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Potential tankering under an EU sustainable aviation fuels mandate

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Summary

Commercial aviation is a significant and growing source of greenhouse gas (GHG) emissions. Sustainable aviation fuels (SAFs) could be a key way for airlines to reduce emissions, but uptake to date has been minimal due to limited supply and high costs. Accordingly, European Union (EU) policymakers are developing a mandate requiring jet fuel providers to blend an increasing share of SAFs into their fuel supply at EU airports starting in 2025. Such an approach raises concerns that airlines might choose to uplift additional fossil jet fuel at non-EU airports in order to avoid purchasing the more expensive SAF blends. This is a practice known as tankering. Tankering saves money for airlines but increases systemwide fuel use and emissions and would reduce SAF sales at mandated airports.

This paper investigates the potential for tankering to undermine the environmental objectives of an EU SAF mandate. Drawing upon our Global Aviation Carbon Assessment (GACA) model, we estimate the emissions and fuel sales impacts of tankering on flights arriving at EU airports through 2035. We find that tankering should be minimal in 2025, but could increase substantially as the relative share of SAF in the fuel mix increases; by 2035, tankering could reduce SAF sales by 22% at EU airports and increase systemwide fuel use by 0.9%. This assumes that adjoining countries do not adopt parallel SAF mandates.

After accounting for both reduced SAF sales and increased systemwide fuel consumption, carbon dioxide (CO_2) reductions attributable to an EU SAF mandate could fall by about one quarter as a result of tankering. Flights originating from the United Kingdom could be responsible for half of tankered flights (52%) and excess fuel (49%) consumed. The integrity of an EU SAF mandate could be safeguarded by obligating airlines to purchase SAFs; by defining, and then prohibiting the carriage of, "excess" fuel; and if neighboring countries like the United Kingdom and Switzerland adopt equivalent SAF mandates.

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Background

Commercial aviation emitted more than 900 million tonnes (Mt) of carbon dioxide (CO_2) globally in 2019 (Graver & Rutherford, 2020), or about as much as the German and Dutch economies combined. The European Union (EU) is the second largest aviation market in the world, with passenger flights departing the EU-27 emitting 120 Mt CO_2 in 2019, second only to the United States. Moreover, prior to the COVID-19 pandemic, which dramatically reduced air travel, airline CO_2 emissions were expected to triple globally by 2050 under business-as-usual growth. Absent policies to reduce aviation emissions, it is unlikely that the European Union will be able to meet its goal of reducing greenhouse gas (GHG) emissions by 55% below 1990 levels in 2030 (Frangoul, 2020).

Sustainable aviation fuels (SAFs) created from biological or synthetic feedstocks could be a key way for airlines to meet their goal to reduce CO_2 emissions to 50% below 2005 levels by 2050 (International Air Transport Association, 2021). SAFs, which have similar chemical and physical properties to fossil jet fuel (Jet A), can be blended into the existing fuel supply and used in planes today at up to 50% fractions. At the same time, current use is negligible—less than 0.05% of global jet fuel supply—due to limited supply and high cost. Since voluntary targets for SAF use by airlines have been missed by a wide margin,[1] policymakers in Europe are now considering mandates for the sale and/or use of SAFs.

Under its ReFuelEU Aviation initiative, the European Commission is investigating a SAF mandate (European Commission, 2020a) pursuant to which sellers of jet fuel at EU-27 airports would be required to blend an increasing fraction of SAFs into their fuel starting in 2025. The mandate could promote SAFs generated from waste fats, oils, and greases (FOGs), advanced biofuels made from cellulosic wastes, and electrofuels generated from renewable electricity. This approach is consistent with O'Malley, Searle, and Pavlenko (2021), which found that diverting existing FOGs from road transport to aviation could meet up to 2% of European jet fuel use by 2025, but that substantial, targeted policy support would be needed to unlock additional supply from pathways like cellulosic biofuels and electrofuels.

The precise design of the European Union's upcoming mandate is still under discussion. Under one approach, fuel providers would be obligated to provide the fuel at affected airports, and the airlines would be indirectly regulated when they purchase the more expensive SAF blends. However, not requiring that airlines purchase SAFs would leave open the possibility that they could evade the SAF mandate by tankering, which is a practice of uplifting excess cheap fuel at one airport to avoid purchasing more expensive fuel at another. Tankering is a common practice today; for example, British Airways reportedly uses it to reduce fuel purchases in Europe (Rowlatt, 2019).

Jet A prices already vary between airports. A 2019 study (Eurocontrol Intelligence Unit, 2019) estimated that tankering saves airlines about €265 million annually on flights within the European Civil Aviation Conference (ECAC) region, and could generate an additional 900,000 tonnes of CO_2 emissions per year. Interviews suggest tankering on 30% of ECAC flights, with lower fuel costs being the motivator in 90% of cases. The existence of tankering today implies that airlines could carry excess fossil jet fuel on flights into the European Union to avoid purchasing SAF blends at mandated airports.

Tankering increases the takeoff mass of the plane on its inbound leg and, therefore, imposes a fuel burn penalty proportional to stage length (flight distance). Most tankering occurs on short-haul flights because savings from purchasing cheaper fuel at one airport become offset as stage length increases. For the foreseeable future, SAFs are expected

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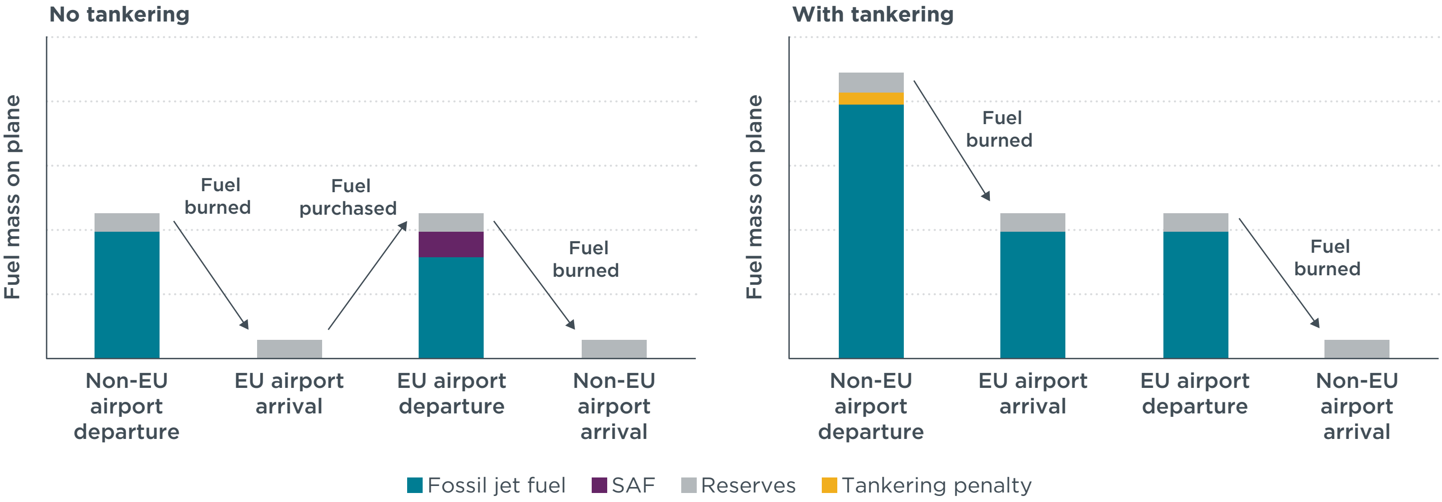
[1] In 2009, the International Air Transport Association established a target for 10% SAF adoption globally by 2017 (Baljet, 2009). In 2011, IATA's goal was reduced to 6% adoption by 2020. It now advises governments to adopt policies consistent with 2% SAF adoption in 2025 (Gill, 2020).

to cost substantially more than fossil jet fuel. This means that airlines operating flights to and from mandated airports in Europe may have an incentive to tanker fuel on flights into the EU to avoid purchasing SAF blends. This would save airlines money, but increase the use of fossil jet fuel and reduce SAF sales within the European Union (Figure 1).



Note: Bar sizes are illustrative and approximate for clarity.

Figure 1. Tankering and forgone SAF sales at EU airports.

This paper investigates the potential for tankering to undermine the environmental objectives of an EU SAF mandate. Drawing upon our Global Aviation Carbon Assessment (GACA) model, we estimate the emissions and fuel sales impacts of tankering on flights arriving at EU airports through 2035.[2] Countries that are likely to generate tankered flights are identified, and we also consider measures that could mitigate the risk of tankering. Note that some neighboring non-EU states already have adopted or might adopt their own SAF mandates. Norway introduced a SAF mandate of 0.5% at the start of 2020 (Surgenor, 2018) and the United Kingdom is expected to launch a consultation in spring 2021 (Read, 2020). These policies would reduce the incentive for airlines to tanker into EU airports, a topic we return to later.

The rest of this paper is arranged as follows. First, we introduce the methods used to identify flights that are likely to tanker and their impact on fuel use and SAF sales. Next, we present our results, including how much fuel would be tankered and the associated emissions increase, along with which routes would be vulnerable to tankering. We conclude with recommendations for policymakers and thoughts on future work.

Methodology

GACA models fuel burn by airport-airport pair, airline, and aircraft type for a given calendar year. We analyzed 2019, the last year of normal operations before the impact of COVID-19, using operations data from the Official Airline Guide (OAG). Due to data disclosure restrictions set by some freight carriers, only passenger flights were analyzed. All routes that did not originate or terminate at an airport in the European Union were removed from the dataset, as were routes operated by airlines defunct as of March 2021. Round trip flights (airport A to B and then back again) were identified by matching one-way legs linking two airports by airline and aircraft type. A small number of one-way legs that could not be linked into round trips, accounting for 1.8% of all CO_2 emissions from EU airports, were removed from the dataset.

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[2] For this paper, we define EU airports as airports located within the EU-27 plus Norway, which is likely to align its SAF mandate to the European Commission's proposal.

Next, a fuel burn penalty for tankered fuel was generated by aircraft class (regional, narrowbody, and widebody) using representative aircraft operated at European airports. Fuel burn across various flight distances up to 2,000 kilometers (km) with various payloads was modeled using Piano 5.[3] Tankered fuel to cover a return trip was added (100% tankering), and fuel burn was modeled a second time. When an aircraft's maximum landing weight (MLW) with tankering was exceeded for a specific distance, flights of that distance and greater were removed from the analysis.[4] The tankering fuel burn penalty was determined by dividing this second fuel burn by the original fuel burn at each flight distance.

The average fuel burn penalty across aircraft classes at increasing flight distances was derived, and then linearly regressed against stage length. The results are shown in Table 1. Partial tankering (e.g., carriage of half of the fuel needed for a return trip) was not analyzed in this paper but could be significant.

Table 1. Tankering fuel burn penalty by aircraft class.

Aircraft class	Example type	Fuel burn penalty per 100 km
Regional	Embraer 190/195 Family	0.322%
Narrowbody	Airbus A320	0.388%
Widebody	Boeing 777 Family	0.342%
Advanced widebody	Airbus A350 Family	0.265%

Fuel costs for baseline Jet A and SAF mandated blends were then projected for the analysis. Blending targets for 2025 to 2035, as presented by the European Commission in November 2020 (bottom row of Table 2), were used to model baseline and SAF-mandated fuel costs. We assume that the ReFuelEU mandate will allow only Annex IX biofuels, as defined under the Renewable Energy Directive (RED II), with an additional sub-target for electrofuels produced from renewable electricity (Directive [EU] 2018/2001). Electrofuels will contribute 0.7% of jet fuel demand in 2030, and this increases to 5% by 2035 at medium and large airports. We assume that biofuels, comprised of a mix of FOGs (List B) and lignocellulosic feedstocks (List A), will contribute 2% of jet fuel demand in 2025 and 15% in 2035.

Table 2. Blending mandate assumed at medium and large airports

Fuel type	Explanation	2025	2030	2035
Biofuels	Annex IX List A and List B biofuels	2.0%	4.3%	15.0%
Electrofuels	E-kerosene or PtL	—	0.7%	5.0%
Expected SAF blend		2.0%	5.0%	20.0%

Source: European Commission (2020b).

These high-level targets were used to derive airport-level sales volumes after assuming that the mandate will be phased in as a minimum sales requirement at medium and large airports first, with small airports following 5 years later. Small airports were defined as those with fewer than 1 million passengers arriving and departing per year.

Jet A prices were assumed to be €0.42, €0.48, and €0.52 per liter in 2025, 2030, and 2035, respectively (Energy Information Agency, 2020). SAF prices were assumed to

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[3] https://www.lissys.uk/index2.html

[4] Every aircraft has a certified MLW that indicates the maximum gross mass, including empty weight, payload, and fuel, at which it can safely land. MLW limits the ability of certain aircraft types, especially widebody aircraft on mid-haul flights, to tanker even when they would otherwise save money by doing so.

be linear to the blend fraction at mandated airports,[5] with net prices generated using a discounted cash flow analysis. Fuel sales were assumed to grow 2% per annum at European airports from 2018 to 2050, per the reference case under Destination 2050 (van der Sman et al., 2021). To identify additional tankering attributable to the SAF mandate, a single price each for Jet A and SAF was used across all airports in a given year.[6] Potential tankering between small and medium/large airports within the European Union attributable to the staggered implementation date was not analyzed (see below).

The costs of gasification Fischer-Tropsch (FT) SAF produced from agricultural residues, gasification-FT SAF produced from municipal solid waste (MSW), and hydroprocessed esters and fatty acids (HEFA) SAF produced from used cooking oil were taken from Pavlenko et al. (2019). Biofuel production costs are based on an assumption of commercial-scale, Nth of a kind facilities producing a mixed product slate. We assume that facilities are configured to produce fuels at the lowest price rather than to maximize SAF output; this may underestimate costs because the mandated fuel volumes outlined in Table 2 may require maximizing output for jet fuel but at higher production costs. These cost estimates align with the literature on SAF production, which suggests that HEFA fuels are generally least cost in the near-term at below €1 per liter, whereas SAFs produced from lignocellulosic feedstocks will be more expensive (Bann et al., 2017; de Jong, 2018).

HEFA fuels produced from waste oils will be cheaper, but their availability is constrained by limited domestic waste oil supply in the European Union and the 1.7% cap on List B fuels toward the RED II target. Based upon an availability assessment of EU SAF feedstocks (O'Malley et al., 2021), we estimate that waste oil-derived HEFA can provide 2% of EU jet fuel demand in 2025; this declines toward 1.9% in 2035 as sectoral demand increases. The remaining biomass-derived SAF is expected to come from a mix of MSW, agricultural residues, and forestry residues.

The cost of electrofuels is derived from Searle and Christensen (2018), which used a financial model to estimate the cost of electrofuels production from additional renewable electricity in the European Union. The model takes into account declining renewable electricity prices, capital costs, and conversion costs to estimate the level of policy support needed to make electrofuels cost-viable. Cost projections for electrofuels are highly dependent on assumptions of the future price of additional renewable electricity, capacity factors for electrolyzers, and taxes and fees for grid-connected projects.[7]

Table 3 outlines the base SAF fuel prices assumed for the modeling, along with a low capital expenditure (CapEx) case used to test the sensitivity of our results to assumptions of declining biofuel costs over time. Results were found to be robust against fuel price assumptions, as outlined below.

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[5] The incremental costs of SAF blends were modeled only at mandated airports. In other words, we assumed that fuel suppliers will not spread the cost of SAF investments to fuel sold at smaller airports initially exempt from the mandate.

[6] The price of both Jet A (Eurocontrol Aviation Intelligence Unit, 2019) and SAF blends are expected to vary from airport to airport, potentially leading to tankering even on trips between EU airports. Since no data is available for the latter, and also to focus on incremental tankering attributable directly to the SAF mandate, a single price for each is assumed here.

[7] Some studies project lower costs for electrofuels due to cheaper renewable electricity than shown in Table 3. For example, the World Economic Forum (2020) assumed a global average solar electricity price of US$ 33 (€28) per megawatt hour in 2030 without factoring in grid fees and taxes. Consequently, the price of electrofuels is approximately €1,670 per tonne (€1.30 per liter) in 2030—about half the price assumed here.

Table 3. Neat SAF price assumptions used

Fuel	Cost	Incremental cost compared to Jet A by year, neat (€/L)		
		2025	**2030**	**2035**
Used cooking oil HEFA	Base	+0.46	+0.40	+0.36
	Low CapEx	+0.46	+0.28	+0.28
Agricultural residue gasification-FT	Base	+1.36	+1.30	+1.26
	Low CapEx	+1.36	+0.85	+0.85
MSW gasification-FT	Base	+0.92	+0.86	+0.82
	Low CapEx	+0.92	+0.40	+0.40
e-kerosene	Base	+1.96	+1.90	+1.85
	Low CapEx	+1.96	+1.90	+1.85

As shown in Table 3, the incremental cost of neat SAFs relative to fossil jet fuel is expected to fall over time, from €0.46 to almost €2 per liter in 2025 down to €0.36 to €1.85 per liter in 2035 under the base case. Used cooking oil is expected to be the cheapest SAF, and e-kerosene the most expensive. Note, however, that while used cooking oil feedstocks are limited, electricity generation for e-kerosene production is more scalable.

These price assumptions, along with the assumed mandate volumes, were used to estimate the incremental cost of SAF blends at airports subject to the EU alternative fuels mandate (Table 4).

Table 4. Fuel split assumed and estimated cost for airports by size

	2025		2030		2035	
	Small	**Medium/ Large**	**Small**	**Medium/ Large**	**Small**	**Medium/ Large**
Jet A	100%	98%	98%	95%	95%	80%
Biofuels	—	2%	2%	4.3%	4.3%	15%
e-kerosene	—	—	—	0.7%	0.7%	5%
Base SAF blend cost (€/L)	0.42	0.43	0.49	0.53	0.57	0.77
Jet A cost (€/L)	0.42		0.48		0.52	
Base cost increase (€/L)	—	0.01	0.01	0.05	0.05	0.25

We assume a 2% alternative jet fuel mandate for medium and large airports starting in 2025 that expands to 20% in 2035. Small airports have a staggered mandate, requiring 2% starting in 2030 and 5% in 2035. In each case, a sub-target of 0.7% is assumed for e-kerosene in the second commitment period, increasing to 5% in 2035 at medium and large airports. The bottom row in Table 4 estimates the overall fuel price increase expected from the mandate. It ranges from a €0.01 per liter price increase from a 2% SAF mandate up to a €0.25 per liter increase in 2035 associated with a 20% SAF mandate at medium and large airports.

These fuel cost increases were used to model the prevalence and impacts of tankering. Each round trip (identified based on origin, destination, airline, and aircraft type) was assigned a tankering fuel burn penalty from Table 1 based on its aircraft class and stage length. Flights expected to tanker were identified based on fuel cost savings, defined by any savings after accounting for the difference between fuel costs with and without tankering minus €37.59 per tonne of excess CO_2 emitted, the current EU Emissions

Trading System (ETS) carbon price (Ember, 2021).[8] Excess CO_2 due to tankering was calculated as 3.16 times the excess fuel burn of the inbound flight. All flight, fuel, and emission values were scaled based on projected fuel consumption from Destination 2050 (van der Sman et al., 2021) in 2025, 2030, and 2035 respectively.

Results

This section introduces the key findings of this paper, namely the number of flights expected to tanker under an EU SAF mandate, the fuel volumes and associated emissions increase, the impact of tankering on SAF volumes sold at mandated airports, and which routes airlines are likely to tanker on. All results presented are for the base-case SAF costs because the results were largely insensitive to the low CapEx SAF prices scenario.[9]

Tables 5, 6, and 7 present the estimated share of round trips, fuel consumed, and tank-to-wake (TTW) CO_2 emissions attributable to tankering in 2025, 2030, and 2035, respectively. No tankering due to the SAF mandate is expected on domestic and intra-EU flights due to the price assumptions used. The identified CO_2 increases are from fuel consumed only and do not take into account emissions reduced in the upstream production of a SAF blend.

Table 5. Round trips, fuel consumed, and CO_2 increase from tankering, 2025

	Round trips (million/%)			Fuel consumed (million tonnes/%)			CO_2 emissions (million tonnes/%)		
Route	**Total**	**Tankered**	**% tankered**	**Base**	**w/ tankering**	**% increase**	**Base**	**w/ tankering**	**% increase**
Domestic	0.9	—	—	4.1	—	—	12.9	—	—
Intra-EU	1.4	—	—	12.9	—	—	40.8	—	—
International	1.6	0.2	11%	49.7	49.7	0.01%	156.9	156.9	0.01%
Total	**3.9**	**0.2**	**5%**	**66.7**	**66.7**	**0.01%**	**210.7**	**210.7**	**0.01%**

Table 6. Round trips, fuel consumed, and CO_2 increase from tankering, 2030

	Round trips (million/%)			Fuel consumed (million tonnes/%)			CO_2 emissions (million tonnes/%)		
Route	**Total**	**Tankered**	**% tankered**	**Base**	**w/ tankering**	**% increase**	**Base**	**w/ tankering**	**% increase**
Domestic	1.0	—	—	4.6	—	—	14.6	—	—
Intra-EU	1.5	—	—	14.6	—	—	46.1	—	—
International	1.8	1.1	60%	56.1	56.4	0.5%	177.3	178.1	0.5%
Total	**4.4**	**1.1**	**25%**	**75.3**	**75.6**	**0.3%**	**238.0**	**238.8**	**0.3%**

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[8] SAFs, which reduce life-cycle emissions of jet fuel, should reduce ETS compliance costs for airlines when used. Since we did not complete a detailed life-cycle assessment of SAFs in this report, we did not quantify those savings for airlines. This slightly overestimates the cost differential between SAF blends and Jet A and therefore may slightly overestimate tankering.

[9] Under the low CapEx case, the frequency of tankering and overall SAF sales did not change from the base case in 2025 and 2035 because the implied SAF blend cost difference was small, either in absolute terms (2025) or relative to the overall fuel cost savings (2035). In 2030, some differences were seen, with the share of tankered flights under the low CapEx case falling five percentage points to 20% of all flights, and SAF sales at EU airports increasing about 70,000 tonnes (3%), both relative to the base case.

Table 7. Round trips, fuel consumed, and CO_2 increase from tankering, 2035

Route	Round trips (million/%)			Fuel consumed (million tonnes/%)			CO_2 emissions (million tonnes/%)		
	Total	Tankered	% tankered	Base	w/ tankering	% increase	Base	w/ tankering	% increase
Domestic	1.2	—	—	5.2	—	—	16.5	—	—
Intra-EU	1.7	—	—	16.5	—	—	52.1	—	—
International	2.0	1.6	78%	63.4	64.2	1.2%	200.3	202.7	1.2%
Total	**5.0**	**1.6**	**32%**	**85.1**	**85.9**	**0.9%**	**268.9**	**271.3**	**0.9%**

As shown, tankering is expected to be rare in 2025—on 11% of international flights and 5% of all flights—due the small cost increase under a 2% mandate. Significant tankering is expected by 2030, when almost two-thirds of international flights, or a quarter of all flights within and into the European Union, are expected to carry excess fuel. This share rises to almost 80% of international flights and a third of all flights to and from EU airports as the SAF mandate escalates in 2035.

While almost 80% of international flights would be expected to tanker by 2035, excess emissions remain modest compared to all emissions from flights to and from EU airports; this is because most flights that tanker will be short-haul. We expect near-zero fuel and CO_2 increase in 2025, less than 1 Mt of CO_2 (0.3% of all emissions) in 2030, and then rising to 2.4 Mt (0.9% of all emissions) in 2035. However, when combined with foregone SAF sales at EU airports (see below), the combined emissions impact of tankering could be substantial (Table 8). Assuming an 80% reduction in life-cycle CO_2 emissions from SAFs, tankering could cause well-to-wake (WTW) emission reductions from the SAF mandate to fall by about one quarter, or 25% and 27%, in 2030 and 2035, respectively.

Table 8. Well-to-wake CO_2 reductions from SAF use with and without tankering, 2025 to 2035

Year	WTW CO_2 reductions from SAF mandate (Mt)			% of emission reductions foregone
	No tankering	+ tankering	+ tankering and excess fuel burn	
2025	2.0	2.0	2.0	-2%
2030	5.8	5.2	4.4	-25%
2035	26.1	21.4	19.0	-27%

Source: ICCT analysis, assuming 80% reductions in WTW emissions from SAFs.

Expected SAF sales at EU airports would also fall due to tankering, as would fuel expenditures by airlines, after taking into account three costs: (1) reduced fuel costs due to the purchase of cheaper fossil jet fuel instead of SAF; (2) the extra fuel consumed associated with the excess fossil jet fuel carriage; and (3) an EU ETS charge for those emissions.[10] This is shown in Figure 2 for SAF sales (bars, left axis) and fuel savings (black line, right axis).

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[10] For this calculation, we assume that emissions units need to be surrendered for 100% of the excess emissions (i.e., no grandfathered permits are allocated to tankering airlines).

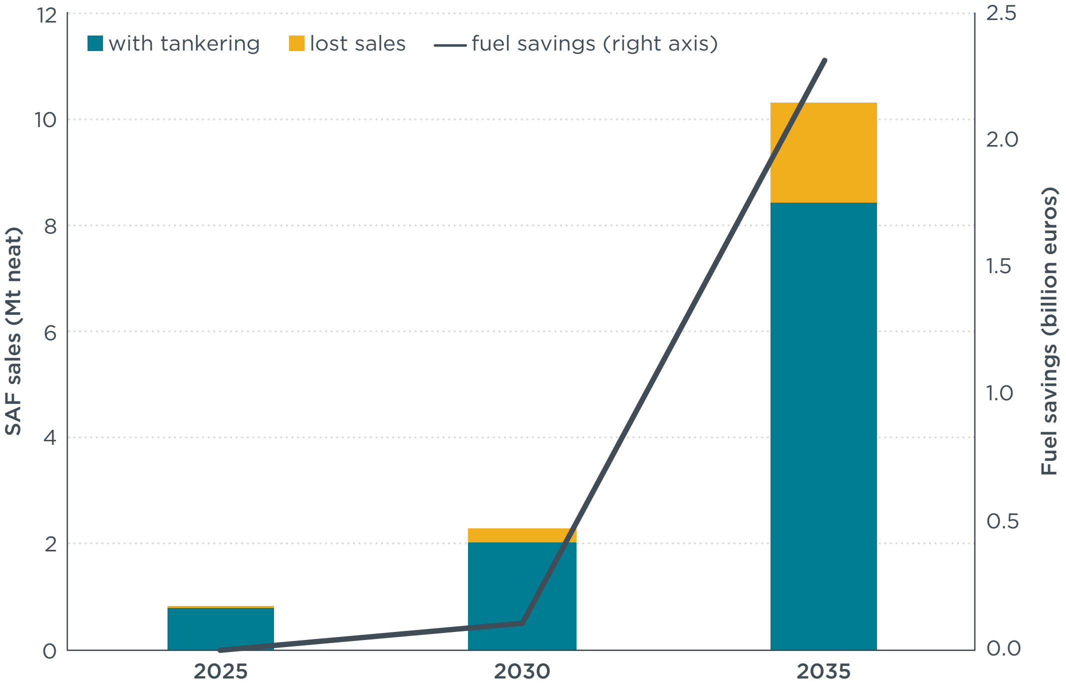
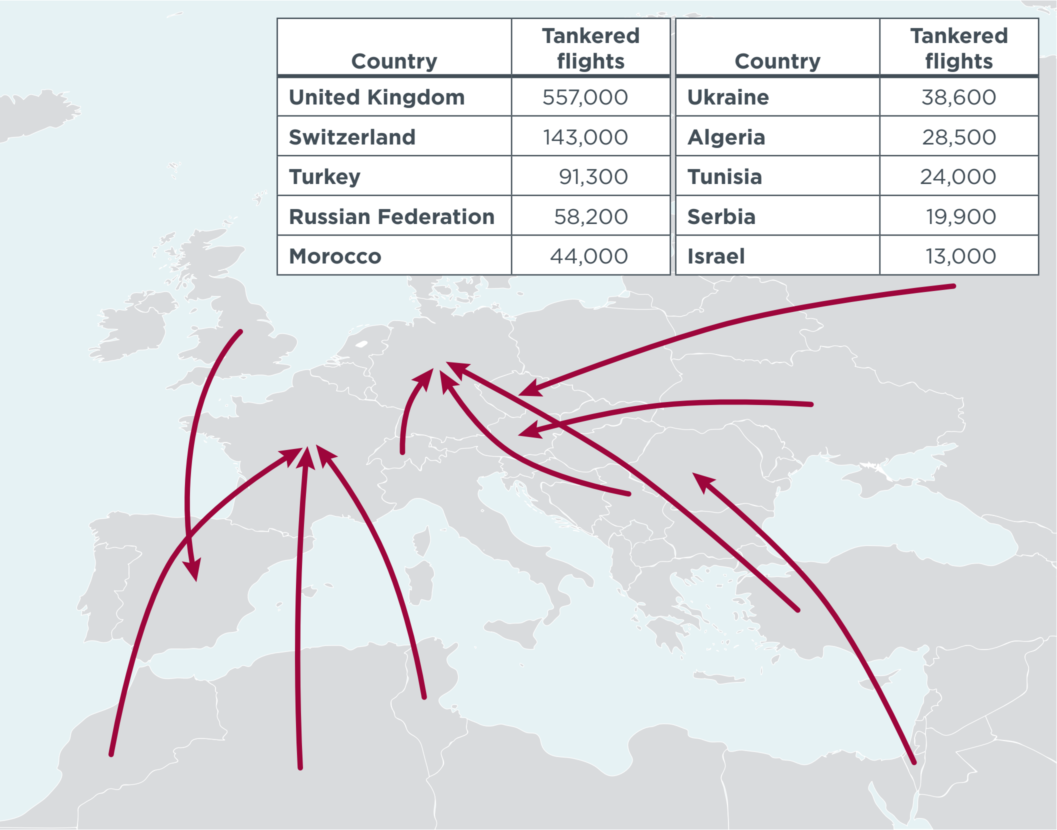


Figure 2. SAF sales lost by tankering and associated fuel savings.

Starting in 2030, tankering would have a material impact on mandated SAF sales under the system, reducing sales at EU airports by up to 1.85 Mt in 2035, or 22% below the hypothetical case where no tankering occurs. Savings for airlines due to tankering could reach €2.3 billion in 2035 after taking into account excess fuel burn and EU ETS costs. Thus, while the emissions impacts of tankering would be small, SAF sales themselves could fall substantially.

Where are tankered flights likely to originate from? We find that most of the flights expected to tanker into EU airports are from a limited number of countries (Figure 3). Of these, flights from the United Kingdom are expected to be particularly important, representing half of tankered flights (52%) and excess fuel use (49%) in 2030; this is four times the second most important country, Switzerland. Turkey and Russia could each generate more than 50,000 tankered flights in 2030.



Country	Tankered flights	Country	Tankered flights
United Kingdom	557,000	**Ukraine**	38,600
Switzerland	143,000	**Algeria**	28,500
Turkey	91,300	**Tunisia**	24,000
Russian Federation	58,200	**Serbia**	19,900
Morocco	44,000	**Israel**	13,000

Figure 3. Origin and destination country of example tankered flights, 2030.

As indicated in the figure, a typical tankered flight would be short-haul—in the range of 900 to 1,700 km in 2030—and link states within the EU-27 to a close neighbor, either the United Kingdom, northern Africa, or Eastern Europe. On longer flights, for example from Gulf States, it is generally not economical to tanker due to the large fuel penalty (e.g., 15% for a typical widebody aircraft on a 4,500 km flight). Moreover, long-haul flights that could reduce costs by tankering, for example under the 2035 mandate, are generally unable to do so because they would exceed their MLW.[11]

Figure 4 presents the cumulative distribution of tankered flights by analysis year. As shown, increasing the SAF blending ratio over time expands the number of flights for which tankering would save airlines money. A 2% mandate in 2025 could spur most international flights into the EU shorter than 500 km to tanker. Starting in 2030, international flights less than 2,000 km could tanker to avoid purchasing 5% SAF blends at medium and large airports. By 2035, a 20% mandate at medium and large airports could motivate essentially all (97%) international flights capable of tankering to do so. Note that Figure 4 already excludes longer flights on which an aircraft's MLW would be exceeded under full tankering.

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[11] In our modeling, we assume that payload is conserved (i.e., airlines do not reduce cargo carried in order to tanker additional fuel). Likewise, we analyze only full tankering (carrying 100% of return fuel), which was identified as more common than partial tankering (Eurocontrol Aviation Intelligence Unit, 2019). Accordingly, we may underestimate tankering on longer flights.

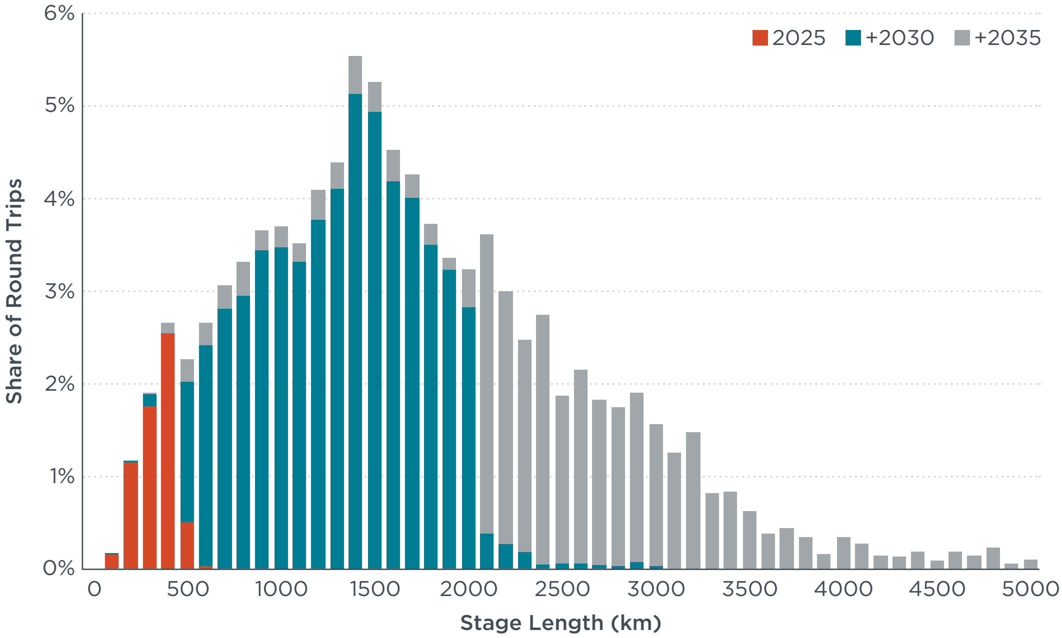

Figure 4. Stage length of international tankered flights by year.

Figure 2 illustrated how SAF sales could fall as the SAF blending ratio and costs rise, leading to tankering. Conversely, EU SAF markets could be expanded if tankering is restricted. Figure 5 shows how eliminating tankering on flights arriving from key nations would increase SAF volumes sold at EU airports. Volumes indicated are for neat (100%) SAF.

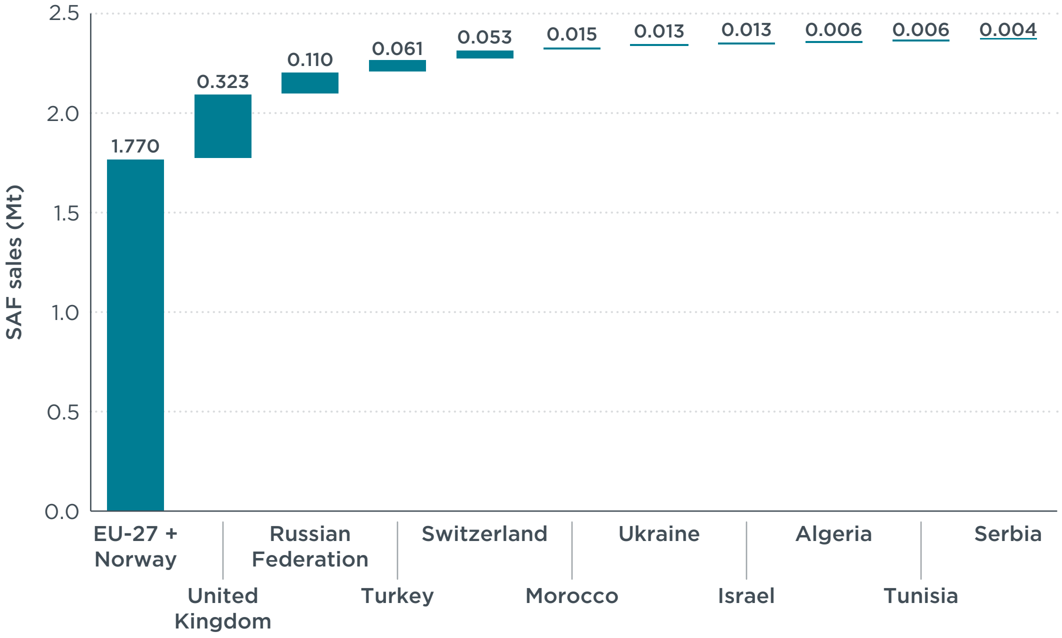

Figure 5. EU SAF sales under a 2030 mandate by eliminating tankering from select nations

Eliminating tankering flights arriving from just the United Kingdom would increase EU SAF sales by almost 20% in 2030, from 1.77 to 2.09 million tonnes. This could be achieved through measures to reduce the incentive to tanker, including requiring that all carriers operating at EU airports purchase SAFs, through a prohibition on the carriage of "excess" fuel, or by the United Kingdom adopting a parallel SAF mandate. Additional gains would come from eliminating tankering from the Russian Federation, Turkey, and Switzerland, but to a smaller extent.

Note that this analysis does not include extra fuel sales in countries that adopt their own SAF mandates, which could be sizeable for large markets. For example, a 5% SAF mandate in the United Kingdom would require about 580,000 tonnes of SAF sales in 2030 for passenger flights departing its airports alone, independent of EU requirements. As noted earlier, the United Kingdom is expected to begin considering its own SAF mandate starting in spring 2021.

Conclusions

This paper used ICCT's GACA model to develop a bottom-up, transparent assessment of potential tankering under an EU SAF mandate. We find that tankering would be minimal before 2030, but could substantially impact SAF sales at mandated airports and dilute the associated emissions benefits as blend ratios rise. Under an escalating SAF mandate, tankering would be limited in 2025, but could occur on almost 80% of international flights to and from EU airports in 2035. The carriage of excess fossil jet fuel could reduce SAF sales at EU airports by 22% in 2035 and lower the CO_2 emissions benefits of a SAF mandate by about one quarter. The United Kingdom is the likely source of half of tankered flights, followed by Switzerland, Turkey, and the Russian Federation.

Reducing tankering could support SAF sales and safeguard the integrity of SAF mandates in Europe. Three approaches are possible: (1) mandating that airlines purchase SAFs at EU airports; (2) defining, and then prohibiting the carriage of "excess" fuel to and from the European Union; (3) encouraging neighboring nations to adopt equivalent mandates. Developing a clear and fair definition of tankering would be needed before any regulations could be imposed. The United Kingdom in particular might adopt a parallel mandate, given the government's interest in promoting alternative jet fuels under its Jet Zero Council (United Kingdom, 2020) and desire to show climate ambition as the host of the 26th Conference of the Parties (COP26) in Glasgow this fall.

This analysis, while valuable, provides only an introductory review of potential tankering under a SAF mandate. To analyze potential tankering above and beyond what already occurs due to fossil jet fuel price differentials across EU airports, we assumed the same Jet A and SAF blend fuel prices across all airports. This does not capture any potential interactions between fossil jet fuel and SAF tankering, or due to price differences in SAFs across airports. Tankering between mandated airports, for example between small and medium/large airports with differing SAF requirements, was also not assessed. Tankering on freighters and business jets was not analyzed.

As more countries consider SAF mandates, additional work on tankering is recommended. This could include how to develop a regulatory definition of tankering to support its prohibition; analysis of intra-EU tankering, either between airports with different blending requirements or due to high regional SAF costs; and the potential role of partial tankering (e.g., carrying half of the fuel needed for a return trip). Analyzing SAF mandates through 2050 would help policymakers understand the potential for tankering to undermine long-term SAF targets. Finally, future work could investigate the sensitivity of other policies to reduce the incremental costs of SAFs, notably the taxation of fossil jet fuel.

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