and short haul, and failure to develop and deploy decarbonising technologies.

However a potentially redeeming feature for the sector is the potential role it can play in the development of fuels and technologies which can be then deployed to decarbonise the larger commercial aviation sector. The fact that private jets are smaller and often travel shorter distances means the sector is well suited to be "first deployers" of zero-emission aircraft which will be, for some time, smaller and mostly suited for short haul trips. The wealth of its users means the sector can afford to contribute to the development and deployment of both these aircraft, and SAFs for longer journeys.

However, though there are promising signs for such new technologies, an unregulated business-as-usual approach will not suffice to see their deployment. Instead, much more effective regulation by governments at national and European level is required. That includes setting an end date for the use of fossil-fuelled private jets on certain distances in Europe, and using the reduced price sensitivity of the sector to drive development and deployment of new fuels and technologies. Even under the best circumstances however, such developments will take some years to appear. Until then, the world's wealthy and their companies must be far, far more reserved in their use of such flights.

Recommendations:

1) By 2030, regulators should only permit the use of hydrogen or electric aircraft powered with green hydrogen and electricity for private jet flights under 1,000km within Europe. Large private jet companies should be obligated to enter into PPA agreements with e-kerosene suppliers for all flights.
2) Until a ban is in place in 2030, a ticket and fuel tax should be imposed on fossil-fuel private jets, scaled with flight distance and aircraft weight, to account for their disproportionate climate impact. We suggest levying a ticket tax on all private flights departing from Europe, at rates similar to those implemented by Switzerland, i.e. at least €3000. This would raise several hundreds of million euros, which should be ring fenced to help fund the development of the new aviation technologies.
3) Pending the development of these new technologies, companies and individuals should commit to substantial reduction in private jet use. Flights should be prohibited when alternatives exist that do not increase travel time by more than 2h30.

8 Appendix 1: Methodology

8.1 CO2 emissions per passenger for private and commercial aircraft

The analysis is based on the following elements:

- Most used private aircraft models in Europe: ranking provided by the EBAA
- Most used commercial aircraft models in Europe: aircraft types with the most models in operation are used as proxies (based on manufacturers' data)
- Emissions vs. flight distance: calculated using EuroControl Master emission calculator for EMEA, available on: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-1/view
- Passenger numbers: manufacturer's data found online
- Load factor for commercial aviation: 0.8. Pre-COVID-19 values are actually slightly higher (source: STATFOR).
- Load factor for private jets: (share of non-empty flights)*(average occupancy of those flights) / (average capacity of the 5 most popular aircraft) = 0.6*4.7/7.4 = 0.38

Consumptions were compared for a distance of 500km, the medium flight length for intra-EU aviation, as calculated based on 2019 traffic data provided by the EBAA.

Table 5 presents the results of the analysis.

ICAO Aircraft Type Designator - Most common associated model	CO_2 intensity for 500km voyage, full capacity (gCO_2/pax.km)	CO_2 intensity for 500km voyage, average load factor (gCO_2/pax.km)
C56X - Cessna Citation Excel	649	1702
BE20 - Beechcraft King Air B200	420	1103
PC12 - Pilatus PC-12 NG	261	684
E55P - Embraer Phenom 300	557	1462
F2TH - Dassault Falcon 2000	613	1609
A320 - Airbus A320-200	108	135
A319 - Airbus A319	121	152

A321 - Airbus A321-200	109	136
B738 - Boeing 737-800	99	121
B737 - Boeing 737-700	114	141

Table 5: Fuel consumption of most used business jets and airliners

8.2 Private aviation emissions analysis

Our analysis of private aviation emissions in Europe is based on 2019 traffic data provided by the EBAA. They provided us with a list of all private flights with a stop in Europe, aggregated by route (both ways) and aircraft model. These include military and ambulance flights that we could not exclude from the analysis as there is no way to determine the purpose of the flight from the provided database.

We calculated the CO_2 emitted for each of these flights based on EuroControl's Master Emission Calculator for EMEA. Some aircraft models do not have emission data in the calculator. **81%** of the total intra-EU(27+UK) distance was flown with aircraft which matched the database, whereas this figure was **86%** for extra+intra-EU flights. When using absolute emissions figures, we thus divided the emissions calculated by these factors, considering the unmatched aircraft would have on average a similar consumption to that of the aircraft in the Master Emissions Calculator.

Finally, we compared the number of flights reported in the EBAA's data with aggregated figures available on EuroControl's STATFOR platform. The result is shown in Table 6. The EBAA's data mostly included flights from, to and over the ECAC area, hence the comparison with STATFOR ECAC figures. The numbers are in excellent agreement with each other. The small differences might be due to certain plane or flight types that were taken into account into one of the datasets (depending on the definition of "business aviation") or incomplete flight tracking data.

Scope	All	Intra+extra-EU(27+UK)	Intra-EU(27+UK)
EBAA data	665589	600857	423414
STATFOR (ECAC)	657482	601305	432418

Table 6: Comparison between EBAA and STATFOR private jet traffic data

Shortly before the publication of this report, the EBAA provided us with their estimation of private aviation total emissions between 2005 and 2019. Their 2019 value ($2.12MtCO_2$) is lower than our estimation ($2.51MtCO_2$). There can be several reasons for this discrepancy:

- Different emissions calculation methods were used
- An approximate engine improvement factor was included in EBAA's calculation, based on a discussion with engine manufacturers, and is unlikely to be included in EuroControl's calculator. This improvement factor has not been verified so we didn't deem justified to include it
- The aircraft with missing emission data for which we assumed average emissions rates could be smaller, less polluting aircraft than the average
- Different scopes could be used (inclusion of military and ambulance flights)

8.2.1 Attribution of airport and country emissions

The data at the basis of the analysis was an aggregate of flights in both directions for each private flight route. We thus divided the total flights and emissions per route by two when attributing emissions to airports and countries (except for domestic routes in the latter case). The real distribution of flights shouldn't be far from 50%/50% in each direction in reality.

8.3 Travel alternatives for flights shorter than 500km

The total duration of private jets trips was calculated as the sum of:

- 15 minutes travel time from the departure city center to the private aviation departure airport and from the arrival airport to the arrival city center
- 10 minutes check-in time
- The duration of the flight, approximated by: (distance between airport) / (cruise speed of average private jet)[16] / 0.75. The factor 0.75 is added to account for landing and take-off. Private flight durations are in any case shorter than what could be found online, showing that this analysis is conservative

For alternative modes of transportation, search engine Rome2Rio was used to compute the travel time, adding 15 minutes travel time when travelling between city centers and train stations. For commercial planes, a two-hour check-in time was assumed.

For airports around London, the city considered in the analysis is the precise city where the airport is located, not London itself. This makes trips with alternative modes of transportation longer than if the trips were between London itself and another city.

8.4 Emissions saved by replacing private flights by car trips

The assumptions for that calculation are:

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[16] https://prijet.com/performance/Cessna%20Citation%20XLS

- Private planes that are boarded are boarded on average by 4.7 passengers and can thus be comfortably replaced by a 7-seater van
- Emissions of a Mercedes Classe V AVANTGARDE (https://voc.i.daimler.com/voc/be_fr?owda=v-class_vans), using average real-world consumption on SpiritMonitor on 11/01/2021 (9.11L/100km, https://www.spritmonitor.de/fr/apercu/28-Mercedes-Benz/930-V-Klasse.html?exactmodel=avan&powerunit=2)

8.5 Paris - Nice flights and equivalent cars trips

Assumptions:

- Average consumption of new car in France: 112 gCO_2/km (http://carlabelling.ademe.fr/chiffrescles/r/evolutionTauxCo2)
- Paris-Nice by car, return trip 1864 km (https://www.google.be/maps/dir/Paris,+France/Nice,+France/@46.1042169,2.3085156,7z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x47e66e1f06e2b70f:0x40b82c3688c9460!2m2!1d2.3522219!2d48.856614!1m5!1m1!1s0x12cdd0106a852d31:0x40819a5fd979a70!2m2!1d7.2619532!2d43.7101728!3e0)

8.6 PtL analysis - increase in price of chartered flights by using e-kerosene with/instead of kerosene

This analysis is based on the following assumptions and calculations:

- Charter rates for one LBG-GVA flight, retrieved from: https://www.fly-efi.com/private-charters/private-jet-charter-quote
- Fuel burn calculated using EuroControl Master Emission calculator
- Flight price = (fuel price) + (fixed part). The fixed part is determined by subtracting the kerosene costs from the charter rates, and assumed to stay constant over time. This is a conservative assumption, as charter rates will likely increase with inflation.
- Kerosene price: 600€/t. Given the high uncertainty in kerosene price fluctuation for the next decades, the analysis is simplified by using a constant price. It is assumed that no tax is levied on this fuel, which is also a conservative assumption for this analysis.
- E-kerosene price: using the values calculated in Ricardo's report commissioned by T&E [31], i.e. 136.6€/MWh (2030) and 99.8€/MWh (2050) and a variation of +-25% around those values for min/max analysis. The resulting prices were found to be close to the values calculated with the PtG/PtL calculator from Agora, accessible on: https://www.agora-energiewende.de/en/publications/ptg-ptl-calculator/

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