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Environmental impact of disruptions and airspace inefficiencies in Europe

Final report

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Key findings

Fuel efficiency improvements through airline investments

- Investments in new aircraft technology and operations improve fuel efficiency on intra-EEA flights by 1.9% per year;
- Over the 2015-2017 period, these investments saved 3.9 Mt (Megatonnes) of fuel and 12.2 Mt of CO_2, corresponding to around 1 million commercial passenger flights or two months of flying within the EEA.

Environmental impact of ATC-strikes and technical failures at European ANSPs

- Europe faced 33 strikes at Air Traffic Control (ATC) and 64 technical failures at Air Navigation Service Providers (ANSPs) over the 2015-2017 period, most of which occurred in France;
- ATC-strikes on average affected more flights (3,468 per day) than technical failures (1,329 per day);
- The impact of ATC-strikes on flight efficiency was also larger than that of technical failures:
  - An average strike increased flight distance by 70,000 kilometres per day requiring 200 tonnes of additional fuel;
  - An average technical failure increased flight distance by 3,000 kilometres per day, requiring 10 tonnes of additional fuel;
- Together ATC-strikes and technical failures increased flight distance by 4.6 million kilometres over the 2015-2017 period. As a result, fuel consumption and CO_2-emissions increased by 13.7 kt (kilotonnes) and 43.0 kt respectively, corresponding to around 3,500 commercial passenger flights within the EEA;
- ATC-strikes were responsible for 95% of the increases in flight distance (4.4 million kilometres), fuel consumption (12.9 kt) and CO_2-emissions (40.7 kt);
- French strikes and technical failures were responsible for almost 98% of the increases in fuel consumption and emissions. This is explained by: (1) the relatively high number of French strikes and technical failures, (2) the central geographic location of France in Europe, (3) the relatively long duration of French strikes and (4) the fact that not all overflights are accommodated.

Environmental impact of ATM-inefficiencies in European airspace

- Due to inefficiencies in European Air Traffic Management (ATM), flight distances for intra-EEA flights were 0.61-0.76% longer than technologically possible over the 2015-2017 period;
- These inefficiencies resulted in 229 kt of additional fuel burn and 721 kt of additional CO_2 over the 2015-2017 period, corresponding to around 60,000 commercial passenger flights or 4 days of flying within the EEA.

Executive summary

Climate change is one of the major challenges facing our generation. The aviation industry has committed itself to reduce its impacts on the climate. Airlines continuously invest in more fuel-efficient aircraft and improving their flight operations. Their achievements are (partly) offset by inefficient flight operations caused by disruptions (strikes and technical failures) at European Air Navigation Service Providers (ANSPs) and the fragmented design of European airspace. Such inefficiencies result in suboptimal flight paths causing additional fuel consumption and CO_2-emissions. Previous studies have analysed the economic impacts of disruptions and the design of European airspace. This study for the first time provides an in-depth analysis of the environmental impact of disruptions and Europe's fragmented airspace.

First, the study describes the technological and operational measures that airlines have taken to improve their fuel-efficiency and quantifies their environmental impact for intra-EEA flights over the 2015-2017 period. Second, it outlines which disruptions have occurred at European ANSPs over the same time period and estimates their impact on the environment. Third, the study describes the progress made in reforming European airspace design, the inefficiencies that remain and their impact on the environment.

Airline measures to improve efficiency

In 2009, the aviation industry recognized the need to address climate change and adopted a set of goals for the short-, medium- and long-term reduction of its CO_2-emissions:

- Short-term (by 2020): improve fuel efficiency and CO_2 emissions by 1.5% per annum;
- Medium-term (after 2020): cap emissions providing carbon-neutral growth (CNG2020);
- Long-term (by 2050): reduce net CO_2 emissions by 50% compared to 2005 levels.

Airlines contribute to these goals by investing in more fuel efficient technologies and operations. Due to technological innovations new generation aircraft are around 15% more fuel efficient than the models they replace. Furthermore, airlines optimize operations, for instance by increasing load factors. Over the past decade, the average load factor for intra-EEA flights increased by almost 10 percentage points to around 82%.

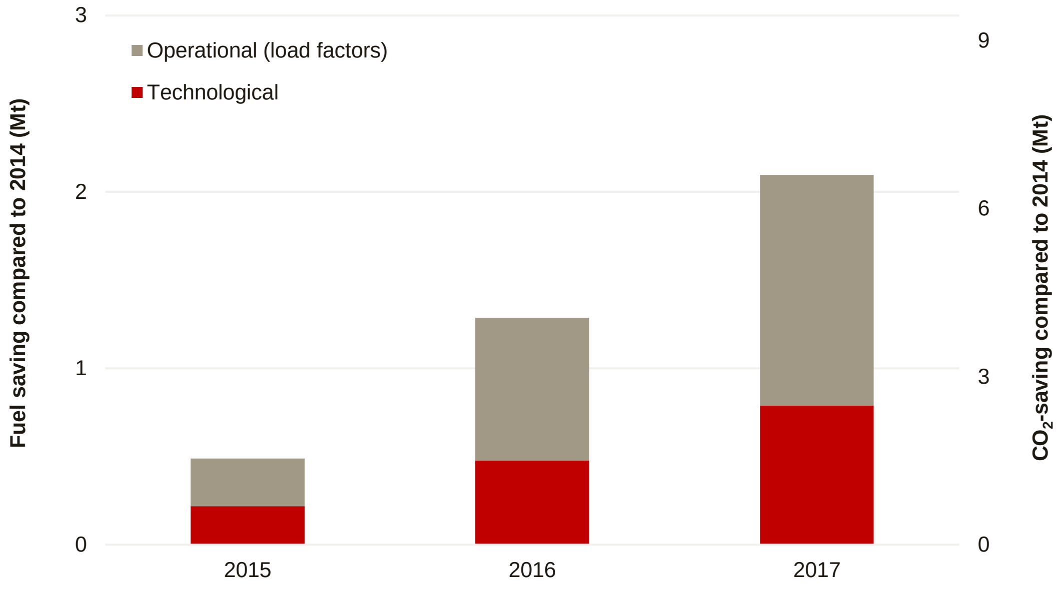
Methodology
First we determine to what extent fuel efficiency for intra-EEA flights has increased as a result of technical and operational (higher load factors) measures taken by airlines. For all scheduled passenger flights sourced from OAG's Schedule Analyser, we calculated the associated fuel consumption per seat kilometre in the various flight phases using our in-house emissions model. The development in the fuel consumption per seat kilometre represents the contribution of investments in new aircraft technology on fuel efficiency. Next, we use average industry load factors for the EEA to estimate fuel consumption per passenger kilometre. This shows the added contribution of higher load factors to fuel efficiency. Based on the increases in fuel efficiency we

calculate how much fuel and emissions were saved within the EEA over the 2015-2017 period because of technological and operational measures taken by airlines.

Results

The average fuel efficiency of intra-EEA flights has improved by almost 2% per year over the last decade. Technological and operational measures both contributed to higher fuel efficiency. Figure S.1 shows the fuel and emissions savings through technical and operational measures taken by airlines for intra-EEA flights in the 2015-2017 period. Fuel and emissions savings increase year by year, reflecting continuous technological and operational improvements. The fuel savings over the 2015-2017 period cumulate to 3.9 Mt (Megatonnes)[1], translating into over 12.2 Mt of CO_2. This corresponds to the fuel consumption and emissions of around 1 million commercial passenger flights or two months of flying within the EEA.

Figure S.1 Technological and operational measures saved over 12 Mt of CO_2



Source: SEO/To70 analysis

Disruptions

Disruptions due to strikes at Air Traffic Control (ATC) and to technical failures at ANSPs may lead to the temporary closure or limitation of available capacity of certain airspace sectors. Such capacity reductions may cause delays, flight cancellations and the rerouting of aircraft, negatively impacting passengers, airlines and the environment. Passengers are confronted with longer travel times disrupting their travel plans. Airlines are confronted with cost increases as a result of compensation payments to passengers, the implementation of contingency plans, extended working time for personnel and increased fuel consumption. The latter translates into more CO_2-emissions, which negatively impacts the environment.

[1] One Megaton equals 1,000 kilotonnes or 1,000,000 tonnes.

Previous studies have assessed the economic impacts of ATC-strikes at ANSPs. One study assessed the impact of strikes on flight distance. No study estimated the impacts of technical failures at ANSPs on flight efficiency yet, nor did the studies assess the environmental impact of disruptions. This study is the first to provide an in-depth analysis of the impacts of strikes and technical failures at ANSPs on flight efficiency and the environment.

Methodology
To estimate the EEA-wide environmental impact of ATC-strikes and technical failures at ANSPs we use a four-step approach:

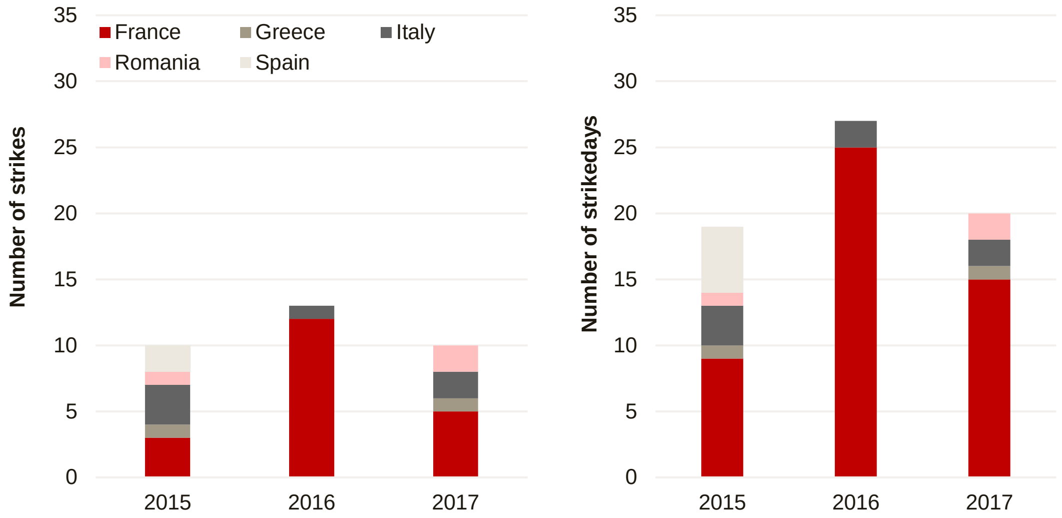
1. **Identification of affected flights.** For each disruption, we first identify which airspace sectors were affected by ATC-strikes and technical failures using Eurocontrol's DDR/NEST data. Next we analyse which routes crossed these sectors one week before the disruption. All EEA-flights that operated on these routes on the day of the disruption were identified as affected flights;
2. **Estimation of additional flight distance per affected flight.** Second, we estimate the additional horizontal flight distance of the affected flights due to the airspace disruptions. For this estimation we use an econometric method called *difference-in-difference* (DiD). This method allows us to compare the horizontal flight distance of the affected flights on the day of the disruption to the flight distance one week before the disruption, while controlling for possible time trends;
3. **Translation of additional flight distance into fuel consumption.** Third, we use Eurocontrol BADA data to translate the increases in horizontal flight distance into additional fuel consumption;
4. **Translation of additional fuel consumption into additional CO_2-emissions.** Finally we translate the additional fuel burn into CO_2-emissions.

Results
Over the 2015-2017 period, traffic controllers at European ANSPs went on strike 33 times (see Figure S.2).[2] The French controllers at DSNA were responsible for the majority of all strikes (60%), followed by the Italian controllers (18%). The majority of the strikes in France were so-called 'solidarity strikes', supporting national labour disputes. Solidarity strikes in France were in many cases supported by DSNA staff. The strikes in Italy had to do with the privatisation of the national ANSP: ENAV.

ATC-strikes in France are normally full day strikes (midnight to midnight) and often cover multiple days, whereas strikes in other Member States, such as Italy and Greece, are generally limited to a few hours. In terms of strike days, France is therefore responsible for an even larger share (74%) than in terms of number of strikes.

2 See Appendix A for an overview of all strikes at ATC-organizations between 2015-2017.

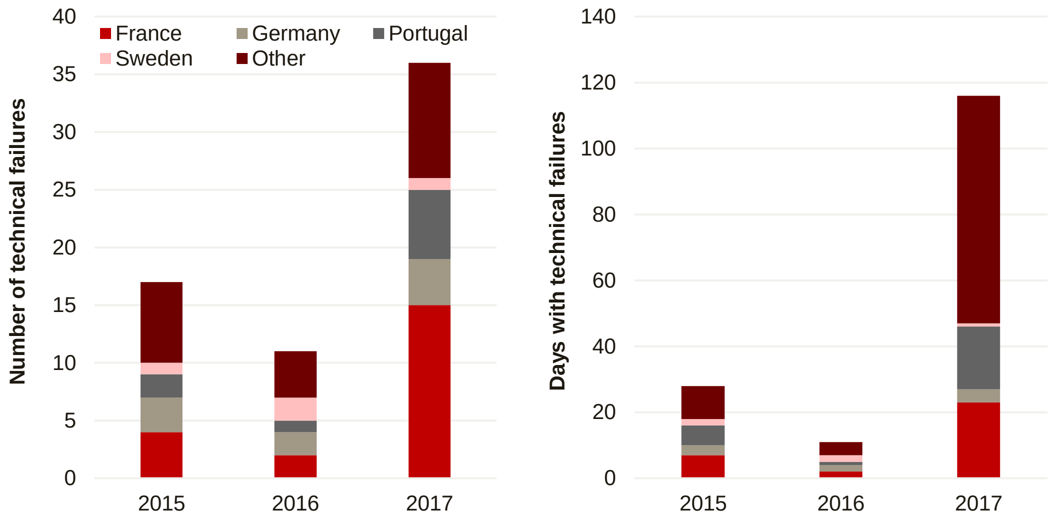
Figure S.2 Most ATC-strike(day)s took place at the French ANSPs between 2015 and 2017



Source: Eurocontrol (2016a, 2017c, 2018a), analysis by SEO/To70
Note: The data includes only strikes by air traffic controllers. Strikes by other categories of staff, such as ATC-technicians, are not included. Also strikes by air traffic controllers that are called on short notice may sometime be recorded as 'staffing issues' and therefore may not be included in the data.

Over the 2015-2017 period, Eurocontrol recorded 64 technical failures, more than half of which occurred in 2017. One in every three technical failures occurred at the French ANSP. Most failures were caused by radar or communication failure. Technical failures on average took 2.5 days to solve. As an exception, the Swiss ATC centres of Geneva and Zurich in 2017 experienced radar instability issues for 30 days. When we exclude these Swiss failures, the average technical failure prolongs for 1.5 days.

Figure S.3 Most technical failures take place at French ATC-organizations



Source: Eurocontrol (2016a, 2017c, 2018a), analysis by SEO/To70

The average number of flights affected by a disruption is 2,310. Strikes on average affected more flights (3,468) than technical failures (1,329). Differences between individual disruptions are large, ranging between 68 and 7,000 flights. French strikes generally affected a relatively large number of flights. This is explained by (1) the central location of France in Europe, (2) the fact that French strikes generally last for an entire day and (3) that not all overflights are accommodated.

During a disruption the horizontal flight distance of affected flights increased by 9.8 kilometres on average. This constitutes a 0.7% increase in total flight distance. For strikes, the increase in flight distance is significantly larger (+17.1 kilometres) than for technical failures (+3.7 kilometres). Again impacts differ significantly between individual strikes and technical failures. The French strike on March 6th 2017 for instance increased the average flight distance of affected flights by 76.1 kilometres (+4.7%). Case studies (see box) show that the the impacts on individual flights may be much larger. There are however also cases in which disruptions led to reductions in flight distance. This may be explained by the fact that cancellation of flights reduce congestion, which allows other flights to follow a more direct flight path. French strikes led to the largest increases in flight distance.

By combining the number of affected flights with the increase in flight distance per affected flight, we estimate the total additional flight distance caused by disruptions. Table S.1 shows that strikes and technological failures at European ANSPs increased flight distances for intra-EEA flights by 4.6 million kilometres over the 2015-2017 period. Unsurprisingly, given that both the number of affected flights and the impact per affected flight is substantially higher for strikes than for technical failures, the strikes account for the majority (95%) of additional kilometres flown. On average each strike day resulted in over 70,000 additional flight kilometres; each day with a technical failure on average led to an additional 3,000 kilometres flown.

Table S.1 Strikes on average increase flight distances by 70,000 kilometres per day

Additional kilometres flown (2015-2017)	Full sample	Strikes	Technical failures
Total	4,619,788	4,377,591	242,198
Mean per disruption day	34,735	71,764	3,364
Minimum per disruption day	-16,679	-13,840	-16,679
Maximum per disruption day	314,257	314,257	51,965

Source: SEO/To70 analysis

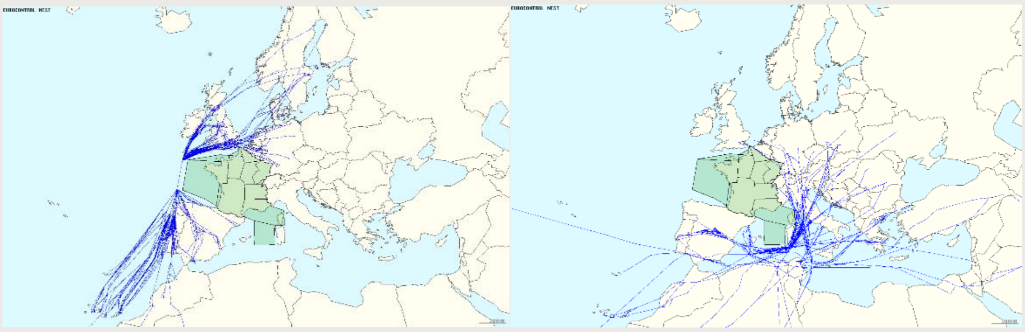
These increases in flight distance lead to additional fuel consumption and CO_2-emissions. Figure S.6 shows the additional consumption and CO_2-emissions caused by strikes and technical failures for intra-EEA flights over the 2015-2017 period. The grand total for the three year period adds up to 13.7 kt (kilotonnes)[3] of kerosene and 43.0 kt of CO_2. To put this into perspective, this corresponds to the fuel consumption and emissions of around 3,500 commercial passenger flights within the EEA.

3 One kiloton equals 1,000 tonnes or 1,000,000 kilograms.

Case study: French ATC strike on March 22nd 2018

Multiple trade unions in France representing public sector workers and airline personnel called for strikes on the 22nd and 23rd of March 2018. On the first day of the strike French air traffic controllers joined the strike. On that day, 28,252 flights operated in European airspace. Of these flights, 5,405 intra-EEA operated in or near French airspace, almost 1,000 less than the week before the strike. Especially short-haul flights were less operated on the day of the strike. Over 200 flights were re-routed around French airspace, either westbound or eastbound (see Figure S.4). This resulted in flight extension of 14% and 21% respectively. The average route extension in the area of interest was 5.22%, an increase of 1.8% compared to the week prior to the strike.

Figure S.4 Re-routings around French airspace

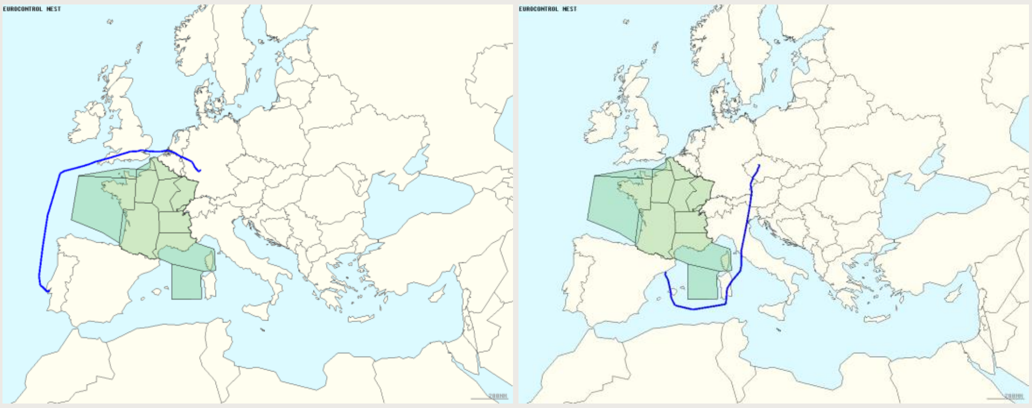


Westbound **Eastbound**

Source: SEO/To70 analysis based on Eurocontrol DDR/NEST

For specific flights the extensions were much larger. A flight from Frankfurt to Lisbon for instance was re-rerouted westbound around France, resulting in a 637 kilometre increase in flight distance (+33%), requiring an additional 1.9 tonnes of fuel and 6.0 tonnes of CO_2 (see Figure S.5). A flight from Barcelona to Prague was re-routed eastbound, adding 741 kilometres to total flight distance (+56%). This required 2.7 tonnes of extra fuel and 8.6 tonnes of CO_2.

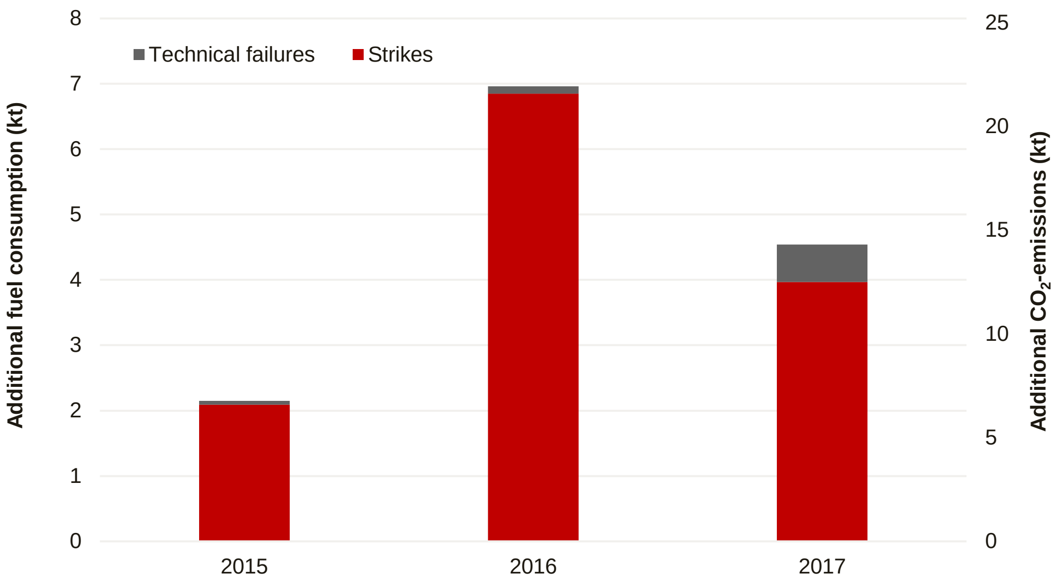
Figure S.5 Strikes may severely impact specific flights



Frankfurt Main to Lisbon (+637km, 33%) **Barcelona to Prague (+741km, 56%)**

Source: SEO/To70 analysis based on Eurocontrol DDR/NEST

Figure S.6 Disruptions in 2016 caused most additional fuel consumption and CO_2-emissions



Source: SEO/To70 analysis

Disruptions in French airspace account for the vast majority of all additional fuel consumption and CO_2-emissions (97.6 percent). The large contribution of French disruptions to additional fuel consumption and CO_2-emissions is explained by the large number of ANSP-strikes in France and their relatively large impact. Portugal appears to be the second contributor to additional fuel consumption and CO_2-emissions, which is completely driven by equipment issues.

Case study: Understaffing at Karlsruhe UAC on 22nd December 2018

In December 2018, Karlsruhe UAC was the biggest generator of en-route delays due to understaffing (Eurocontrol, 2019d). Furthermore, Karlsruhe generated 37.4% of ATC capacity delays in the European network. Due to the staffing and capacity issues it had a limited number of sectors available in 2018, up to 10 less than required and 6 less than in 2017 (Eurocontrol, 2018b).

Eurocontrol (2019d) labelled Saturday 22nd of December 2018 as a day with high ATC understaffing and capacity issues Karlsruhe. On this day 29 regulations applied causing 18,000 minutes or delay. The causes of these delays were labelled as 'ATC staffing' (around 1,200 minutes) and 'ATC capacity' (around 16,800 minutes).[4]

In the week after[5] the 22nd of December, flights passing through the Karlsruhe airspace already showed a higher flight inefficiency (2.44%) than flights that exclusively passed through adjacent airspace (2.33%). On the 22nd of December the flight inefficiency for Karlsruhe airspace

4 As understaffing at Karlsruhe UAC has become a structural issue, operational configurations are now planned considering the staff limitations. This means that part of structural understaffing is now regulated as a capacity issue, i.e. labelled as 'ATC capacity'.

5 We did not choose the week before the 22nd, as this week was characterized by many regulations and therefore was not considered a good reference.

deteriorated by 0.14 percentage points, whereas flight inefficiency in adjacent airspace deteriorated by 0.08 percentage points.

Apart from airspace regulations, traffic scenarios can be implemented to reduce airspace complexity and therefore the workload of the understaffed ATC. Such scenarios may include level capping whereby flight level restrictions are applied to specific airspace sectors. This may lead to suboptimal vertical flight trajectories, increasing fuel consumption and CO_2-emissions. These level caps scenarios are also used in Karlsruhe. On the Dusseldorf to Munich route such caps increase fuel consumption by 120 kilograms and CO_2-emissions by 400 kilograms.

ATM-inefficiencies

Air transport came of age and grew rapidly during the fifties and sixties because of the introduction of radar technology and jet aircraft. European airspace in this period largely followed national borders and this is largely still the case. Back in the days civil air traffic routes were designed as direct routes between the largest centres of population. Military training areas were designed around the civil route network. To navigate through the route network, ground-based equipment along these routes was required. Thanks to technological development routes do not fully rely on ground equipment anymore, nevertheless these routes largely remain in use today. The fragmented airspace and original route design appears inefficient in managing current and future number of air traffic movements.

An initiative to reform the architecture of ATM was first launched by the European Commission in 1999 known as Single European Sky (SES). On the technological side, SES is supported by the Single European Sky ATM Research (SESAR) Programme launched in 2004. SESAR's high-level goals are to increase capacity, reduce delays, improve safety, reduce costs for airspace users and reduce emissions by 10%.

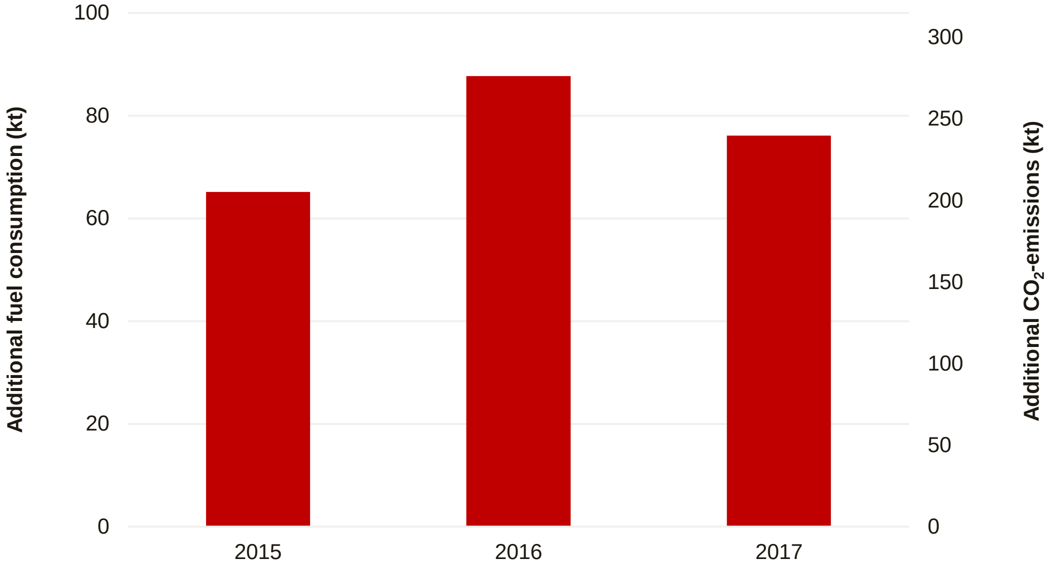
These goals should be achieved through innovative technical and operational solutions, such as Functional Airspace Blocks (FABs), Flexible Use of Airspace (FUA) and Free Route Airspace (FRA). Their implementation status differs across Europe; general progress has been relatively slow due to political, legal and technical impediments.

Methodology
Based on the performance indicators published by the Performance Review Body of the SES we estimate the ATM-inefficiencies that remain within en-route airspace. These estimates are used to assess to what extent these inefficiencies increased flight distances for intra-EEA flights over the 2015-2017 period. Finally, we calculate the associated additional fuel consumption and CO_2-emissions using our in-house emissions model.

Results
In 2015, 2016 and 2017, ATM-inefficiencies caused flight distances to be respectively 0.60%, 0.76% and 0.61% longer than technologically possible. These inefficiencies led to additional fuel consumption for intra-EEA flights ranging between 65-88 kt per year (see Figure S.7).

Over the entire 2015-2017 period additional fuel burn of intra-EEA flights cumulates to 229 kt, resulting in 721 kt of additional CO_2, corresponding to around 60,000 commercial passenger flights or 4 days of flying within the EEA.

Figure S.7 ATM-inefficiencies lead to unnecessary fuel consumption and CO_2-emissions



Source: SEO/To70 analysis