

# The interdependency between the environment and capacity KPIs of the performance and charging scheme of the Single European Sky

## Annex

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## 1 INTRODUCTION

- 1 This Annex to the report on the interdependency between the environment and capacity key performance indicators within the performance and charging scheme provides supporting information relating to the study.
- 2 This Annex includes:
  - Section 2: The detailed literature review, a summary of which was included in Section 2 of the main report.
  - Section 3: A description of the methodology and summary of results of the statistical analysis.
  - Section 4: Flight trajectory case studies to illustrate the interdependency between the environment and capacity on specific days and explore the conclusions of the statistical analysis.

## 2 LITERATURE REVIEW

3 This section presents the outcome of the literature review of previous work relating to the interdependency between the environment and capacity KPAs. The following sources were reviewed:

- Manual on global performance of the air navigation system (ICAO);
- ATM global environment efficiency goals for 2050 (CANSO);
- Environmental assessment: European ATM network fuel inefficiency study (Eurocontrol);
- Impact assessment of the enhanced NM/ANSPs Network Measures for Summer 2019 (Network Manager);
- Interdependencies within ATM performance in the context of a dynamic environment (Workshop BLUE MED FAB, and FABEC); and
- Climate change and the role of air traffic control (Workshop Baltic FAB, FABEC, GARS, Vilnius TU).

### 2.1 *Manual on global performance of the air navigation system (ICAO Doc 9883)*

- 4 This manual (Doc 9883) was produced by the ICAO Air Traffic Management Requirements and Performance Panel in 2009 and addresses the basic and common performance management terminology and techniques. The aim of the manual is not to analyse the interdependencies within the ATM system, but rather to give an overview of performance planning and management techniques. While the manual does not directly address the interdependency between environment and capacity areas, it recommends that there should be an approach to deal with the issue of performance trade-offs.
- 5 Appendix B, 4.3 of the manual is of particular relevance. It analyses the trade-offs between key performance areas, including the link between flight efficiency and capacity. It highlights the example of objectives related to providing flight trajectories closer to user preferred trajectories having to be balanced against the objective of increasing capacity.
- 6 The manual suggests that in order to improve performance when there are interdependencies, one must first determine if there are conflicting objectives that need to be balanced. When conflicting objectives emerge, the manual raises techniques

from ‘multi-criteria decision-making (MCDM)’, such as the development of a common performance metric across multiple objectives or the technique of the analytical hierarchy process (AHP) allowing decision makers to rank preferences.

- 7 It is also highlighted that after the initial target setting and where simultaneous meeting of different targets is not possible, the balance between targets must be adjusted so that they reflect acceptable and feasible compromise.
- 8 In Chapter 2 (Measuring and Assessing performance), the manual highlights the necessity to develop an understanding of the interrelationships between different performance objectives within a KPA and between different KPAs.
- 9 These interdependencies can allow improvement in performance in one KPA via a trade-off in performance within another KPA. The manual gives examples of the interdependencies including between the environment and capacity KPA. For example, Continuous Descent Operations (CDO) procedures may provide improvements in both noise and emissions at the expense of capacity.

### 2.2 *ATM global environment efficiency goals for 2050 (CANSO)*

- 10 In its report of 2012, ATM global environment efficiency goals for 2050, CANSO presented its aspirational goals for fuel efficiency improvements and addressed the topic of interdependencies (such as capacity limitations, weather, noise, and others) and how they may affect fuel efficiency.
- 11 These efficiencies may be achieved by introducing a range of initiatives. Some of these can be introduced by ANSPs directly, such as new operational procedures. However, many rely on other stakeholders of the ecosystem, such as airspace users, airports, and regulators to bring change. Improvements are also possible by reducing the effect of interdependencies such as increasing capacity and reducing noise restrictions.
- 12 The report, now over ten years old, estimated that interdependencies relate to half the total inefficiencies in the system at that time, however, it does not go into the details of the environment and capacity KPA interdependency.

### 2.3 *Environmental assessment: European ATM network fuel inefficiency study (Eurocontrol)*

- 13 In a 2020 study, Eurocontrol estimated the fuel inefficiency of the ATM network in 2019 to be between 8.6% and 11.2% from take-off to landing for flights within Europe.
- 14 When addressing operational efficiency, the report states that it is a result of various interactions between airspace users, airport operators, and ATM. As such, the report highlights that operational efficiencies cannot be reduced to zero (for example due to safety requirements, and operational trade-offs) and that improvements require joint efforts from all stakeholders.
- 15 The report does not directly address the interdependencies, however, particularly on HFE, the analysis undertaken suggests that the lack of capacity and the resulting ATFM constraints have a significant negative effect on flight efficiency. Where traffic density is highest and FRA is not fully implemented, the en route flight efficiency is comparatively low. Where FRA is fully implemented, there is a clear 0.5% higher flight efficiency versus other states.
- 16 In addition, the Think Paper #10 (April 2021) published by Eurocontrol, identifies solutions that exist and could contribute to making every flight as environmentally efficient as possible including on-board systems, minimisation of the adoption of hard ATM constraints such as permanent RAD restrictions by ATC and efficient/optimal capacity management of the Network (e.g. 4D business trajectories and Free Route Airspace).<sup>1</sup>

### 2.4 *Impact assessment of the enhanced NM/ANSPs network measures for summer 2019 (Network Manager)*

- 17 Due to the lack of capacity in some critical areas of the network and the complexity in managing the increasing traffic demand effectively and most efficiently at individual centre level during summer 2019, the Network Manager and all the involved ANSPs (eNM/S19) built a common strategy to prepare, manage and deliver a better service, focused on optimising the en route flows in between the centres and increasing the overall capacity and throughput.

- 18 An impact assessment of the measures proposed in the above-mentioned strategy was held from a flight efficiency, delay, user charges, and flight cancellations point of view. More precisely, it identified that the delay mitigation measures within the eNM/ANSPs/S2019 for the period 25<sup>th</sup> April 2019 to 6<sup>th</sup> November 2019 would result in:
  - A delay reduction of 1.72 minutes/flight;
  - Additional route extension for hundreds of flights leading to approximately 1.1 million NM flown extra, i.e., the equivalent of 6,600 tons of fuel, or increased emissions of 22,000 tons of CO<sub>2</sub>; and
  - Approximately 26,080 tons of additional fuel consumption from flight level constraints resulting in vertical flight inefficiency.
- 19 Although the report did not look at the environment and capacity performance areas interdependency per se, it still provided some facts confirming that changes regarding capacity in the network affects both horizontal and vertical flight efficiency.

### 2.5 *Interdependencies within ATM performance in the context of a dynamic environment (Workshop BLUE MED FAB, FABEC)*

- 20 The objective of the workshop (October 2020 - BLUE MED FAB and FABEC) was to investigate the impact of interdependencies within the ATM Performance areas of safety, environment, capacity, and cost-efficiency. One of the main conclusions of the workshop, was that interdependencies within the ATM performance areas exist and influence decision making.
- 21 The workshop found that the majority of the information available relates to the cost-efficiency - capacity trade-off, whilst there is a substantial lack of knowledge on metrics, methodology and, thus, trade-offs between the other areas. It concluded that interdependencies must be addressed appropriately in order to ensure robust operations, especially with the ongoing challenge of extreme traffic demand volatility and route preferences, forcing more flexible and adaptive ways of working.

<sup>1</sup> <https://www.eurocontrol.int/publication/eurocontrol-think-paper-10-flying-perfect-green-flight>.

## 2.6 *Climate change and the role of ATC (Workshop Baltic FAB, FABEC, GARS, Vilnius TU)*

- 22 The workshop (September 2021 - Baltic FAB, FABEC, GARS and Vilnius Gediminas Technical University) looked at the climate change and aviation nexus and considered the role of air navigation services as an essential enabling infrastructure. According to the main outcomes of the workshop there is a clear link between capacity, defined as a maximum number of flights passing through a sector, and the environmental impact.
- 23 The workshop concluded that clear policy priorities, enriched forecasts and improved efficiency benchmarks are required while the adaptation of the current performance and charging scheme should be considered to balance the KPAs of safety, environment, capacity, and cost-efficiency.

### 3 STATISTICAL ANALYSIS

24 This section provides the description of the methodology followed for the statistical analysis conducted by the PRB. The interpretation of the analysis is presented in the main report.

25 The study defined the following four key research objectives which have been modelled using linear regression (since there were no indications of non-linearity):

- Quantify the interdependency between Union-wide HFE and en route ATFM delays;
- Quantify how seasonal changes affect the interdependency between HFE and en route ATFM delays;
- Quantify if/how en route ATFM delays due to different causes have different impacts on HFE;
- Estimate if/how en route ATFM delays occurring at different locations of the European ATM network have different impacts on Union-wide HFE.

A total of three sets of models were used and are presented in the following sections.

#### 3.1 Scope and data

26 The time period analysed covers the years from 2017 to 2021. The period selected is a balance between analysing a large enough sample while including the years most relevant for current-day operations. All days within this time period were considered during the analysis. The years prior to 2017 were not considered due to three main reasons:

- A significant traffic increase materialised during 2017-2019 (the number of IFR movements increased by 8.7% between 2019 and 2016 on average), which significantly altered the traffic flows and the distribution of traffic;
- Following the very high delays in 2018, the Network Manager started an intensive collaboration with ANSPs to develop and implement measures to avoid peak period delays; and

- Many ANSPs changed the ways they operated by introducing free route airspace, more arrival/departure managers and other advanced functionalities.

27 On the other hand, 2020 was kept in the scope, to ensure a continuous sample, despite its outlier nature due to the COVID-19 pandemic impact. The observations are at day level for each of the years considered (in total 1,826 observations).

28 Depending on the model, the observations are at Union-wide level (variable defined as '*uw*'), or at FIR level (variable defined as '*fir*'). When considering the FIR level observations, Spain was included in the datasets as Spain Continental and Spain Canarias. For the FIR level analysis, the States included are the ones within the scope of the performance and charging scheme (Member States) as well as States that are not part of the performance scheme but that are located along some of the major traffic axes in Europe.<sup>2</sup>

29 The source of the data is the Aviation Intelligence Unit of Eurocontrol. Data does not include post-ops adjustments.

30 All models have been tested for linearity, homoscedasticity, independency, and multicollinearity.<sup>3</sup> The variables have been adjusted during the analysis to fulfil the statistical assumptions.<sup>4</sup>

#### 3.2 Interdependency between HFE and ATFM delays

31 The model generated to study the interdependency between HFE and the en route delays is:

$$\text{Model}_1: \quad HFE_{uw_i} = \alpha + \beta_1 DLY_{uw_i} + \beta_2 S\_DLY_{uw_i} + \varepsilon_i$$

Where:

- *HFE<sub>uw<sub>i</sub></sub>* is the Union-wide average horizontal flight efficiency in day *i*;
- *DLY<sub>uw<sub>i</sub></sub>* is the Union-wide average minutes of en route ATFM delay per flight in day *i*; and
- *S\_DLY<sub>uw<sub>i</sub></sub>* is the Union-wide average minutes of en route ATFM delay per flight in

<sup>2</sup> U.K., Bosnia and Herzegovina, Serbia and Montenegro.

<sup>3</sup> Estimations have been performed with the JASP statistical tool kit. <https://jasp-stats.org/>.

<sup>4</sup> For the FIR level models, some of the observations of Finland, Lithuania, and Moldova have been removed due to multicollinearity.

day  $i$  multiplied by a seasonal dummy identifying the summer days (days between May and September).

32 The results of Model\_1 are shown in Table 1. The regression is significant with an acceptable level of adjusted  $R^2$ .

Model_1		
Variable	Coefficient (Std. error)	t-value <sup>5</sup>
Intercept	2.59 (0.007)	339.826 ***
DLY_uw	0.14 (0.010)	14.315 ***
S_DLY_uw	-0.01 (0.010)	-0.983
adjusted $R^2$ : 0.31		

Table 1 – Results of Model\_1 (Source: PRB elaboration).

33 The daily average Union-wide en route ATFM delay ( $DLY_{uw}$ ) is significant and positive. The coefficient shows that an increase of one minute of Union-wide average of en route delay per flight causes an increase by 0.14 percentage points in the Union-wide horizontal flight efficiency when considering all days in the year. Thus, an increase in the delay levels is negatively impacting the environmental performance. The delay variable multiplied by the seasonal dummy ( $S_{DLY_{uw}}$ ) is not significant, showing that, on average, there is not a statistical difference in the impact of delays depending on the season.

34 Since the model includes a single explanatory variable, the intercept value may be interpreted as the value of the Union-wide daily HFE on days when there were no delays. Therefore, assuming no delays, the average day Union-wide HFE is estimated to be 2.59%.

### 3.3 Impact of different ATFM delay causes on HFE

35 The model generated to study the impact of different ATFM delay causes on HFE is:

$$\begin{aligned}
 HFE_{uw_i} = & \alpha + \sum_{n=1}^7 \beta_n REAS_{uw_{n,i}} \\
 & + \sum_{n=1}^7 \beta_n S_{REAS_{uw_{n,i}}} \\
 & + \varepsilon_i
 \end{aligned}$$

Where:

- $HFE_{uw_i}$  is the Union-wide average horizontal flight efficiency in day  $i$ ;
- $REAS_{uw_{n,i}}$  are the Union-wide daily average en route ATFM delays per flight in day  $i$  for reason  $n$ . The reasons analysed are: ATC capacity (CAPATC), ATC staffing (STAFFATC), ATC disruptions (DSRPTNATC), weather (WEATHER), special events (EVENTS), non-ATC capacity (CAP), and non-ATC disruptions (DSRPTN); and
- $S_{REAS_{uw_{n,i}}}$  are the Union-wide daily average en route ATFM delays per flight in day  $i$  for reason  $n$  multiplied by a seasonal dummy identifying the summer days (days between May and September).

36 The results of Model\_2 are shown Table 2. The regression is significant with an acceptable level of adjusted  $R^2$ .

Model_2		
Variable	Coefficient (Std. error)	t-value <sup>6</sup>
Intercept	2.58 (0.008)	329.39 ***
CAPATC_uw	-0.08 (0.039)	-2.103 **
STAFFATC_uw	0.28 (0.058)	4.880 ***
DSRPTNATC_uw	0.18 (0.015)	12.125 ***
WEATHER_uw	0.34 (0.108)	3.113 ***
EVENTS_uw	0.49 (0.160)	3.047 ***
CAP_uw	2.90 (0.312)	9.290 ***
DSRPTN_uw	-0.06 (0.028)	-2.136 **
S_CAPATC_uw	0.28 (0.046)	6.158 ***
S_STAFFATC_uw	-0.32 (0.069)	-4.666 ***
S_DSRPTNATC_uw	-0.06 (0.038)	-1.694 *
S_WEATHER_uw	-0.20 (0.109)	-1.860 *
S_EVENTS_uw	-0.04 (0.220)	-0.199
S_CAP_uw	-1.67 (0.344)	-4.837 ***
S_DSRPTN_uw	-0.02 (0.139)	-0.154
adjusted $R^2$ : 0.39		

Table 2 – Results of Model\_2 (Source: PRB elaboration).

37 The results show that the delay reasons have a different impact on the HFE, with some of them being not significant at all. Moreover, differently from Model\_1, the estimated coefficients show that for some of the delay reasons, the season can be a determinant on the impact on HFE:

- ATC capacity (CAPATC): The impact during winter is negligible and close to zero (-0.08),

<sup>5</sup> The number of asterisks indicates the significance level: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.001$ .

<sup>6</sup> The number of asterisks indicates the significance level: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.001$ .

while during summer is estimated to be 0.19 (i.e.  $-0.08+0.28$ );

- ATC staffing (STAFFATC): The impact during winter is positive and significant (0.28), while during summer becomes negligible and close to zero (i.e.  $0.28-0.32=-0.04$ );
- ATC disruptions (DSRPTNATC): The impact during winter is positive and significant (0.18), and remains similar during summer (i.e.  $0.18-0.06=0.12$ );
- Weather (WEATHER): The impact during winter is positive, significant, and relatively high (0.34), it remains positive and significant during summer but with a milder impact (i.e.  $0.34-0.20=0.14$ );
- Special events (EVENTS): The impact is equal during both summer and winter, being positive, significant and relatively high (0.45 and 0.49);
- Non-ATC capacity (CAP): The impact is by far the highest among the delay causes. During winter it is estimated to be equal to 2.9, while decreasing in summer to 1.23 (i.e.  $2.9-1.67=1.23$ ); and
- Non-ATC disruptions (DSRPTN): The impact is negligible and close to zero for both winter and summer ( $-0.06, -0.08$ ).

### 3.4 En route ATFM delays occurring at different locations of the European ATM network have different impacts on Union-wide HFE

38 To study if the interdependency between HFE and the en route delays are dependent on the location, two sets of models have been generated:

$$\text{Model\_3a: } HFE_{uw_i} = \alpha + \sum_{t=1}^{30} \beta_n DLY_{fir_{t,i}} + \varepsilon_i$$

$$\text{Model\_3b: } HFE_{fir_i} = \alpha + \sum_{t=1}^{30} \beta_n DLY_{fir_{t,i}} + \varepsilon_i$$

Where:

- $HFE_{uw_i}$  is the Union-wide average horizontal flight efficiency in day  $i$ ;
- $HFE_{fir_i}$  is the average horizontal flight efficiency in day  $i$  for a specific FIR area; and

- $DLY_{fir_{t,i}}$  is the average minutes of en route ATFM delay per flight in day  $i$  in a specific IFR area  $t$ .

39 Model\_3a has been estimated through a stepwise variable selection method. Starting with the a model only including the intercept, the estimation introduces the next most significant explanatory variable (based on the "p" values), through a series of iterations, to maximise the R<sup>2</sup>-value. Therefore, some of the original explanatory variables are omitted from the model because of their low explanatory power.

40 The results of Model\_3a are shown in Table 3. The regression is significant with a relatively high level of adjusted R<sup>2</sup>.

Model_3a		
Variable	Coefficient (Std. error)	t-value <sup>7</sup>
Intercept	2.57 (0.008)	336.071 ***
DLY <sub>Germany</sub>	0.11 (0.006)	0.419 ***
DLY <sub>France</sub>	0.02 (0.003)	7.144 ***
DLY <sub>Poland</sub>	0.03 (0.006)	6.111 ***
DLY <sub>Spain</sub> can	-0.04 (0.007)	-5.280 ***
DLY <sub>Spain</sub> con	0.03 (0.010)	2.979 ***
DLY <sub>Hungary</sub>	0.05 (0.007)	6.729 ***
DLY <sub>Slovakia</sub>	-0.09 (0.028)	-3.357 ***
DLY <sub>Cyprus</sub>	0.02 (0.005)	3.637 ***
DLY <sub>Italy</sub>	0.08 (0.025)	3.183 ***
DLY <sub>Nether-</sub> lands	0.09 (0.028)	3.245 ***
DLY <sub>Estonia</sub>	-0.14 (0.062)	-2.198 **
adjusted R <sup>2</sup> : 0.49		

Table 3 – Results of Model\_3 (Source: PRB elaboration).

41 The results show that the delay variables from the FIRs of Germany, France, Poland, Spain Canarias and Continental, Hungary, Slovakia, Cyprus, Italy, the Netherlands, and Estonia are retained in the model being significant for the impact on HFE.

42 Most of the Member States show a positive impact (i.e. an increase in delay per flight in the FIR, decreases the Union-wide environmental performance). However, Spain Canarias, Slovakia, and Estonia show a negative coefficient.

43 All the FIRs areas not included in the model are estimated to have a negligible impact on environ-

<sup>7</sup> The number of asterisks indicates the significance level: \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.001.

mental performance. The results show that the locations of the delay are a determinant of the level of impact on the Union-wide HFE results.

- 44 Model\_3b is a set of regressions, each of them with the dependent variable ( $HFE_{fir_i}$ ) representing a specific FIR area (i.e. there is an estimation for each FIR area).
- 45 Due to the large number of regressions, results are shown in the following pages (Table 4). The interpretation of the results is similar to the ones of Model\_3a with the only difference that the impact is at IFR level and not Union-wide.

<b>Model_3b</b>
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<b>Austria, adjusted R<sup>2</sup>: 0.526</b>		
<b>Variable</b>	<b>Coefficient (Std. Error)</b>	<b>t value</b>
Intercept	1.847 (0.009)	205.78***
DLY Germany	0.134 (0.007)	18.22***
DLY Austria	0.111 (0.01)	10.867***
DLY Croatia	0.056 (0.015)	3.681***
DLY Switzerland	0.068 (0.019)	3.634***
DLY Bosnia and Herzegovina	-0.103 (0.034)	-3.056**
DLY Latvia	0.309 (0.086)	3.578***
DLY Italy	0.122 (0.032)	3.799***
DLY Portugal (Lisboa FIR)	0.046 (0.014)	3.24**
DLY Serbia and Montenegro	-0.038 (0.012)	-3.061**
DLY Hungary	0.028 (0.011)	2.579**
DLY Spain (Canarias)	-0.015 (0.007)	-2.045**
DLY Poland	-0.013 (0.007)	-2.021**

<b>Belgium, adjusted R<sup>2</sup>: 0.193</b>		
<b>Variable</b>	<b>Coefficient (Std. Error)</b>	<b>t value</b>
Intercept	3.437 (0.019)	184.146***
DLY Germany	0.138 (0.017)	8.177***
DLY France	0.051 (0.008)	6.381***
DLY Netherlands	0.309 (0.068)	4.536***
DLY Spain (Canarias)	-0.072 (0.015)	-4.767***
DLY Cyprus	0.059 (0.012)	4.794***
DLY Bosnia and Herzegovina	-0.208 (0.059)	-3.515***
DLY Portugal (Lisboa FIR)	-0.076 (0.029)	-2.579**
DLY Czech Republic	-0.041 (0.018)	-2.303**
DLY Sweden	-0.167 (0.078)	-2.141**

<b>Bulgaria, adjusted R<sup>2</sup>: 0.312</b>		
<b>Variable</b>	<b>Coefficient (Std. Error)</b>	<b>t value</b>
Intercept	2.476 (0.015)	166.061***
DLY Hungary	0.169 (0.014)	12.079***
DLY Bosnia and Herzegovina	0.25 (0.055)	4.581***
DLY Poland	0.093 (0.011)	8.626***
DLY Slovakia	-0.343 (0.054)	-6.333***
DLY Cyprus	-0.05 (0.011)	-4.628***
DLY Belgium	-0.088 (0.02)	-4.454***
DLY Romania	0.177 (0.047)	3.769***
DLY Germany	0.055 (0.012)	4.466***
DLY Estonia	-0.479 (0.121)	-3.97***
DLY Serbia and Montenegro	0.073 (0.02)	3.712***
DLY Spain (Canarias)	-0.033 (0.012)	-2.761**
DLY Denmark	-0.409 (0.174)	-2.351**
DLY Netherlands	-0.137 (0.06)	-2.278**
DLY Portugal (Lisboa FIR)	-0.047 (0.023)	-1.999**

<b>Croatia, adjusted R<sup>2</sup>: 0.368</b>		
<b>Variable</b>	<b>Coefficient (Std. Error)</b>	<b>t value</b>
Intercept	1.397 (0.007)	188.89***
DLY Croatia	0.14 (0.013)	10.464***
DLY Hungary	0.048 (0.009)	5.119***
DLY Austria	0.047 (0.009)	5.232***
DLY Serbia and Montenegro	0.041 (0.011)	3.823***
DLY France	0.011 (0.003)	3.492***
DLY Spain (Canarias)	-0.022 (0.006)	-3.728***
DLY Greece	-0.039 (0.012)	-3.276**
DLY Switzerland	0.039 (0.015)	2.642**
DLY Sweden	-0.092 (0.034)	-2.727**
DLY Bosnia and Herzegovina	-0.084 (0.029)	-2.931**
DLY Italy	0.064 (0.028)	2.292**
DLY Netherlands	0.056 (0.028)	2.026**

<b>Cyprus, adjusted R<sup>2</sup>: 0.052</b>		
<b>Variable</b>	<b>Coefficient (Std. Error)</b>	<b>t value</b>
Intercept	4.261 (0.019)	227.246***
DLY Croatia	0.083 (0.026)	3.233**
DLY Cyprus	0.039 (0.014)	2.757**
DLY France	-0.023 (0.008)	-2.92**
DLY Greece	0.102 (0.03)	3.402***
DLY Norway	-0.57 (0.281)	-2.033**
DLY Portugal (Lisboa FIR)	-0.1 (0.031)	-3.206**
DLY Spain (Canarias)	-0.06 (0.016)	-3.728***

<b>Czech Republic, adjusted R<sup>2</sup>: 0.543</b>		
<b>Variable</b>	<b>Coefficient (Std. Error)</b>	<b>t value</b>
Intercept	2.083 (0.009)	239.357***
DLY Austria	0.086 (0.01)	8.38***
DLY Cyprus	0.021 (0.006)	3.365***
DLY Czech Republic	0.026 (0.009)	3.007**
DLY Estonia	-0.15 (0.071)	-2.104**
DLY France	-0.008 (0.004)	-2.02**
DLY Germany	0.141 (0.008)	17.277***
DLY Hungary	0.062 (0.01)	6.213***
DLY Italy	0.094 (0.031)	3.058**
DLY Poland	0.055 (0.007)	8.463***
DLY Serbia and Montenegro	-0.038 (0.011)	-3.347***
DLY Slovakia	-0.081 (0.035)	-2.343**

Denmark, adjusted R <sup>2</sup> : 0.101		
Variable	Coefficient (Std. Error)	t value
Intercept	1.086 (0.008)	137.274***
DLY Croatia	0.022 (0.01)	2.094**
DLY Germany	0.035 (0.006)	5.953***
DLY Netherlands	0.146 (0.029)	5.026***
DLY Poland	0.023 (0.006)	4.033***
DLY Slovakia	-0.085 (0.029)	-2.916**
DLY Spain (Canarias)	-0.016 (0.006)	-2.516**
DLY Sweden	0.072 (0.034)	2.105**

Estonia, adjusted R <sup>2</sup> : 0.676		
Variable	Coefficient (Std. Error)	t value
Intercept	1.401 (0.029)	49.032***
DLY Bosnia and Herzegovina	1.809 (0.111)	16.301***
DLY Poland	0.344 (0.022)	15.94***
DLY Germany	0.431 (0.029)	14.705***
DLY Belgium	-0.325 (0.04)	-8.163***
DLY Serbia and Montenegro	0.319 (0.04)	8.028***
DLY Austria	-0.183 (0.032)	-5.738***
DLY Czech Republic	0.132 (0.029)	4.526***
DLY Estonia	-0.844 (0.236)	-3.581***
DLY Italy	0.371 (0.103)	3.583***
DLY France	-0.044 (0.013)	-3.419***
DLY Cyprus	-0.081 (0.021)	-3.797***
DLY Croatia	0.125 (0.046)	2.705**
DLY Slovakia	-0.402 (0.115)	-3.503***
DLY UK (Continental)	0.218 (0.068)	3.223**
DLY North Macedonia	0.203 (0.098)	2.081**
DLY Netherlands	-0.24 (0.121)	-1.977**

Finland, adjusted R <sup>2</sup> : 0.525		
Variable	Coefficient (Std. Error)	t value
Intercept	0.983 (0.026)	37.918***
DLY Bosnia and Herzegovina	1.419 (0.097)	14.635***
DLY Czech Republic	0.127 (0.026)	4.883***
DLY Poland	0.168 (0.019)	8.619***
DLY Serbia and Montenegro	0.228 (0.035)	6.469***
DLY Germany	0.268 (0.026)	10.222***
DLY Belgium	-0.195 (0.033)	-5.945***
DLY Austria	-0.151 (0.029)	-5.188***
DLY Greece	-0.134 (0.039)	-3.421***
DLY Hungary	0.084 (0.029)	2.868**
DLY Cyprus	-0.046 (0.019)	-2.437**
DLY France	-0.024 (0.012)	-2.078**

France, adjusted R <sup>2</sup> : 0.257		
Variable	Coefficient (Std. Error)	t value
Intercept	3.215 (0.009)	367.888***
DLY France	0.04 (0.004)	10.229***
DLY Belgium	0.052 (0.011)	4.929***
DLY Spain (Canarias)	-0.056 (0.008)	-6.77***
DLY Switzerland	0.069 (0.018)	3.849***
DLY Portugal (Lisboa FIR)	-0.055 (0.014)	-3.901***
DLY Germany	0.028 (0.008)	3.749***
DLY Spain (Continental)	0.041 (0.011)	3.712***
DLY Serbia and Montenegro	-0.034 (0.01)	-3.42***
DLY Sweden	-0.102 (0.037)	-2.729**
DLY UK (Continental)	0.047 (0.02)	2.379**

Germany, adjusted R <sup>2</sup> : 0.512		
Variable	Coefficient (Std. Error)	t value
Intercept	2.324 (0.011)	209.334***
DLY Germany	0.229 (0.011)	21.421***
DLY Austria	0.044 (0.013)	3.371***
DLY Netherlands	0.253 (0.041)	6.16***
DLY Czech Republic	-0.054 (0.011)	-4.98***
DLY Cyprus	0.037 (0.008)	4.626***
DLY Poland	0.03 (0.008)	3.656***
DLY Bosnia and Herzegovina	-0.117 (0.04)	-2.907**
DLY Estonia	-0.206 (0.09)	-2.29**
DLY Portugal (Lisboa FIR)	0.05 (0.016)	3.038**
DLY Slovakia	-0.106 (0.044)	-2.405**
DLY France	0.015 (0.005)	3.126**
DLY Hungary	0.037 (0.013)	2.984**
DLY Serbia and Montenegro	-0.03 (0.015)	-1.983**
DLY Greece	-0.034 (0.017)	-1.97**

Greece, adjusted R <sup>2</sup> : 0.130		
Variable	Coefficient (Std. Error)	t value
Intercept	2.461 (0.014)	176.199***
DLY Spain (Canarias)	-0.071 (0.011)	-6.312***
DLY Serbia and Montenegro	0.091 (0.016)	5.648***
DLY Portugal (Lisboa FIR)	-0.14 (0.022)	-6.458***
DLY Germany	-0.044 (0.012)	-3.655***
DLY Croatia	0.08 (0.02)	3.997***
DLY Cyprus	-0.044 (0.01)	-4.49***
DLY Poland	-0.036 (0.01)	-3.577***
DLY Czech Republic	0.042 (0.014)	3.121**
DLY Greece	0.076 (0.021)	3.57***
DLY France	-0.016 (0.006)	-2.613**
DLY Bulgaria	1.651 (0.75)	2.202**
DLY Slovakia	-0.103 (0.052)	-1.985**

Hungary, adjusted R <sup>2</sup> : 0.414		
Variable	Coefficient (Std. Error)	t value
Intercept	1.509 (0.01)	152.264***
DLY Germany	0.095 (0.009)	11.154***
DLY Hungary	0.089 (0.011)	7.879***
DLY Poland	0.081 (0.007)	11.312***
DLY Belgium	-0.073 (0.012)	-5.934***
DLY Serbia and Montenegro	0.052 (0.013)	3.946***
DLY Cyprus	-0.03 (0.007)	-4.165***
DLY Spain (Canarias)	-0.026 (0.008)	-3.354***
DLY Austria	0.043 (0.011)	3.822***
DLY Bosnia and Herzegovina	0.111 (0.037)	3.02**
DLY Greece	0.049 (0.015)	3.286**
DLY Estonia	-0.213 (0.081)	-2.616**
DLY France	-0.01 (0.004)	-2.322**
DLY Sweden	-0.095 (0.043)	-2.209**

Ireland, adjusted R <sup>2</sup> : 0.052		
Variable	Coefficient (Std. Error)	t value
Intercept	1.088 (0.009)	124.4***
DLY France	0.021 (0.004)	5.431***
DLY Belgium	0.034 (0.01)	3.265**
DLY Portugal (Lisboa FIR)	0.052 (0.014)	3.699***
DLY Cyprus	0.018 (0.006)	2.895**

Italy, adjusted R <sup>2</sup> : 0.290		
Variable	Coefficient (Std. Error)	t value
Intercept	2.879 (0.011)	261.892***
DLY France	0.068 (0.005)	13.834***
DLY Austria	0.04 (0.013)	3.034**
DLY Spain (Canarias)	-0.053 (0.009)	-5.916***
DLY Italy	0.216 (0.041)	5.301***
DLY Belgium	0.072 (0.013)	5.442***
DLY Greece	-0.078 (0.018)	-4.437***
DLY Croatia	0.057 (0.02)	2.89**
DLY Switzerland	0.09 (0.022)	4.132***
DLY Serbia and Montenegro	-0.045 (0.015)	-3.063**
DLY Sweden	-0.13 (0.05)	-2.585**
DLY Hungary	0.031 (0.014)	2.269**
DLY Ireland	0.406 (0.18)	2.257**

Latvia, adjusted R <sup>2</sup> : 0.647		
Variable	Coefficient (Std. Error)	t value
Intercept	1.478 (0.036)	41.177***
DLY Bosnia and Herzegovina	2.213 (0.137)	16.13***
DLY Poland	0.438 (0.027)	16.185***
DLY Czech Republic	0.172 (0.036)	4.721***
DLY Serbia and Montenegro	0.397 (0.049)	8.086***
DLY Austria	-0.195 (0.036)	-5.376***
DLY Germany	0.484 (0.037)	13.242***
DLY Belgium	-0.427 (0.047)	-9.152***
DLY Cyprus	-0.101 (0.026)	-3.863***
DLY Estonia	-1.04 (0.296)	-3.514***
DLY France	-0.048 (0.016)	-3**
DLY Italy	0.386 (0.13)	2.976**
DLY Slovakia	-0.42 (0.144)	-2.912**
DLY UK (Continental)	0.201 (0.082)	2.451**
DLY North Macedonia	0.281 (0.122)	2.308**

Lithuania, adjusted R <sup>2</sup> : 0.660		
Variable	Coefficient (Std. Error)	t value
Intercept	2.471 (0.071)	34.622***
DLY Bosnia and Herzegovina	4.343 (0.27)	16.06***
DLY Poland	0.909 (0.053)	17.018***
DLY Czech Republic	0.358 (0.072)	4.995***
DLY Austria	-0.461 (0.072)	-6.407***
DLY Germany	1.078 (0.072)	14.991***
DLY Belgium	-0.942 (0.092)	-10.227***
DLY Serbia and Montenegro	0.678 (0.095)	7.136***
DLY Cyprus	-0.221 (0.052)	-4.281***
DLY Estonia	-2.189 (0.581)	-3.77***
DLY France	-0.089 (0.032)	-2.774**
DLY UK (Continental)	0.471 (0.162)	2.911**
DLY Italy	0.677 (0.255)	2.656**
DLY Slovakia	-0.671 (0.282)	-2.374**
DLY Spain (Continental)	-0.153 (0.077)	-1.989**

Malta, adjusted R <sup>2</sup> : 0.230		
Variable	Coefficient (Std. Error)	t value
Intercept	2.626 (0.026)	99.573***
DLY Germany	-0.247 (0.023)	-10.931***
DLY Cyprus	-0.103 (0.018)	-5.789***
DLY Spain (Canarias)	-0.072 (0.021)	-3.402***
DLY Belgium	-0.119 (0.031)	-3.803***
DLY Portugal (Lisboa FIR)	-0.145 (0.041)	-3.521***
DLY Estonia	-0.604 (0.209)	-2.888**
DLY Poland	-0.052 (0.019)	-2.688**
DLY Czech Republic	0.053 (0.026)	2.084**

Netherlands, adjusted R <sup>2</sup> : 0.196		
Variable	Coefficient (Std. Error)	t value
Intercept	2.689 (0.018)	145.817***
DLY Germany	0.156 (0.016)	9.997***
DLY Netherlands	0.374 (0.068)	5.485***
DLY Poland	0.084 (0.014)	6.138***
DLY Cyprus	0.049 (0.013)	3.724***
DLY Slovakia	-0.297 (0.071)	-4.18***
DLY Austria	0.06 (0.018)	3.281**
DLY Czech Republic	-0.057 (0.018)	-3.18**
DLY Spain (Canarias)	-0.044 (0.014)	-3.075**
DLY Estonia	-0.348 (0.148)	-2.349**

Norway, adjusted R <sup>2</sup> : 0.110		
Variable	Coefficient (Std. Error)	t value
Intercept	1.561 (0.017)	93.913***
DLY Hungary	0.148 (0.016)	9.195***
DLY Serbia and Montenegro	-0.108 (0.022)	-4.798***
DLY Greece	-0.092 (0.026)	-3.548***
DLY Germany	-0.03 (0.012)	-2.463**
DLY Cyprus	0.052 (0.012)	4.277***
DLY Estonia	-0.517 (0.138)	-3.741***
DLY Malta	3.084 (0.973)	3.17**
DLY Ireland	0.674 (0.259)	2.607**
DLY Bosnia and Herzegovina	-0.142 (0.061)	-2.329**
DLY Slovakia	-0.151 (0.063)	-2.399**
DLY Poland	-0.024 (0.012)	-1.974**

Poland, adjusted R <sup>2</sup> : 0.514		
Variable	Coefficient (Std. Error)	t value
Intercept	2.018 (0.027)	75.384***
DLY Poland	0.429 (0.02)	21.79***
DLY Bosnia and Herzegovina	0.815 (0.098)	8.307***
DLY Czech Republic	0.066 (0.027)	2.483**
DLY Belgium	-0.256 (0.033)	-7.694***
DLY Germany	0.285 (0.026)	10.901***
DLY Cyprus	-0.074 (0.019)	-3.907***
DLY Spain (Continental)	-0.075 (0.029)	-2.567**
DLY Serbia and Montenegro	0.151 (0.034)	4.389***
DLY Slovakia	-0.197 (0.104)	-1.891*
DLY Estonia	-0.63 (0.214)	-2.938**
DLY Austria	-0.073 (0.027)	-2.735**
DLY Portugal (Lisboa FIR)	-0.101 (0.041)	-2.445**
DLY France	-0.024 (0.012)	-2.022**

Portugal Continental, adjusted R <sup>2</sup> : 0.044		
Variable	Coefficient (Std. Error)	t value
Intercept	1.777 (0.013)	137.164***
DLY France	0.035 (0.006)	6.316***
DLY Bosnia and Herzegovina	-0.157 (0.05)	-3.139**
DLY Hungary	0.047 (0.012)	4.008***
DLY Slovakia	-0.141 (0.051)	-2.786**
DLY Poland	-0.026 (0.01)	-2.623**
DLY Serbia and Montenegro	-0.044 (0.019)	-2.377**

Romania, adjusted R <sup>2</sup> : 0.396		
Variable	Coefficient (Std. Error)	t value
Intercept	2.161 (0.015)	140.132***
DLY Hungary	0.181 (0.014)	12.526***
DLY Poland	0.139 (0.011)	12.469***
DLY Bosnia and Herzegovina	0.296 (0.056)	5.246***
DLY Belgium	-0.115 (0.02)	-5.626***
DLY Slovakia	-0.328 (0.056)	-5.899***
DLY Serbia and Montenegro	0.112 (0.02)	5.522***
DLY Germany	0.075 (0.013)	5.938***
DLY Cyprus	-0.045 (0.011)	-4.091***
DLY Spain (Canarias)	-0.036 (0.012)	-2.924**
DLY Estonia	-0.471 (0.125)	-3.775***
DLY Portugal (Lisboa FIR)	-0.062 (0.024)	-2.547**
DLY Denmark	-0.407 (0.18)	-2.262**
DLY Netherlands	-0.123 (0.062)	-1.985**

Slovakia, adjusted R <sup>2</sup> : 0.431		
Variable	Coefficient (Std. Error)	t value
Intercept	2.327 (0.018)	127.544***
DLY Poland	0.236 (0.014)	17.293***
DLY Germany	0.151 (0.018)	8.192***
DLY Bosnia and Herzegovina	0.375 (0.06)	6.255***
DLY Hungary	0.155 (0.017)	9.253***
DLY Belgium	-0.119 (0.023)	-5.218***
DLY Estonia	-0.516 (0.149)	-3.478***
DLY Cyprus	-0.039 (0.013)	-2.961**
DLY France	-0.02 (0.008)	-2.447**
DLY Czech Republic	0.049 (0.018)	2.691**
DLY Spain (Continental)	-0.046 (0.02)	-2.324**

Slovenia, adjusted R <sup>2</sup> : 0.457		
Variable	Coefficient (Std. Error)	t value
Intercept	1.47 (0.009)	156.361***
DLY Croatia	0.13 (0.016)	8.209***
DLY Austria	0.118 (0.01)	11.38***
DLY Germany	0.044 (0.008)	5.497***
DLY Italy	0.141 (0.032)	4.368***
DLY Switzerland	0.065 (0.019)	3.355***
DLY Netherlands	0.101 (0.035)	2.919**
DLY Hungary	0.036 (0.011)	3.222**
DLY Spain (Canarias)	-0.019 (0.007)	-2.601**
DLY Cyprus	-0.015 (0.007)	-2.187**
DLY Sweden	-0.092 (0.041)	-2.248**
DLY France	0.009 (0.004)	2.172**

Spain Canarias, adjusted R <sup>2</sup> : 0.112		
Variable	Coefficient (Std. Error)	t value
Intercept	2.309 (0.018)	126.364***
DLY Spain (Canarias)	0.127 (0.018)	7.128***
DLY Hungary	-0.129 (0.017)	-7.751***
DLY France	0.034 (0.008)	4.306***
DLY Netherlands	0.262 (0.066)	3.935***
DLY Slovakia	0.2 (0.069)	2.915**
DLY Estonia	0.452 (0.152)	2.97**
DLY Portugal (Lisboa FIR)	0.11 (0.03)	3.647***
DLY Spain (Continental)	-0.081 (0.024)	-3.333***
DLY Cyprus	0.026 (0.014)	1.925*
DLY Italy	0.173 (0.066)	2.629**
DLY Bosnia and Herzegovina	-0.128 (0.061)	-2.094**

Spain Continental, adjusted R <sup>2</sup> : 0.396		
Variable	Coefficient (Std. Error)	t value
Intercept	3.305 (0.013)	249.167***
DLY France	0.065 (0.006)	10.974***
DLY Belgium	0.112 (0.016)	7.113***
DLY Hungary	0.044 (0.013)	3.466***
DLY Spain (Continental)	0.16 (0.017)	9.411***
DLY Spain (Canarias)	-0.078 (0.012)	-6.41***
DLY Cyprus	0.059 (0.009)	6.322***
DLY Germany	0.072 (0.01)	6.907***
DLY Serbia and Montenegro	-0.058 (0.016)	-3.731***
DLY Sweden	-0.149 (0.057)	-2.606**

Sweden, adjusted R <sup>2</sup> : 0.405		
Variable	Coefficient (Std. Error)	t value
Intercept	1.077 (0.009)	120.824***
DLY Germany	0.113 (0.008)	13.948***
DLY Poland	0.091 (0.007)	13.714***
DLY Bosnia and Herzegovina	0.245 (0.03)	8.137***
DLY Sweden	0.162 (0.04)	4.074***
DLY Romania	-0.065 (0.028)	-2.284**
DLY Switzerland	-0.043 (0.019)	-2.291**
DLY France	-0.007 (0.004)	-1.805*
DLY Hungary	0.031 (0.01)	3.193**
DLY Austria	-0.028 (0.01)	-2.802**

Switzerland, adjusted R <sup>2</sup> : 0.287		
Variable	Coefficient (Std. Error)	t value
Intercept	4.082 (0.019)	213.747***
DLY Germany	0.128 (0.016)	8.117***
DLY France	0.093 (0.008)	11.099***
DLY Switzerland	0.208 (0.038)	5.418***
DLY Greece	-0.13 (0.028)	-4.668***
DLY Malta	5.091 (1.095)	4.65***
DLY Ireland	1.048 (0.292)	3.59***
DLY Cyprus	0.042 (0.013)	3.323***
DLY Spain (Canarias)	-0.053 (0.015)	-3.467***
DLY Serbia and Montenegro	-0.061 (0.021)	-2.883**
DLY Poland	0.032 (0.014)	2.379**
DLY Portugal (Lisboa FIR)	0.068 (0.03)	2.284**
DLY Sweden	-0.159 (0.079)	-1.998**

Table 4 – Results of Model\_3b (Source: PRB elaboration).

## 4 FLIGHT TRAJECTORY CASE STUDIES

46 This section presents a set of case studies aiming to illustrate the interdependency between the environment and capacity KPA analysis of trajectories on certain days. The case studies were conducted to further explore some of the findings of the statistical analysis (i.e. to provide some insight into the mechanisms behind the quantified results).

47 Case studies are defined based on the following key aspects:

- Impact on HFE of other Member States;
- Impact on local HFE received from other Member States; and
- Strength of the regression model ( $R^2$  value).

48 Further to this, the selection also considered the following operational factors (to the extent possible):

- Level of FRA implementation in the Member State;
- Historical Level of local average en route ATFM delay;
- Dominant delay cause; and
- Military activity.<sup>8</sup>

49 Following this approach, the Member States selected for the case studies were: Estonia, Cyprus, and Spain Canarias.

50 A key part of the case studies is to provide a deeper understanding of how flight trajectories were affected by capacity underperformance. To this end, the major traffic flows impacted by the Member State in question were identified and translated into representative city pairs, to the maximum extent possible. This allowed a comparison of the trajectories of typical flights in the respective Member States under different circumstances (e.g. on days with high levels of en route ATFM delays compared to days with low levels of en route ATFM delays). The use of typical city pairs also enabled more in-depth analysis of both the capacity performance and the environmental performance associated with those flights.

51 Given that the main objective of the case studies was to examine trajectories in greater detail, the time scope of the analyses was limited to specific

days, which were characteristic of: 1) Inefficient HFE, 2) high levels of en route ATFM delays, and 3) relatively efficient HFE combined with low delay levels (compared to average). All days were chosen from the years 2018 and 2019 as these years were most representative of a pre-pandemic traffic scenario.

### 4.1 Case study of Estonia

52 The FIR of Estonia lies at the junction of two main traffic flows: A North-East – South-West flow connecting major European hub airports with Chinese, South-Korean and other Asian airports, and a north-south flow connecting Estonia and Finland with other parts of Europe. There is also a third, less dominant North-West / South-East flow. These major flows are illustrated in Figure 1.



Figure 1 – The FIR of Estonia and the major traffic flows (Source: NEST tool of Eurocontrol).

53 For the case of Estonia, the State-level regression (Model 3b) included 16 States as explanatory variables, out of which the following were considered for the selection of the dates:

- Bosnia and Herzegovina;
- Germany;
- Italy;
- Poland;
- Serbia and Montenegro;
- Poland;
- Estonia (negative coefficient);
- Slovakia (negative coefficient); and

<sup>8</sup> Approximated by the estimated size of the air force (i.e. number of fighter aircraft), proximity to publicly known geopolitical hot-spots, and the relative size of the airspace.

- Belgium (negative coefficient).
- 54 The case study focused the analysis on three keys dates:
- 6<sup>th</sup> July 2019, when local HFE was high (inefficient);
  - 28<sup>th</sup> July 2018, when the en route ATFM delays in the States affecting the State-level regression model were high; and
  - 2<sup>nd</sup> November 2019, when the HFE was low (efficient) in Estonia and there were no delays.
- 55 For the three days selected, the additional distance flown and the associated HFE were calculated for each flight crossing the Estonian FIR. This enabled the calculation of the contribution of each flight to the horizontal flight inefficiency.

#### 4.1.1.1 Day when local HFE was inefficient

- 56 On the 6<sup>th</sup> July 2019, the aircraft flew an additional 1.62 nautical miles on average, compared to the great circle distance (249% more than on the reference day). The average fuel burn per flight was 493 kilograms which correspond to 1.55 tons of CO<sub>2</sub> emissions.<sup>9</sup> Average fuel burn per flight and associated emissions were 12% lower than on the reference day, despite the route extensions being higher. This is related to the fact that in comparison to the reference day, flights were on average 3% shorter and the share of arrivals and departures to and from Estonian airports, which operate with less optimal fuel consumption, than overflights, was also lower.
- 57 The top ten city pairs which contributed the most to HFE deterioration in terms of additional distance flown were typically arrivals to Helsinki-Vantaa airport from various European cities, and the city pair of St. Petersburg – Antalya. The overview of the trajectories for these city pairs is shown in Figure 2.

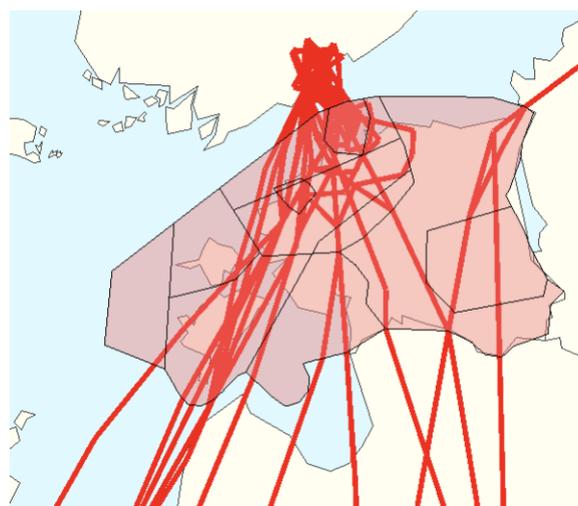


Figure 2 – City pairs with the highest additional distance on 6<sup>th</sup> July 2019 (Source: NEST tool of Eurocontrol).

#### 4.1.1.2 Day when delays in the States affecting the State-level regression model were high

- 58 On the 28<sup>th</sup> July 2018, the aircraft flew an additional 0.76 nautical miles on average, compared to the great circle distance (64% more than on the reference day). The average fuel burn per flight was 579 kilograms which corresponds to 1.82 tons of CO<sub>2</sub> emission. The average fuel burn per flight and associated emissions were 4% higher than on the reference day. The share of local arrivals and departures was also the highest out of the three examined days.
- 59 The top ten city pairs, which contributed the most to horizontal flight inefficiency in terms of additional distance flown were as follows:
- Shanghai – London;
  - Beijing – Amsterdam;
  - Seoul – Paris;
  - Beijing – London;
  - St. Petersburg – Rimini;
  - Hong Kong – London;
  - Riga – Helsinki;
  - Seoul – Amsterdam; and
  - Frankfurt am Main – Helsinki.
- 60 The trajectories of the flights between these city pairs are summarised in Figure 3 (next page).

<sup>9</sup> Fuel burn was modelled based on the Eurocontrol Base of Aircraft Data (BADA), considering trajectory data and aircraft type. CO<sub>2</sub> emissions were computed from fuel burn with the application of the standard coefficient of 3.15kg of CO<sub>2</sub>/kg of fuel burn.

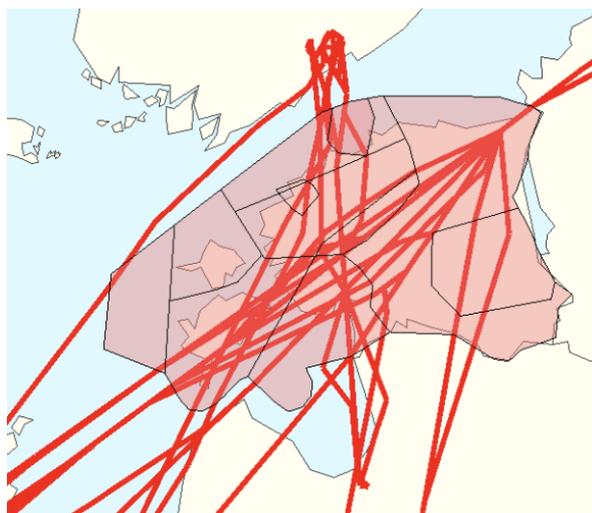


Figure 3 – City pairs with the highest additional distance on 28<sup>th</sup> July 2018 (Source: NEST tool of Eurocontrol).

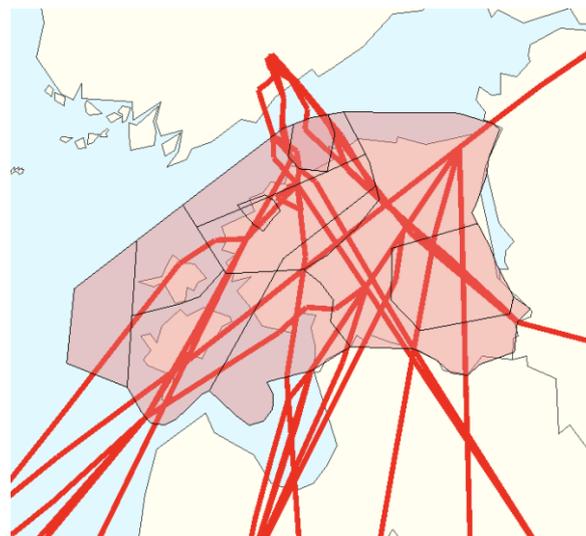


Figure 4 – City pairs with the highest additional distance on 2<sup>nd</sup> November 2019 (Source: NEST tool of Eurocontrol).

#### 4.1.1.3 Day when the HFE was low and there were no delays

61 On 2<sup>nd</sup> November 2019, aircraft flew an additional distance of 0.46 nautical miles on average, with an average fuel burn of 557 kilograms per flight and 1.75 tons of average CO<sub>2</sub> emission per flight. Local departures and arrivals had a slightly smaller share than on the day with relatively high delays, but still a higher share compared to the day with inefficient HFE. The top ten city pairs with the highest route extensions were:

- St. Petersburg – Antalya;
- Visby – Kuressaare;
- St. Petersburg – Khrabrovo (Kaliningrad);
- Shanghai – Amsterdam;
- Cannes-Mandelieu – Kuressaare;
- Helsinki – Monastir;
- Moscow – Helsinki;
- Tallinn – Bern;
- Helsinki – Istanbul; and
- Berlin – Helsinki.

62 Compared to the other two dates, flights departing from or arriving to Estonia contributed relatively more (although in absolute terms, these contributions were still low), and the share of long-haul, intercontinental flights also was lower. Flight trajectories from the top ten city pairs for the reference date are shown on Figure 4.

#### 4.1.1.4 Individual flight contribution to delay and HFE

63 Further to looking into the trajectories of the most relevant city pairs, Figure 5 shows the results of the comparison of the three dates. On the date with relatively high horizontal inefficiency, the route extensions were more concentrated: 10% of the flights were responsible for almost 80% of the additional distance, whereas on the other two dates this figure was around 65%. On all three days, 40 to 50% of flights generated the total amount of additional distance.

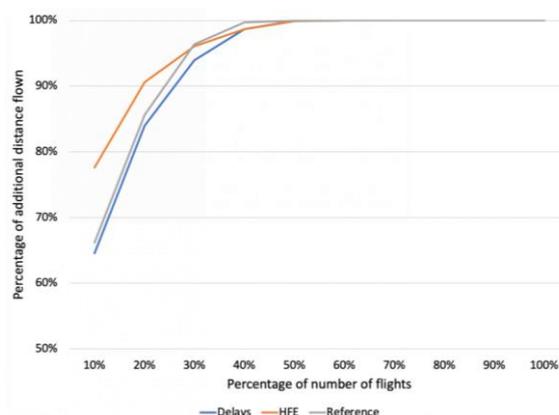


Figure 5 – Distribution of additional distance flown in Estonia, comparing the three dates (Source: PRB elaboration).

### 4.3 Case study of Cyprus

64 The Cyprus FIR is located at the South-Eastern corner of the SES area. Traffic flows to and from the large European hub airports, to and from Turkey, Africa, and the Middle East cross the airspace. Arrivals and departures to and from Beirut Rafic Hariri and Tel Aviv Ben Gurion airports also converge within the Cyprus FIR, further complicating the traffic. All these flows are shown on Figure 6.

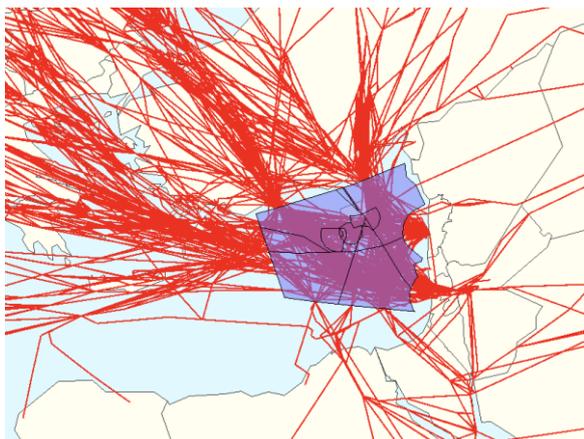


Figure 6 – The FIR of Cyprus and the major traffic flows (Source: NEST tool of Eurocontrol).

65 For the case of Cyprus, the FIR-level regression model included seven FIR-level delay variables as explanatory variables, out of out of which the following were considered for the selection of the dates:

- Cyprus;
- Croatia;
- Greece;
- Norway (negative coefficient); and
- Portugal (negative coefficient).

66 The case study considered the following dates:

- 18<sup>th</sup> July 2019, when local HFE was high (inefficient);
- 12<sup>th</sup> July 2019, when the en route ATFM delays in the States affecting the FIR level regression model were high; and
- 2<sup>nd</sup> December 2019, when the HFE of Cyprus was relatively low (efficient), and there were almost no delays.

67 The political situation between Turkey and Cyprus, military activities in the Sovereign Base Areas of Akrotiri and Dhekelia, as well as tensions between Cyprus and Turkey are likely key contributing factors to such inefficiencies.

#### 4.3.1.1 Day when local HFE was inefficient

68 On 18<sup>th</sup> July 2019, an average 4.17 nautical miles of additional distance was flown by aircraft in Cyprus FIR (250% more than on the reference day). Aircraft burned 848 kilograms of fuel on an average flight, corresponding to 2.67 tons of CO<sub>2</sub> emissions per flight. The average fuel burn per flight and associated emissions were 15% higher than on the reference day. The share of local arrivals and departures was higher than on the reference day but slightly lower than on the day with high delays.

69 The top ten city pairs contributing to horizontal flight inefficiency were arrivals and departures to and from Tel Aviv and Beirut, and flights between Amman and Istanbul. Flights from the top ten city pairs are shown on Figure 7.



Figure 7 – City pairs with the highest additional distance on 18<sup>th</sup> July 2019 (Source: NEST tool of Eurocontrol).

#### 4.3.1.2 Day when local delay was high

70 On 12<sup>th</sup> July 2019, a date with relatively high en route ATFM delays, aircraft flew an additional 2.65 nautical miles per flight in the FIR of Cyprus, compared to the great circle distance (123% more than on the reference day). The average fuel burn per flight on this day was 690 kilograms, associated with 2.17 tons of CO<sub>2</sub> emissions per flight. Both figures were 6% lower than on the reference day, despite the higher route extensions. The share of local departures and arrivals was the highest among the three days, so this could not explain why average fuel burn and CO<sub>2</sub> emissions were lower, however, flights on average were

shorter on the day with relatively high delays, explaining at least some of the difference in average fuel burn and emissions.

71 The top ten city pairs with the most additional distances on this date were:

- Tel Aviv – Antalya;
- Amman – Istanbul;
- Dubai – Larnaca;
- Amman – Beirut;
- Moscow – Larnaca;
- Sharjah – Beirut;
- Larnaca – Bucharest;
- Tel Aviv – Budapest;
- Tel Aviv – Vienna; and
- Kuwait – Beirut.

72 The key factors driving horizontal flight inefficiencies were the flights to and from Beirut and Tel Aviv (apart from the arrivals and departures of Larnaca). Flights departing from or arriving to Beirut circumnavigate the Israeli airspace, which results in deviations from the great circle distances, whereas flights between Tel Aviv and Istanbul tend to fly around Cyprus from the South, resulting in route extensions. Examples of these trajectories are shown in Figure 8.

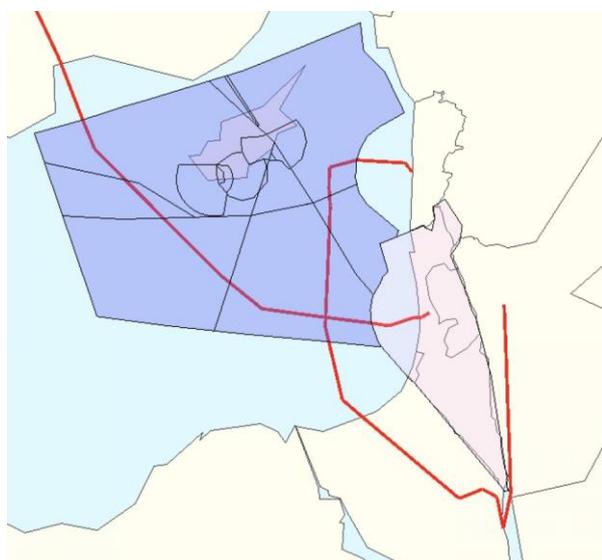


Figure 8 – Example of flights avoiding Israeli airspace in the FIR of Cyprus (flight from Amman to Beirut), and flights flying around Cyprus from the South between Tel Aviv and Istanbul (Source: NEST tool of Eurocontrol).

#### 4.3.1.3 Day when the HFE and delays were low

73 On 2<sup>nd</sup> December 2019, the average additional distance flown in the Cyprus FIR was 1.19 nautical miles per flight. The average fuel burn per flight was 736 kilograms, corresponding to 2.32 tons of

CO<sub>2</sub> emissions per flight. Both figures are higher than on the day with relatively high delays, and this could not be explained by local arrivals and departures, as the share of these flights was the lowest this day. A likely explanation for this anomaly is that on this day traffic to and from military airbases was more significant (see following paragraphs) which presumably involved aircraft which were less fuel efficient than modern civilian passenger carriers.

74 The top ten city pairs with highest additional distances flown on the reference day were:

- Tel Aviv – Istanbul;
- Camp Taji – Limassol;
- Dubai – Larnaca;
- Beirut – Cairo;
- Warsaw – Larnaca;
- Paphos – Be’er Sheva;
- Dubai – Beirut;
- Amman – Beirut;
- Paphos – Tel Aviv; and
- Moscow – Larnaca.

75 These city pairs are indicated on Figure 9. Interestingly, there were two city pairs in the top ten which are likely to represent military activities (between Camp Taji and Limassol and Paphos and Be’er Sheva), since with the exception of Paphos, these locations are hosting military airbases. Once again, flights to and from Beirut, Tel Aviv and Larnaca are strong contributors to horizontal flight inefficiency.

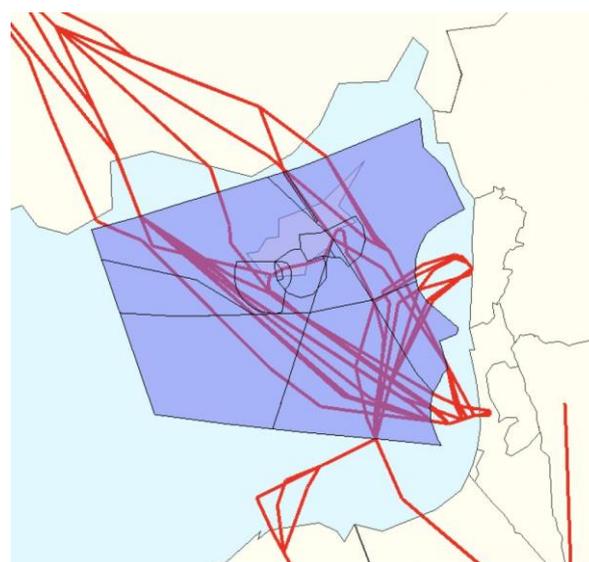


Figure 9 – City pairs with the highest additional distance on 12<sup>th</sup> July 2019 (Source: NEST tool of Eurocontrol).

#### 4.3.1.4 Individual flight contribution to delay and HFE

76 When looking at the distribution of the route extension across the different flights, the case study found that on the reference dates fewer flights were responsible for the additional distance flown: 10% of the flights generated around 75% of the additional distance, and only 40% of the flights were responsible for all the additional distance. On the two other dates, route extensions were more distributed. The overview of the results is shown on Figure 10.

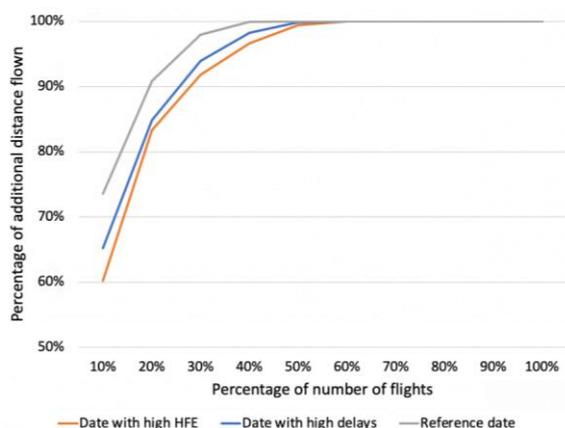


Figure 10 – Distribution of additional distance flown in Cyprus, comparing the three dates (Source: PRB elaboration).

#### 4.4 Case study of Spain Canarias

77 The airspace of Spain Canarias is detached from the core European airspace, located to the South-West of Spain. The main traffic flows are flights from major European cities, combined with traffic from South America. The airspace and the traffic patterns are shown on Figure 11.

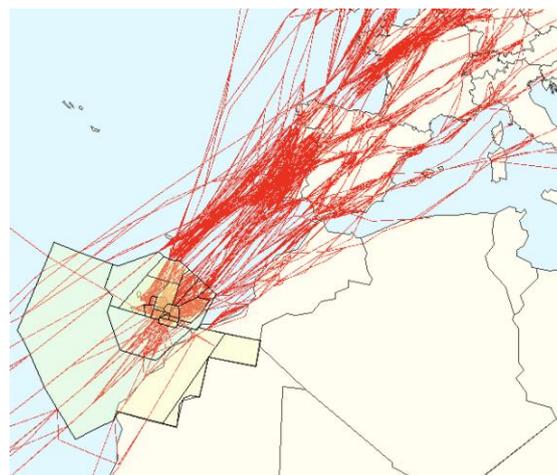


Figure 11 – Overview of the airspace and the main traffic flows of Spain Canarias (Source: NEST tool of Eurocontrol).

78 Due to the fact that en route ATFM delays in Spain Canarias showed up with a negative coefficient, as relevant and significant variables in many of the State-level regression models as well as in the Union-wide model, the selection of dates for the case study was different from the other cases. Different in that the Union-wide HFE was used to define days with relatively inefficient HFE, and the only delay variable considered for the selection of the date with relatively high delays was that of Spain Canarias. These altered criteria led to the selection of the following dates:

- 25<sup>th</sup> December 2018 as the reference day, when there were no delays in Spain Canarias, and the Union-wide HFE was relatively low (efficient);
- 1<sup>st</sup> July 2019, when horizontal flight inefficiency in the SES area was relatively high; and
- 21<sup>st</sup> December 2019, when en route ATFM delays in Spain Canarias were relatively high.

79 Since the additional distance flown in the Spain Canarias FIR was not relevant in this case study, as the focus was on the impact on the SES area, the analysis looked into how the trajectories were different on the three days. In order to identify the impact of delays in Spain Canarias on the Union-wide flight efficiency, traffic density maps were generated for the three specified dates.

##### 4.4.1.1 Day when the HFE was low and there were no delays

80 On the reference date (Figure 12, next page), traffic density is high along the east-west and south-west – north-east axes, but other areas remain

less saturated. The area of Spain Canarias is moderately dense.<sup>10</sup> This reflects the lower number of flights over the day, compared to the other two days.

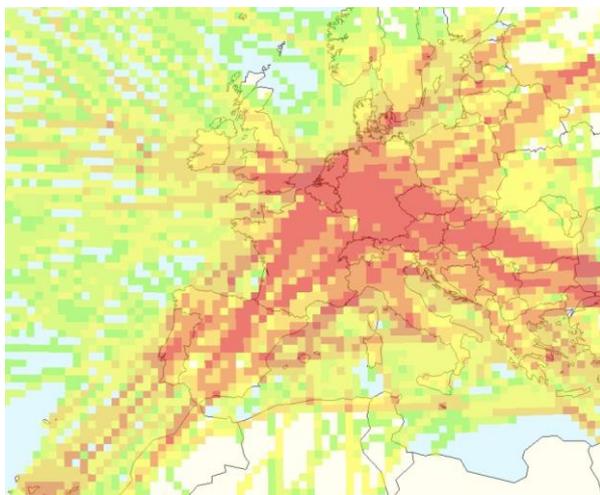


Figure 12 – Traffic density in Europe on the day without delays in Spain Canarias, and relatively low Union-wide horizontal flight inefficiency (Source: NEST tool of Eurocontrol).

#### 4.4.1.2 Day when Union-wide HFE was inefficient

81 On the date when Union-wide flight inefficiency is relatively high (Figure 13), most of the European airspace appears to have high traffic density with some hot spots around major hub airports (London, Paris, Frankfurt am Main, Brussels, and Amsterdam). This is the representation of the increased traffic levels compared to the reference day. It is also understood that the more the traffic density increases around the hot spots and major flows, the harder it is to circumnavigate such areas, leading to worsening HFE.

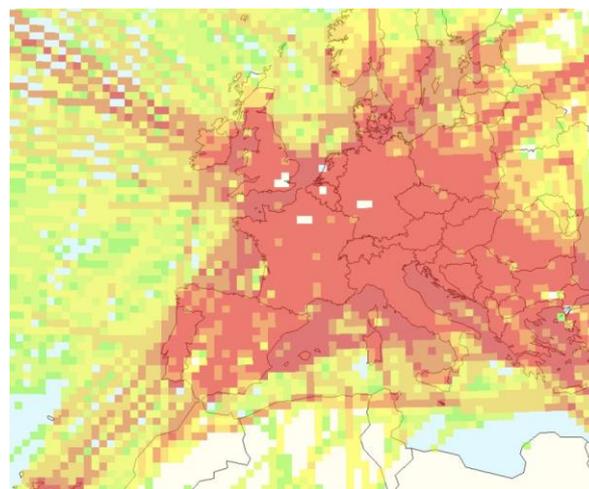


Figure 13 – Traffic density in Europe on the day with relatively high Union-wide horizontal flight inefficiency (Source: Nest tool of Eurocontrol).

#### 4.4.1.3 Day when local delay was high

82 Finally, when looking at the day with relatively high delays in Spain Canarias (Figure 14), a shift in density over Europe can be observed: The airspace over and adjacent to Spain Canarias is denser with traffic, while the airspace over Spain, France, and Portugal has lower density (compared to the day with relatively high Union-wide flight inefficiency).

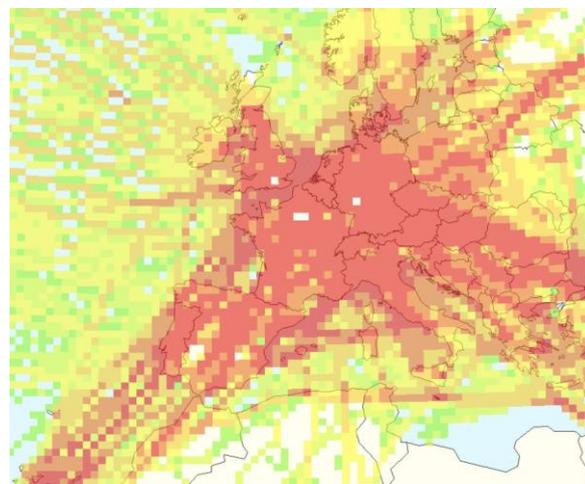


Figure 14 – Traffic density in Europe when en route ATFM delays in Spain Canarias are relatively high (Source: NEST Tool of Eurocontrol).

83 This indicates that en route ATFM delays in airspaces relatively far away from the core area of Europe reduce the density in the most complex and dense areas, and thus contribute to improving flight efficiency. This could explain why the en route ATFM delay variable in Spain Canarias was

<sup>10</sup> Traffic density is measured as daily IFR movements in 30NM by 30NM cells. Red color corresponds to 200 or more movements per day.

significant despite a negative coefficient in the Union-wide regression model, and also in many FIR-level models as well.

- 84 The analysis of individual flight contribution to HFE and delay was not conducted for this case, due to the difference in the applied approach (individual trajectories and route extensions were not calculated).