Assessment of carbon leakage potential for European aviation

Direct flights stopping over in non-EU airports

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Executive Summary

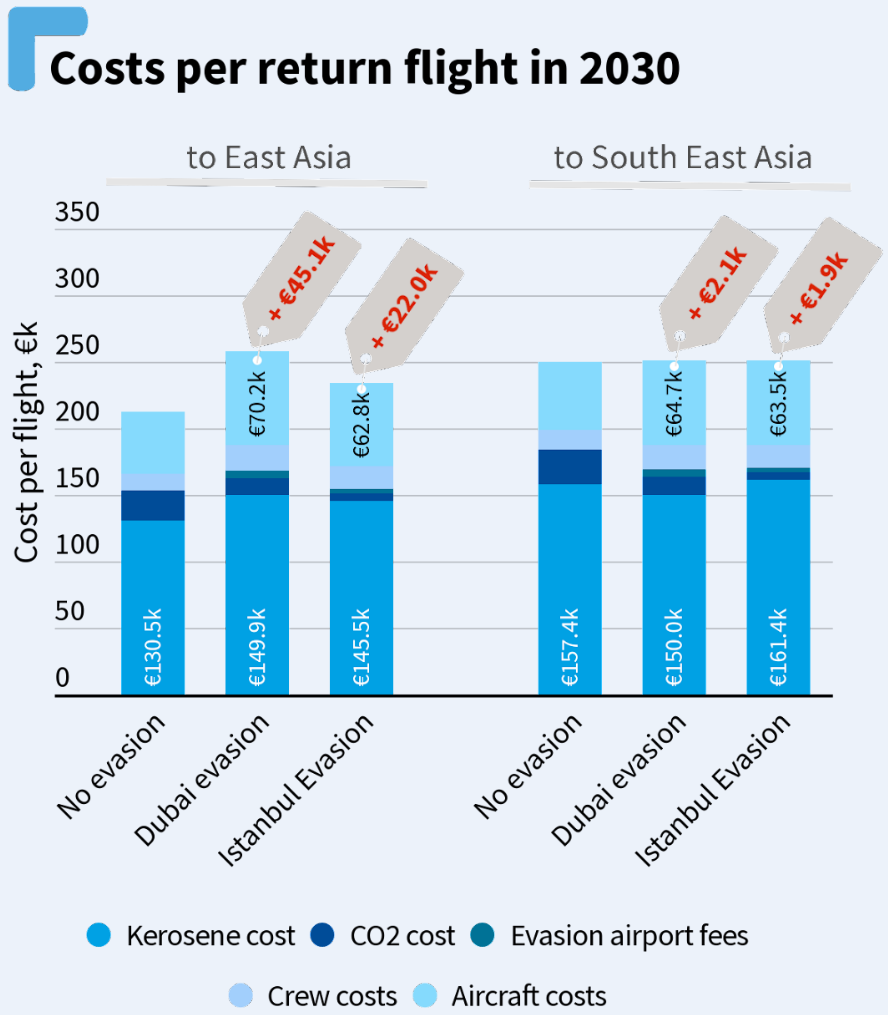
To address the aviation sector's growing climate impact, the European Commission has proposed[2] to mandate the use of sustainable aviation fuels (SAFs) and to strengthen CO_2 emission pricing (through the EU emissions trading system, the ETS). In order for these policies to effectively address aviation emissions, their scope of application needs to cover all departing flights. But the aviation industry continues to question such climate regulation, notably by claiming that EU and UK airlines would be at a disadvantage to third country airlines if effective policies to reduce their emissions were introduced[1]. If flights were rerouted to avoid EU policies aiming at cutting carbon, this would result in carbon leakage, meaning emissions occurring elsewhere would cancel a portion of emission reductions occurring within the scope of the measure.

This study assesses and quantifies **the potential carbon leakage linked to the cost of EU climate measures, namely applying the EU ETS and a SAF mandate on all departing flights in 2030**. Whether the carbon leakage and additional emissions would occur depends on the cost to airlines and the passengers' willingness to take a longer flight. This analysis considers one type of carbon leakage, whereby direct long-haul flights are replaced with an evasion stop-over at a non-EU hub, namely Istanbul and Dubai. The results were then generalised to cover all departing flights from the EU and UK.

- East Asia (mainly China, Japan, and South Korea) and South East Asia (mainly Singapore and Thailand) were the only regions deemed to have the highest potential for carbon leakage with a stop-over flight in Istanbul or Dubai. These flights represent 15% of the EU's total aviation emissions, or a total of 92,000 flights.

- From the financial perspective of the airline, the results of the analysis show that there is **no financial advantage for any direct flights to these regions to stop-over in Dubai or Istanbul**, primarily driven by the additional fuel, crew, and aircraft costs. Furthermore, when considering the passengers' value of travel time (VTT) and therefore consumer demand, the economic cost of evading would even more significantly overpass the benefits of avoiding EU measures.

- The study shows that **no direct flights leaving Europe are at risk of being replaced by stop over flights in airports outside of Europe in 2030.** Flights to North America stopping over in the UK were evaluated as having a much weaker evasion potential, given that the UK is planning on establishing similar pricing and fuels policy and that UK's largest airports have very limited capacity to accommodate extra demand.



We conclude that some of the aviation industry's claims on carbon leakage risks are unfounded and there is **no reason for the EU not to impose its climate measures on at least all departing flights from its territory**. This will help mitigate the biggest chunk of aviation emissions linked to extra-EU long haul journeys. Indeed over 80% of some airlines' emissions[3] are not even subject to any carbon prices, therefore the scope of the measures is key to their effectiveness.

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1. Introduction

Right up until the COVID-19 groundings, aviation was one of the fastest growing polluting modes of transport. Aviation emissions covered under the EU emissions trading system (ETS) in 2019 increased 27.6% since 2013[2]. Despite a temporary drop in emissions due to COVID-19 groundings, industry projections expect traffic to bounce back to 2019 levels by 2024. In order to address the sector's growing climate impact, the European Commission has published proposals[3] in July 2021 to finally address aviation emissions by not only mandating the use of cleaner fuels known as sustainable aviation fuels, or SAFs, through ReFuelEU, but also putting an effective price on CO_2 emissions (through the EU Emission Trading System (ETS) and the Energy Taxation Directive (ETD)).

The scope of these measures is key to their effectiveness. Today, airlines are exempt from paying tax on their fuel and most aviation emissions generated by EU air passenger traffic outside the scope of EU regulation despite representing an increasing share of the EU's climate problem. Indeed, the EU ETS is limited to intra-EEA flights, meaning over 80% of some airlines' emissions[4] are not even subject to carbon prices.

Despite benefiting from fossil fuel subsidies through lack of taxation for decades, the aviation industry continues to resist effective climate regulation, notably by claiming that EU airlines would be disadvantaged with third country airlines if an ambitious policy to reduce their emissions was imposed on them[1]. They claim that EU regulations risk being avoided by parts of the industry and therefore leading to carbon leakage. Carbon leakage would be caused by airlines or passengers being able to avoid paying the total or partial forecasted extra costs of clean fuel, ETS allowances or fuel taxes by changing their operations, making the overall climate policy ineffective, as emissions would not reduce but just be displaced to other regions. Carbon leakage from aviation has been investigated in great detail for the UK[5], however there is little publicly available research on the risks for European aviation.

1.1. Types of carbon leakage

Depending on factors such as pass-through rates and actual cost, the proposed EU climate measures will likely increase ticket prices from their current unsustainably low levels. The additional costs will lead to changing passengers' behaviour, by deciding to fly less (reduce the demand of flying), a crucial element to the long term prospects of decarbonising the industry[6]. Demand reduction is a desirable outcome of the fair pricing of aviation. Carbon leakage is typically understood to be an undesirable outcome of climate measures, where in a waterbed type effect, activity in one region (like the EU) is reduced, only for the activity and associated pollution to have been shifted and potentially increased due to inefficiencies (from for example longer routes) beyond the borders of EU jurisdiction. The intended reductions in emissions may not be achieved in the global context, to the detriment of businesses in the EU who will have higher operating costs than their competitors. However from a climate point of view, carbon leakage is only problematic if the emissions increase outside the scope of the measure exceed the emission reductions within the scope of the measure. The different carbon leakage types are listed below.

1) **Adding a stop-over outside of the EU instead of a direct flight**: Instead of taking a direct flight from the EU to a non-EU destination (for example Paris-Hong Kong), passengers decide to add a

stop-over in an airport close to the EU, in Dubai or Istanbul for instance. This would mean the additional costs of EU aviation climate measures would not apply over the entire journey, but it would imply other costs and time penalties from adding an extra stop. The greatest economic benefit would logically occur for a hub close to the EU with a distant final destination. This would both reduce the relative increase in travel time and produce the largest economic incentive for evasion. **This type of carbon leakage is the subject of this study.**

2) **Passengers choosing non-EU destinations or non-EU carriers**: Increased ticket prices due to EU climate measures would lead passengers to choose non-EU destinations (and as a consequence, non-EU carriers) instead of EU destinations. If the scope of the measures covers all departing flights from the EU, this would mainly affect the choice of leisure travellers living outside of the EU. For example, a passenger in North America may choose to holiday in Asia rather than the EU. If the scope of EU measures was to only include intra-EU flights, this would affect mainly EU passengers. For example, instead of going on holiday to the Canary islands, a German passenger would choose to go to Marrakech. This case is not part of the current study, but industry commissioned studies[7] showed that by imposing EU measures on all flights departing the EU would reduce tourists switching to non-EU destinations.

3) **Switching a stopover from EU airport hub to a non-EU hub**: Paris Charles de Gaulle, Frankfurt Am Main, Amsterdam Schiphol and London Heathrow are major hubs that typically channel feeder flights from smaller airports within the EU or from each other, to service long-haul flights to extra-EU airports. An example of such a journey could be Madrid to Hong Kong via Paris. Airlines would shift the first segment of that journey outside of the EU to a non-EU airport (Madrid to Hong Kong via Istanbul) to avoid the additional costs due to EU aviation climate measures on the second leg, which would be from a third country outside the EU (Istanbul to Hong Kong instead of Paris to Hong Kong). A secondary risk could be from flights originating outside the EU that currently use the EU hubs (for example, New York to Hong Kong via Paris) shifting to a non-EU hub like Dubai or Istanbul. This case of switching feeder flights from the EU to a third country hub has not been analysed in this study but is the subject of upcoming work.

4) **Tankering**: Tankering occurs when airlines uplift excess fuel in one airport to cover the full or partial return leg for economic benefit. This has a CO_2 penalty owing to the extra weight carried in the first leg. In terms of EU climate measures, tankering would occur in non-EU airports to avoid uplifting more costly SAF blended fuels. These risks have been shown to be minimal if the UK adopts policies in line with the EU[8]. Tankering can also occur within the EU, but has shown to be low risk and almost entirely mitigated with an anti-tankering mandate that obliges 90% of the fuel for a segment to be uplifted at the departure airport, as proposed by the EU's ReFuelEU regulation [9][10].

1.2. Aim of this study

The purpose of this study is to **assess and quantify the carbon leakage from the cost of the EU climate measures, namely applying EU ETS and a SAF mandate on all departing flights**. In the Annex, we analyse an additional scenario for the case where a kerosene tax on all departing flights is applied as part of a revised Energy Taxation Directive (ETD). We focus on the first type of carbon leakage listed above, where direct flights are replaced by flights with a stop-over at a non-EU airport to reduce the cost burden of EU climate measures across the entire journey. We highlight the routes and airports most at risk, while quantifying the total change in emissions. We consider two main geographical areas:

- Flights to Asia, with an intermittent stop in a hub like Istanbul or Dubai.
- Flights to the Americas stopping over in London.

2. Aviation in the EU: identifying routes prone to carbon leakage

To determine the potential of aviation carbon leakage of the first type as listed in Section 1.1 (replacing a direct flight with a non-EU hub in the Middle East), we first analyse the existing (2019) aviation market. The lower chart in Fig. 1 **shows the breakdown of departure and arrival emissions from the EU27+UK to continental regions**, where arrival emissions are considered to be equivalent to the departure emissions. Intra-EU & UK emissions (including domestic) are 24% of total emissions and are not at risk from carbon leakage, as we explained above intra-EU flights are mainly operated by EU airlines and cannot be shifted to other destinations.

The routes that have potential carbon leakage are to extra-EU27+UK destinations, with a share of 76% of all emissions. **Flights destined for Asia are the largest EU destination and account for 32% of emissions**, closely followed by emissions to North America at 27%. Flights to North America are deemed to be at a low risk of carbon leakage as a key candidate airport for evasion, Reykjavik in Iceland, is part of the EEA and thus subject to applying the same EU ETS prices[11]. **Flights to the rest of Europe (i.e. outside the EU and UK), Africa, South America and Oceania make up the remaining 17% combined**. We make the hypothesis that these destinations have lower potential for carbon leakage, due to either the lower number of flights (which is detrimental to the a hub system) and from geographical considerations, where a suitably located stop-over is not possible. We discuss these destinations and test this hypothesis in Section 4.3.

In the lower chart of Fig. 1, the emissions of flights to Asia are further disaggregated into regions. We make the hypothesis that **the greatest potential for carbon leakage would be from direct flights to Asia that could introduce a stop in a Dubai or Istanbul hub, both of which are in the Middle East.** Of all the flights to and from Asia, **those to the Middle East account for 43% of the total emissions to Asia**, which means that these emissions would not be at risk of carbon leakage, as they are already stopping in areas close enough to Istanbul or Dubai. There is little financial advantage for a direct flight to the Middle East to add a stop-over in Istanbul or Dubai (see Section 4.3).

The next biggest region is East Asia (mainly China, Japan, and South Korea) representing 35% of the total emissions to Asia. South East Asia is the next largest region, with 14% of the total emissions. **The main carbon leakage risk would therefore come from direct flights to East and South East Asia passing**

through the Middle-East. Then, South and Central Asian destinations represent the lowest share of emissions at a combined share of 8%. And, like the Middle East, have little financial incentive for evasion due to their close proximity to the EU and potential hubs.

The direct flights to **East and South East Asia,** associated with 45 Mt CO_2 of emissions, are geographically at greater risk of being shifted to stop-over flights and therefore leading to carbon leakage. This compares to a total of 291 Mt CO_2, or **a maximum of 15.4% of total EU return flight emissions**. In terms of flights, this represents 92,000 flights out of approximately 3.7 million passenger return flights to, from, and within the EU27 & UK region, or 2.5%.

In the sections that follow, we will assess the **potential increase in emissions if all those flights changed their routes to avoid carbon pricing**, and **analyse the cost implications** of doing so. This assessment will help to qualify the carbon leakage to other regions.

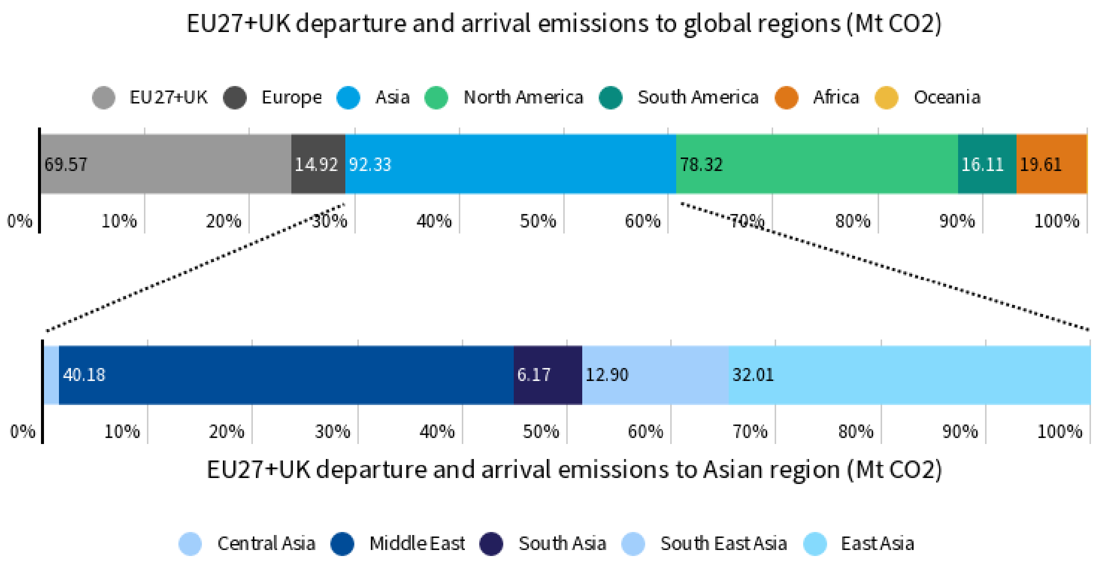

Figure 1: Aviation emissions departing from the EU27&UK, by destination, 2019

Fig. 2 shows the top 20 airports in the EU27+UK with direct departure emissions to Asia, representing 85% of all emissions to Asia. The airports with the most departure emissions to Asia are the European hub airports: **London Heathrow, Frankfurt Am Main, Paris Charles de Gaulle, and Amsterdam Schiphol**. These **four airports represent around half of the emissions from flights destined to Asia**. The departure emissions do not reflect the origin of the passengers, so it is not possible to know where passengers going to Asia from those airports come from just the flight information (see Info box on feeder flights).

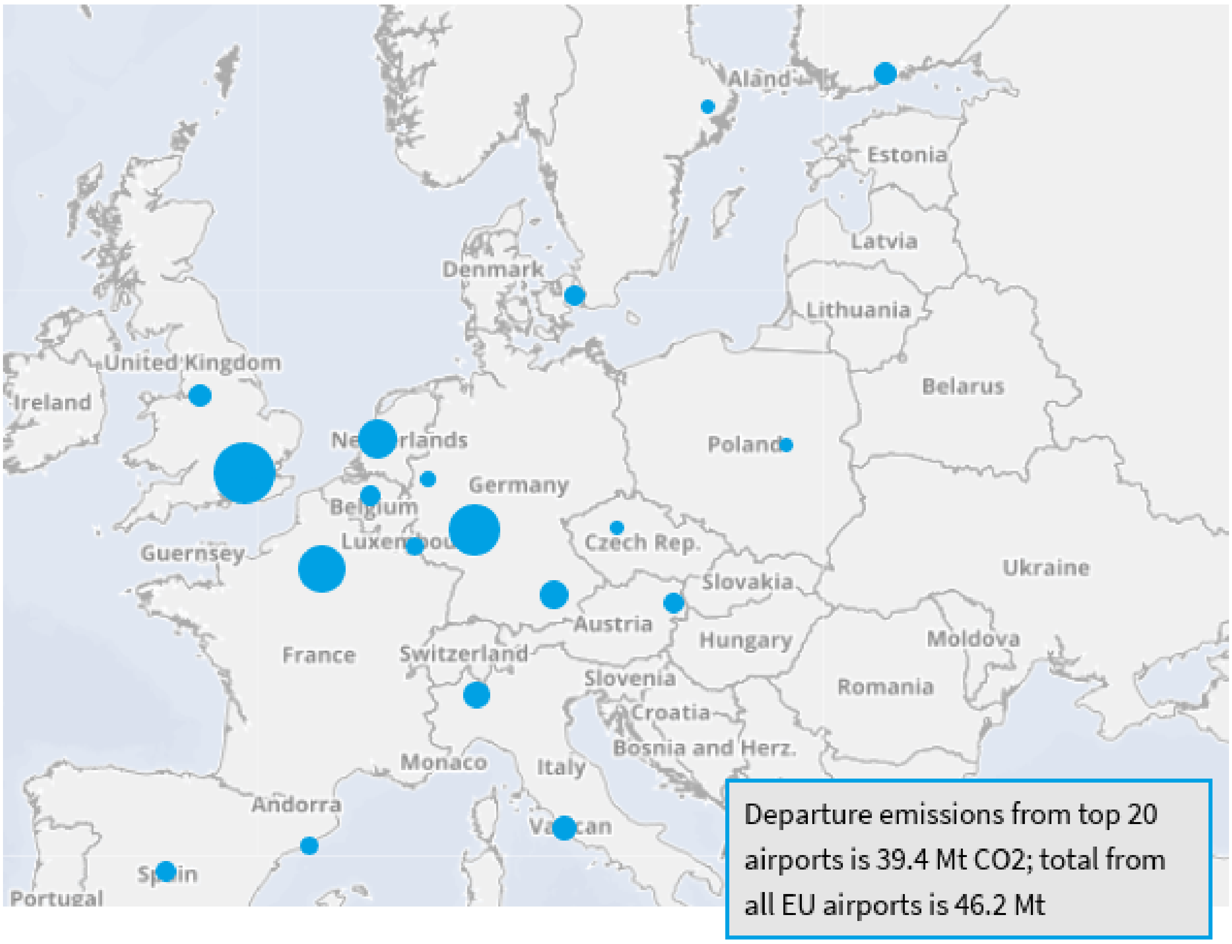

Figure 2: Top 20 EU27+UK airports by departure emissions to Asia, 2019.

Info box - feeder flights

Hub airports are the nodes in the network of air passenger movements. Unlike point-to-point airports, they not only deal with large amounts of departing and arriving passengers, but also transfers. For example, in 2019, 36.1% of passenger movements through Schiphol were transfers [12]; in Frankfurt the figure is 53.7%[12, 13]. They service passengers not just from their neighboring city and surrounding area, but smaller airports from regions feed into them and allow passengers to connect to international destinations at convenient times. While there are very few flights between Budapest and Shanghai, there are several flights a day from Budapest to each of the hubs (feeder flights), and from each of the hubs, several flights a day to Shanghai. By pooling demand, airlines can offer more flights to more destinations[14].

However, despite servicing many transfer passengers, it is unclear how many passengers passing through these hub airports continue flying on to Asia. This information would help quantify the passengers actually at risk of passing through Istanbul instead of an EU hub, with third country airlines taking the opportunity to offer stop-overs in Istanbul instead of Paris or Frankfurt. For example, a passenger from Budapest going to Tokyo through Frankfurt, could choose instead to go to Tokyo through Istanbul. The Istanbul-Tokyo route would be exempt from EU measures, whereas the Frankfurt-Tokyo would not.

The hub system has perverse effects and has introduced significant inefficiencies, skewing efficient point-to-point routes. For example, a direct flight from Schiphol to Hong Kong may be more expensive than the same flight that includes a stop-over in another hub, like Paris, despite emitting less CO_2 emissions. This is because an additional stop requires an additional take-off and landing and longer distance, implying more fuel usage and therefore releasing more CO_2 emissions. These hub airports, along with their legacy carriers (Air France, KLM, Lufthansa, and British Airways), have a particular business model that incentivises these transfers, and this can partially be supported by policy. For example, transferring passengers through Heathrow do not have to pay the Air Passenger Duty. In addition to favouring unnecessary stop-over, the four European hubs are located in countries with effective high speed rail networks, which should be used as a priority to connect other European localities to hubs.

3. Assessing potential for carbon leakage

3.1. Scope

To quantify potential carbon leakage, the 40 largest airports in Asia by arrival emissions from all EU27 and UK airports were identified (Fig. 3), covering 95% of all emissions. These airports represent the scope of this study, enabling both a granular and representative assessment to be carried out. For this analysis, we consider the combined arrival and departure emissions, as we want to determine the carbon leakage associated with the return journeys of passengers. The economics of avoiding EU climate measure is a function of:

- the **costs of fuels, fuel taxes, carbon emissions**
- **airport fees, cabin crew costs, the cost of aircraft**
- passengers' **value of travel time (VTT)**

The VTT is dependent on the willingness to pay (WTP) for a direct service rather than a service with a stop-over; passengers will balance the cost of the ticket to the total travel time along with the inconvenience of a stop-over, and the associated risks of missed connections or long airport transfer with it. Although an indirect cost, VTT would tend to lower demand for a particular stop-over option, and make it less commercially viable.

The scope of the future fuel taxes is uncertain. For the main analysis, we assume that a kerosene tax would only apply to intra-EU flights, and is not applied to journeys to non-EU airports. In the Annex, we investigate the costs if the kerosene tax were applied to all departing flights.

Carbon leakage is at higher risk if there is a non-EU airport close enough to the EU for an airline to minimise the costs of servicing the market and maximising the benefit of the evasion; that is, there is asymmetry between the first and second leg of the journey. As discussed previously, we assume that carbon leakage risk for flights to Asia is small in Central and South Asia, as well as in the Middle East, as the cost of evasion would not outweigh the cost of compliance; we investigate this further in Section 4.3. **The main part of this analysis will therefore focus on East and South East Asia**.

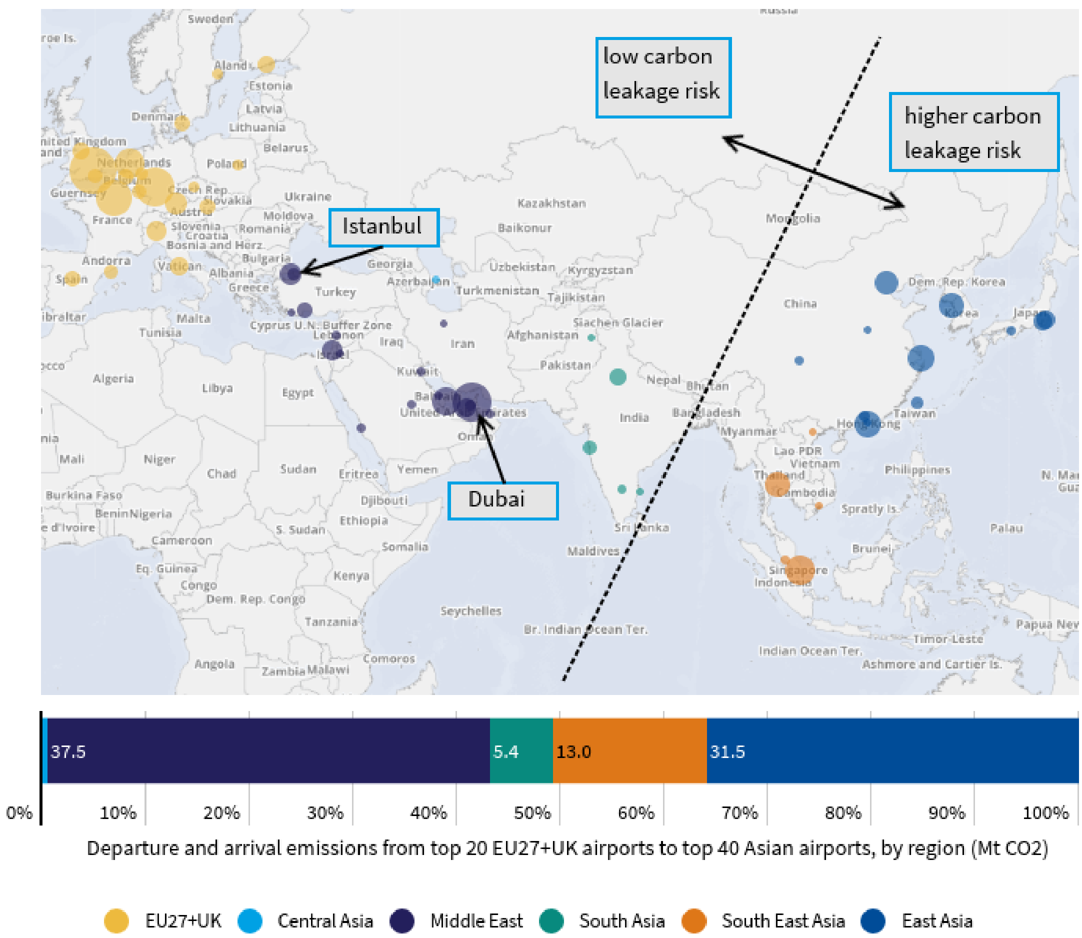

Figure 3: Top 20 EU27+UK airports by arrival and departure emissions to Asia, 2019. Map shows regions by carbon leakage risk; Possible evasion airports highlighted are Dubai and Istanbul.

3.2. Methodology and scenarios

We use a route-based approach (i.e. a return leg) to assess the potential of carbon leakage. We have compiled routes from global aircraft automatic identification system (AIS) data; more information about the methodology can be found in [15]. We consider a return flight, even if the additional EU departure costs due to the EU climate measures do not apply on the return leg in our analysis. All routes to the top 40 East and South East Asian airports (from Fig. 3) from the top 20 EU27 & UK airports are assessed in a what-if scenario. Thus the emissions, total flight and journey time, and costs are assessed for:

- Direct return flights in a no-leakage scenario
- If all of the direct return flights evaded at Dubai
- If all of the direct return flights evaded at Istanbul

We assume that there is no capacity constraint at Istanbul or Dubai. Based on the quantitative analysis of Asian flights, in a separate scenario we assess the potential of North American routes which may fly via the UK should the UK not implement climate mitigation measures for aviation in line with the EU. We do not adjust for the expected demand reduction from the increased costs.

3.3. Main assumptions

This analysis assumes that the aircraft activity in 2030 remains the same as it was in 2019, but uses 2030 projections of ETS and kerosene prices and fuel blending mandates. The key assumptions are detailed in Table 1. The ETS price, kerosene tax, and additional costs of kerosene incurred from a SAF mandate are only applied to the entire outbound EU leg of the journey. **This implies that all new proposed regulations in the Fit for 55 package for aviation have a scope covering all departing flights (except for the kerosene tax — see Annex)**. For the main analysis of flights to Asia, we assume for this analysis that the UK implements identical measures as the EU.

Aircraft and passenger charges were obtained from publicly available information from Dubai airport[16] and Istanbul airport[17] for the evasion scenarios; the most recent prices are assumed to remain unchanged in 2030. They were applied on the basis of 250 transiting passengers per flight and the maximum take-off weight (MTOW) of 254 t, based on the average of Boeing 787 and Airbus A350. **Other airport charges, such as aerobridge costs, costs for airlines to staff check-in gates, were not included nor were the potential additional costs of congestion at Dubai or Istanbul airport**. We assume that the aircraft costs are €300 million[18, 19], financed over 20 years at 5% interest rate[20]. This is then converted to a cost per hour, for which the airline and eventually the passengers must bear. This means that the longer the travel time for a given journey, the greater the cost of the aircraft is borne by the passenger. We do not consider refurbishment costs, depreciation costs, maintenance costs, aircraft manufacturer credits, etc. We expect that this exclusion will **tend to underestimate the aircraft costs to an airline which would make any carbon leakage risk even less likely**, but it will depend on the ownership period.

Table 1: Key cost input assumptions

Metric	Value in 2030	Notes/sources
Fossil kerosene prices	€898/t; €731/t (Dubai only)	Prices based on EU prices from Stratas data. Transport, distribution and handling assumed at 0.28€/L; we assume this to be halved in Dubai.
SAF prices	€1640/t (advanced biofuels); €2540/t (e-kerosene)	Combined e-kerosene and advanced biofuel blend of 5.0% (4.3% biofuels + 0.7% e-kerosene). Note that SAF is zero-counted in the ETS but is assumed to have a WTW reduction of 80% compared to fossil kerosene.
ETS allowance price	€100/tCO_2	Assuming no free allowances; all departing scope. Equivalent to €315/t of kerosene. In line with recent projections[21]
Fuel Tax (on blended fuel)	€309/t	From the European Commission proposal, equivalent to €0.264/L of fossil kerosene. Main results omit this cost while further analysis presented in the Annex.
Passengers	250 per flight	Based on the simple average of a Boeing 787 Dreamliner and an Airbus A350. This metric influences landing fees.
MTOW	254 t	
Landing fees	€5470 (Dubai); €3586 (Istanbul)	Current prices assumed constant until 2030; per flight with 250 passengers on board[16, 17]
Value of travel time, VTT	€27.47/h	The price people are willing to pay to avoid additional travel time and connections; T&E calculated central value from studies[22–25]

Further, we assume an average cruising speed of 903 km/h with further allowance for climb and descent at 60% of cruising speed to approximate flight times; route lengths are the shortest distances between two airports following the great-circle distance. **We assume two hours additional time is taken for passenger transfers at the evasion airport.** The central VTT is for all passengers and is applied as a simplified per hour rate and is an arithmetic average of three values from the listed studies in Table 1.[1]

Lastly, we do not investigate the costs of potential aircraft congestion increase at the airports. Congestion in Europe has been estimated to cost airlines €37 billion each year[28]. Forecasts for airports in the area,

[1] First, the average net earnings of EU citizens was approximately €14,000 per year and adjusted to household earnings[26], giving €14.8/h Second, the average weighted and inflation adjusted business and leisure ticket VTT was computed from [25], giving €38.9/h. Third, from [24], willingness to pay for connecting versus direct flights were compared, with disaggregation for flight time ($15.2/h), connection time ($23.8/h), and the stop itself ($140.1). These values were adjusted for the exchange rate, and the US's superior purchasing price parity per capita income by 40% compared to the EU[27] and converted into a per hour rate, yielding €28.7/h.

that pre-date the European Commission's proposals, predict that congestion could cost the region and airlines a further **€14 billion in the coming decade from traffic delays and additional fuel costs**[29]. Dubai and Istanbul could adapt, by expanding the airports with additional runways and passenger terminals or investing in air traffic management systems**. However these investments would also impart a cost to airlines and eventually passengers.** Omitting congestion costs would tend to make evasion and thus carbon leakage appear more likely.

4. Results

This chapter analyses the environmental impact of having all direct flights to East and South East Asia from Europe passing through Istanbul or Dubai due to increased EU climate measures as well as the potential economic consequences of doing so. It then further analyses the potential for direct flights to North America to add a stop-over to the UK in response to the EU's climate measures. All else being equal, with the zero counting of SAF (as per the EU ETS, for TTW emissions only) applied to the legs of the return flights that depart from the EU and the UK, the emissions shown in horizontal bar in Fig. 3 for East Asia and South East Asia decrease to 30.7 Mt CO_2 and 12.7 Mt CO_2, respectively (or both by 2.5%). The total aviation emissions in the scope of this work is 282.1 Mt CO_2. If all departing flights from the EU and UK had the full 5% SAF blend, this would equate to 2.8 Mt of SAF consumption, approximately 120 PJ in energy terms at 2019 consumption[2].

4.1. Flights to East and South East Asia through the Dubai and Istanbul

Environmental Impact

Table 2 shows the key results of flight averaged changes to total flight length, time, and CO_2 emissions, for each scenario. The CO_2 emissions are zero counted for the quantity of SAF consumed on the aircraft. The results show that if every flight to East Asia were to evade at Dubai, it would increase total aviation emissions for the EU and UK by 3.5%; if they were to evade at Istanbul, total emissions would increase by 1.7%. If every flight to South East Asia was to evade at Dubai or Istanbul, that would increase total emissions by 0.4% or 0.3% respectively. **If all direct flights to these regions were to add a stop over, the total increase in emissions would be between 5.7 Mt CO_2 and 10.8 Mt CO_2, 2.0% to 3.8% of the EU's total return flight aviation emissions.** There would also be an impact on the amount of SAF uplifted, or required to be produced, in the EU. With no evasion, 353 kt of SAF would need to be produced. With an evasion in Dubai or Istanbul, this would decrease to 194 kt and 80.6 kt, respectively.

[2] In an upcoming study[6], we show that a ramp up of SAF could feasibly reach 90 PJ, highlighting the importance of demand reduction measures that will be required to ensure the 5% SAF target can be reached sustainably.

Table 2: Key flight metrics across scenarios. *With fraction of total scope, i.e. 282.1 Mt CO_2

Region	Metric	No evasion	Dubai evasion	Istanbul evasion
East Asia	Return flights per year	70,000		
	Total one-way flight distance (km)	8,889	11,530	10,099
	Total one-way flight time (hours)	10.0	15.1	13.5
	Total return flight CO_2 (Mt)	30.7	40.5	35.6
	Evasion CO_2 emissions (Mt)*	--	9.8 (3.5%)	4.9 (1.7%)
	Total SAF uplift (kt)	248.8	140.3	58.1
South East Asia	Return flights per year	24,000		
	Total one-way flight distance (km)	6,737	7,352	6,984
	Total one-way flight time (hours)	11.0	13.8	13.6
	Total flight CO_2 (Mt)	12.7	13.7	13.5
	Evasion CO_2 emissions (Mt)*	--	1.0 (0.4%)	0.8 (0.3%)
	Total SAF uplift (Mt)	102.5	52.6	22.0
East & South East Asia total	Total flight CO_2 (Mt)	43.4	54.2	49.1
	Evasion CO_2 emissions (Mt)*	--	10.8 (3.1%)	5.7 (1.6%)
	Total SAF uplift (Mt)	351.3	193.0	80.2

Economic Impact - per flight

Whether the carbon leakage and additional emissions due to adding an evasion airport would occur as shown in Table 2 **will depend on the cost to airlines and the passengers' willingness to take a longer flight.** Fig. 4 shows the average per flight costs of the three scenarios, with East Asian flights on the left and South East Asian flights on the right.

- The cost of kerosene is the most significant cost, as it correlates with distance. The SAF blended in kerosene results in an increase in fuel price of 5%, thus the length of the EU leg also influences the total fuel costs. Dubai is assumed to have cheaper fuel, and as can be seen in the flights to South East Asia, is a lower cost despite a longer distance.
- The other significant costs are the aircraft purchasing or leasing costs. These costs are converted to a cost per hour, for which the airline and eventually the passengers must bear. These costs increase for an increase in travel time for a given passenger activity: if it takes more time to do the same passenger movements, then these passengers will have to bear the extra cost of the aircraft flying for longer. If the same passenger movements can be met with less aircraft time, more

passengers will share the aircraft costs because more passenger movements can happen. Flights to East Asia have the largest increases in aircraft costs, while flights to South East Asia have more modest increases.

- The final results show that a direct return flight to East Asia costs €212,000, while evading at Dubai or Istanbul would increase those costs to €257,000 and €234,000, respectively. A direct return flight to South East Asia would cost an airline €250,000 while evading at Dubai or Istanbul would increase those costs to €252,000 and €251,000, respectively. **This indicates that from an airline perspective, there is no economic competitive advantage to go through Istanbul or Dubai hubs to evade EU climate measures.**

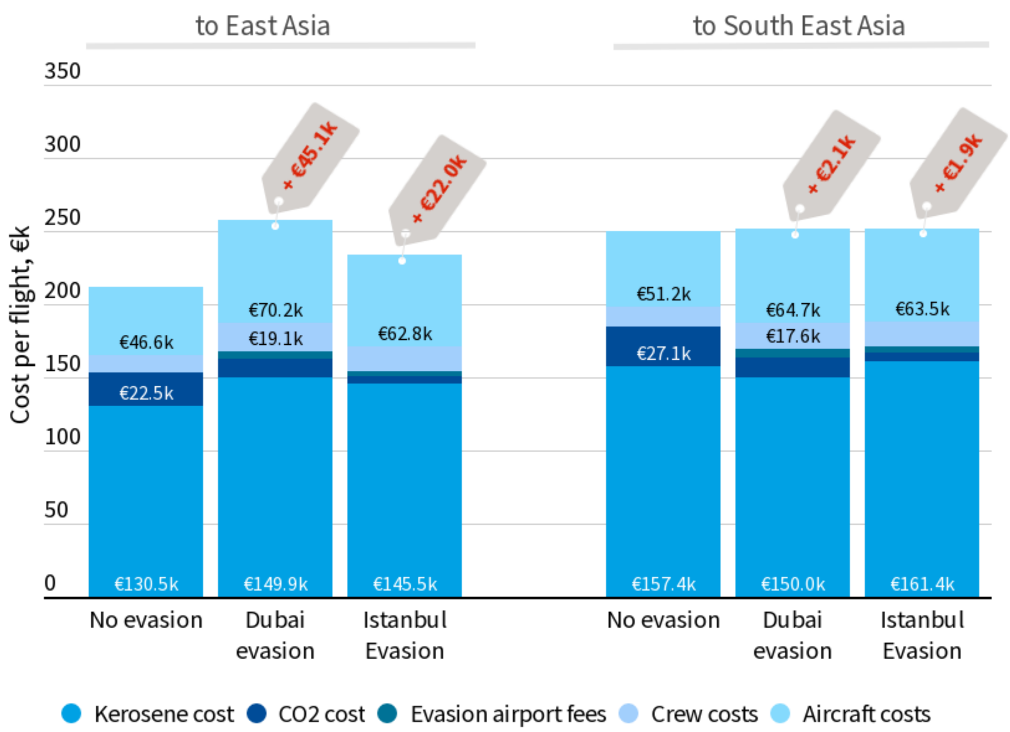

Figure 4: Costs per return flight, direct and with evasion airport in East Asia (left) and South East Asia (right)

Economic Impact - per passenger

Per flight, we see that it is still more costly for an airline to have stopovers in Istanbul or Dubai instead of flying direct, so the additional cost of climate measures does not surpass the overall cost of adding a stop-over. We do not include airline profit margin when assessing these costs, therefore we assume that the additional costs from the EU's climate measures would need to be covered by passengers in full through the ticket price. Passengers will make decisions on which airline and which flight to choose for their travel based on price but also time. These costs are shown in Fig. 5, and would represent an average return ticket price (i.e. averaged over all cabin classes), not taking into account the omitted costs and airline margin. The value of travel time is added as a differential to the direct flight scenario. **The results show that the additional travel time increases the relative costs for a passenger significantly.** For the flights to South East Asia, which on a per flight basis could compete with direct flights (Fig. 4), the value of travel time differential for a passenger would make Dubai €159 more costly, and flights to Istanbul would be €145 more costly.

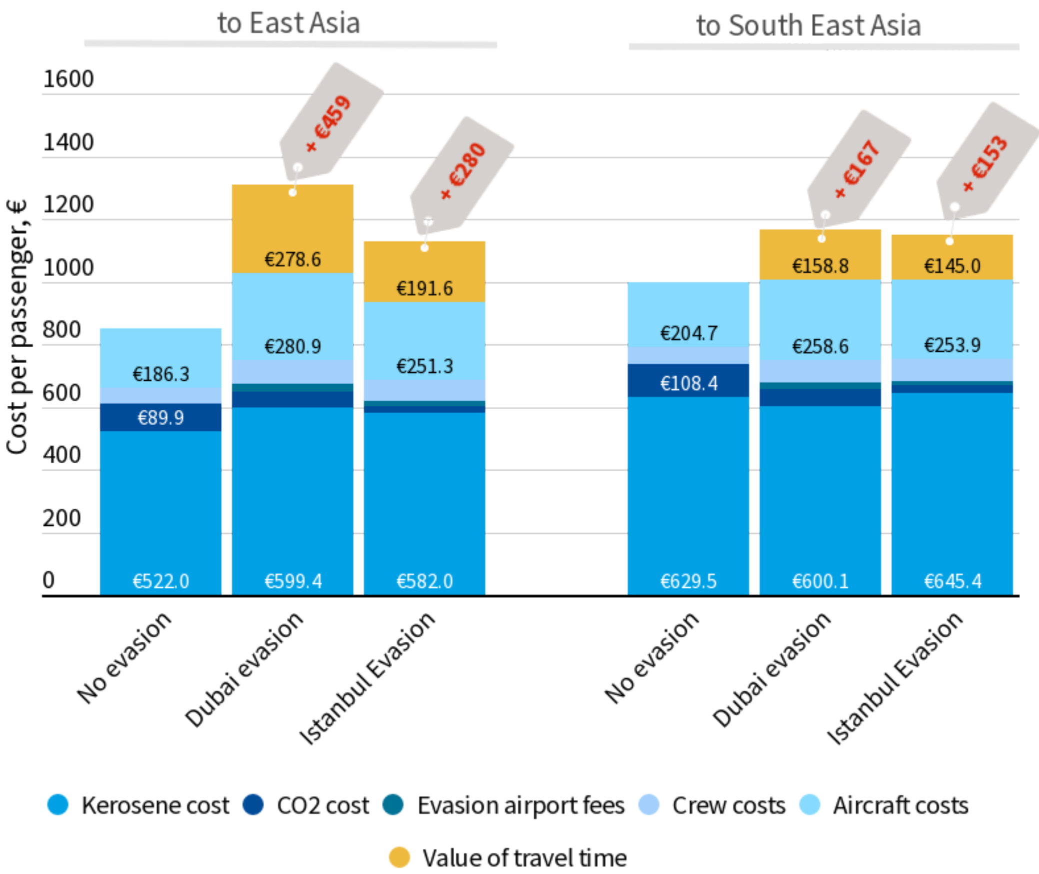

Figure 5: Costs per passenger for a direct return flight and with evasion airport in East Asia (left) and South East Asia (right)

These findings show that not only would flights stopping-over in Istanbul or Dubai **not be economically competitive** compared to direct flights that are subject to EU climate measures, but **from a passenger perspective these stop over flights would also be more costly**.

4.2. North America through the London Heathrow

According to our findings, flights to North America represent 27% of the EU's departure emissions, which involves 222,000 return flights per year. Given the geographical situation, the only airport(s) where direct flights from the EU to the US could benefit from a stop-over to reduce carbon costs would be in the UK. But, there are a number of reasons why **this scenario of avoidance is very unlikely to take place**.

UK carbon budget

In 2021, the UK government committed to introduce legislation to include international aviation emissions within the scope of its five-yearly carbon budgets, therefore taking responsibility for emissions on flights that leave the country[30]. This means that the UK has an incentive to put in place measures to decrease emissions coming from international aviation.

UK aviation climate policy (ETS & SAF mandate)

The UK-EU Brexit agreement[31] includes measures to ensure the EU ETS and UK ETS work together, with routes from the EU to the UK covered by the EU ETS and routes from the UK to the EU covered by the UK ETS. The agreement also states that neither the UK or the EU should reduce its environmental or climate levels of protection below the levels that are in place at the end of the transition period which again reduces the chances of the UK weakening its climate policy.

On carbon pricing, the agreement states that the EU and the UK should consider linking their carbon markets. As in the case with Switzerland[32], linking agreements with the EU ETS require third countries to apply the same rules as those applied by the EU. (Article 6 of the EU-Switzerland agreement states that "inclusion of aviation activities in the ETS of Switzerland shall reflect the same principles as those of the EU ETS, in particular with regard to coverage, cap and allocation rules".) **Therefore should the UK decide to link its carbon pricing mechanism with the EU's system, the two schemes will mirror each other which will make the adoption of less ambitious pricing impossible.**

On SAF mandates, the UK is also considering imposing a similar measure[33] than the one proposed in the ReFuelEU initiative, with **the UK government aiming for 10% SAF use by 2030**. This mirroring of policy again reduces the risk of cheapening the price of polluting or refueling in the UK and incentivising airlines to stop over in the UK. Taking the slated carbon pricing mechanism and SAF blends into account, the UK's aviation climate measures could be considered more stringent (and thus incur higher costs), than the EU proposal.

Congestion

The UK's largest airports are well known to have very limited capacity to accommodate extra demand, as **there is limited space for additional slots for airlines to open new routes**. Congested airspace has an important cost for airlines and passengers, valued for Heathrow at £34/return flight for short haul and £217/return flight for long haul[34]. Apart from Manchester Airport, **regional, smaller airports are unlikely to have the adequate infrastructure to accommodate long haul flights**. There have been many discussions on building a third runway at Heathrow, which could increase capacity by 50%. But it is still unclear whether and when this will happen, with main investors pulling out of the project[35] and confusing signals from governments[36]. But even if the UK increases capacity and puts in place weaker environmental measures that would make flights stopping over in the UK economically more competitive, there wouldn't be enough air space to accommodate these additional 160,000 return flights from the EU27 to North America.

4.3. Leakage risks to other regions

This report identified East and South East Asian destinations as those most susceptible to potential carbon leakage. In this section, we generalise the findings to determine the carbon leakage to other destinations. The two key metrics for the financial benefit of flying with a stop in a non-EU airport instead of flying direct are **the scope of EU climate measures and time increases**. More specifically, the relative distance between the EU leg and the non-EU leg will indicate how much of the EU climate measures could be avoided, while the relative time increase has a direct correlation with airline costs and also for VTT.

We present the results of this analysis for Asia in Fig. 6. In both charts, all costs from Fig. 5 are summed for the top 40 Asian airports in the scope of the study. A relative cost increase less than one implies that it is financially beneficial to evade.

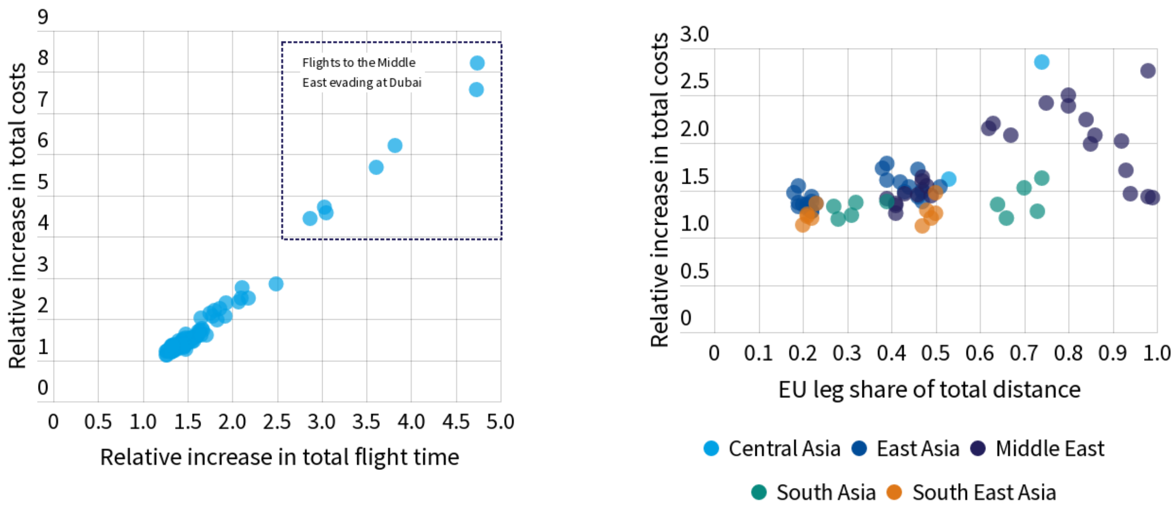

Figure 6: Relative increase in costs for all Asian regions compared to the increase in travel time (left) and the ratio of the EU leg to the total distance (right)

The chart on the left of Fig. 6 shows a clear **correlation between the increased flight time and the change in relative costs**. Airline costs such as crew and aircraft costs, as well as VTT, scale linearly with time. In the top right of the chart, **the highest relative cost increase destinations were those in the Middle East evading through Dubai**. As Dubai is on the southern border of the Middle East region (see Fig. 3), those flights essentially back-track towards their EU departure airport. These destinations were filtered out of the chart on the right of the figure.

The correlation is weaker when comparing the relative cost increase to the EU leg share of total distance (right hand side chart of Fig. 6), an index that describes how much of the journey falls under EU climate regulations. Here the data are grouped by Asian region, clearly showing that East and South East Asia have low relative increases in total costs because the relative share of the EU leg of the journey is smaller. The EU climate measures only increase some of the costs to an airline, such as the kerosene costs, whereas adding a stop increases distance and thus time, increasing all costs, including aircraft, crew, and airport costs. **Our results show that the impact of increasing the relative length of the EU leg increases total costs by around two thirds less than the impact of increasing the total time**.

Using the increase in total time as the main metric to predict evasion, we find that evasion would occur when the relative increase in total journey time is less than 1.17, that is increasing the journey time by 17%. **So if the total journey time increases by more than 17%, we assume there is no reason to take that flight instead of a direct one.** A critical assumption for this analysis is thus the transfer time, which we assumed as two hours. Transfer times of this length can only be feasibly achieved with large airports, as they offer more flights, and thus reinforce the hub model. **With this transfer time, we can assert that all direct flights less than 11 hours 50 minutes will not attract evasion**, as the two hour transfer alone (so without considering the extra time for detours to the evasion airport nor the additional time for climb and approach) **would represent an increase above the 17%**, making the flight less attractive for passengers.

We identified 14 routes where direct flights from Europe would take more than 11 hours 50 mins departing from the EU and UK, of which 5 were already included in the main analysis of top 40 Asian airports. This was to identify the flights that could potentially be more costly compared to stop over flights in an airport in between the EU and those destinations. One of the identified flights was the direct **London to Perth**, a premium direct flight to serve a limited market and thus servicing a passenger base that would have a higher VTT and less likely to be affected by EU climate measures. **Honolulu** is the only destination that fits the criteria in North America, which given the length of the flight is similar to the London to Perth flight. Of the remaining 7 flights, 4 are to destinations in **South East Asia** (Bali and Jakarta in Indonesia, Brunei and Manila). These airports account for only 0.6 $MtCO_2$, around 5% of the total South East Asian emissions, so representing a very small share of overall emissions. We have also shown that the top South East Asian destinations are unlikely to evade EU climate measures, and thus the same would hold for these destinations.

The remaining 3 airports are in **South America** associated with 6.6 $MtCO_2$ (Lima, Santiago, and Buenos Aires); there are no hub airports that are close to the EU from where to evade. In a hypothetical case that Casablanca could be an evasion airport for these destinations (it had 10 million passengers per year in 2019, compared to around 90 million in Dubai), and assuming that the transfer time of two hours could be achieved, we considered the economics of a flight departing from Paris to either of these three South American airports, evading in Casablanca. Once the total distance and flight stages such as climb and approach are considered (as per Section 3.3), we find that even for this scenario, **evasion is unlikely to be financially beneficial** (see Table 3) **as the increased travel time for all airports is greater than the 17% threshold.**

Table 3: Hypothetical case of flights from Paris to South American cities evading in Casablanca

Destination	Direct distance from CDG (km)	Distance after evasion at Casablanca (km)	Direct travel time, one way (h)	travel time with evasion, one way (h)	Increase in time
Buenos Aires	11,101	11,186	12.6	15.4	22%
Santiago	11,673	11,864	13.2	16.2	23%
Lima	10,276	10,843	11.7	15.0	28%

5. Conclusions and policy recommendations

We investigated the potential for carbon leakage linked to direct flights stopping-over in non-EU hubs like Dubai and Istanbul instead of flying direct, due to the EU applying the EU ETS and imposing a SAF mandate on all departing flights from its territory. We took a deep dive into the potential for carbon leakage for flights to East and South East Asia that may stop in Istanbul or Dubai. **The results of the analysis show that there is no economic advantage for any direct flights to these regions to stop-over in Dubai or Istanbul, given the additional fuel, staff, and aircraft costs.** There is therefore very limited risk of passengers choosing third country airlines to go to East or South East Asia through Istanbul or Dubai instead of EU airlines.

If passengers still chose to take stopover flights to evade EU measures, it could increase total EU return flight (i.e. arrival and departure) emissions from 2.0% to 3.8% in 2030. But **the costs of doing so were shown to be disadvantageous compared to direct flights**, increasing the costs for airlines and passengers significantly to East Asia. For flights to South East Asia, the costs for airlines were more comparable, **however given the value of travel time of passengers, the additional time required to make a stop would make these itineraries less desirable**, with an effective ticket increase of between €159 to €145.

Extrapolating these results, we discussed the carbon leakage risk of flights from the EU27 to North America going via London Heathrow in the UK. We concluded that there is also low risk of carbon leakage from these types of flights. We then generalised our findings for all non-EU destinations with a direct flight. This analysis shows that there is no financial advantage for evasion for any of the current long haul direct flights originating in the EU27+UK.

Based on this type of carbon leakage, there is no reason for the EU not to impose its climate measures on at least all departing flights from its territory. This will help mitigate the biggest chunk of aviation emissions linked to extra-EU long haul journeys. Further investigation will be conducted for different types of carbon leakage in upcoming work.

Finally, it should be noted that the importance of internalising the externalities, along with fair taxation, in the aviation industry. The increased costs would likely result in a reduction in passenger demand. This is a desirable outcome given the sector's unsustainable growth over the last three decades and the imperative of the EU to reduce the sector's emissions to zero by 2050.

6. Annex

This section investigates the impact of a change to the European Energy Taxation Direction (ETD). Fig. 7 and Fig. 8 show the per flight costs and per passenger costs, respectively. The results show that the cost per direct flight to East Asia is still cheaper than the same flight with a stop-over in either Dubai or Istanbul. This result also translates to the cost per passenger, even if VTT effective costs are omitted. However, for flights to South East Asia, the result shows that the evasion can result in cheaper flights for airlines. When it comes to the per passenger price, the evidence suggests that the VTT associated with the connection and extra flight time mean that fewer passengers would opt for the flight with a stop-over.

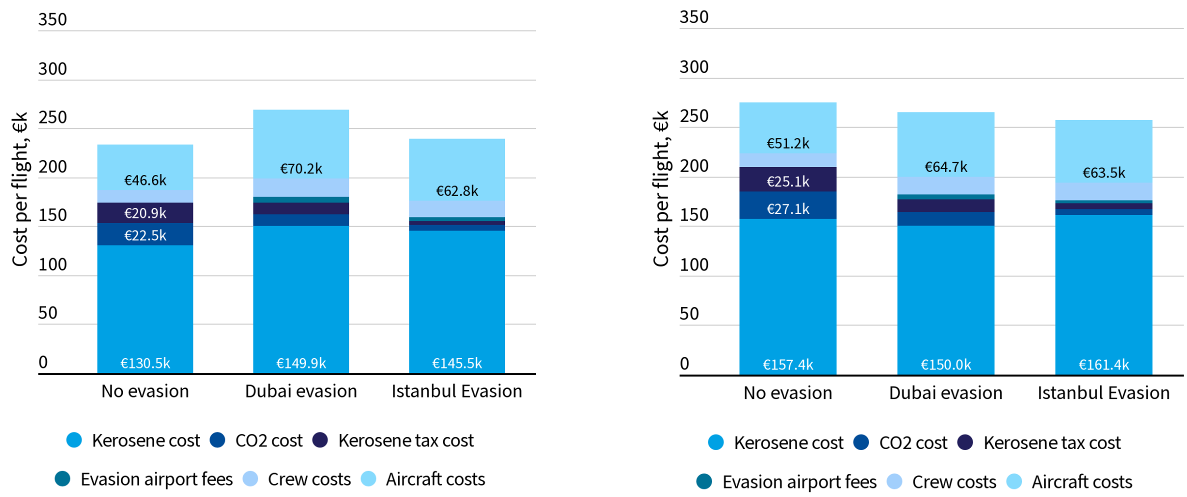

Figure 7: Costs per return flight with kerosene tax on EU departure leg, direct and with evasion airport in East Asia (left) and South East Asia (right)

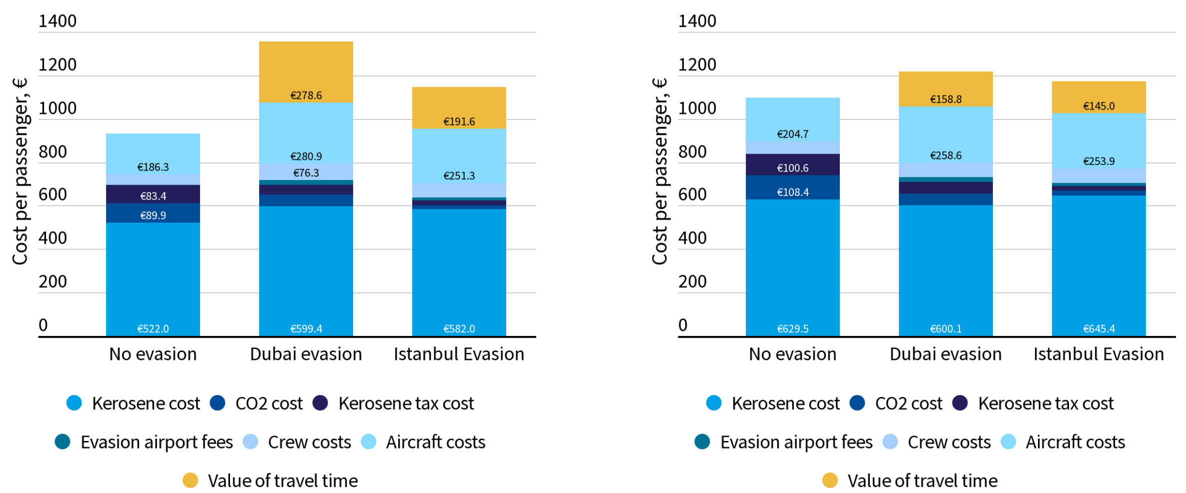

Figure 8: Costs per passenger with kerosene tax on EU departure leg, for a direct return flight and with evasion airport in East Asia (left) and South East Asia (right)

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