**EUROPA XXI**
Vol. 43, 2022, pp. XX-XX
https://doi.org/10.7163/Eu21.2022.43.5

Institute of Geography and Spatial Organization
Polish Academy of Sciences

# COVID-19 PANDEMIC AND ITS IMPACT ON AIR TRANSPORT FLOWS OF EUROPEAN REGIONS

**Björn Schwarze, Klaus Spiekermann**

S&W Urban and Regional Research
Lindemannstraße 10, 44137 Dortmund: Germany

bs@spiekermann-wegener.de ● ks@spiekermann-wegener.de

**Abstract.** The impact of the COVID-19 pandemic on air passenger traffic was dramatic with reductions in numbers that have never been seen before since flying became a mass mode for medium and long distance travel in Europe. Air freight transport was less affected. This paper sheds light on these impacts with high temporal and spatial resolutions. The novelty of this analysis compared to other reflections on air transport in COVID-19 times is that it not only looks at total volumes of air transport in Europe, European countries and single airports, but also focuses on the spatial interaction between European regions in terms of air transport flows for passengers and freight.

**Keywords:** air freight transport, air passenger transport, COVID-19 impacts.

## Introduction

The COVID-19 pandemic has had dramatic impacts on air transport and related economic activities, a disruption of the functioning of the air market never seen in history before. Before the pandemic, the basic trend in air transport had been overall growth for decades, in which the development of GDP seems to be the main driver of the dynamics of the air market (Dobruszkes & van Hamme, 2011). Growth was also the expectation for the future. Despite energy and climate concerns, the expected annual passenger growth rate for the 2010s and 2020s was about 5 percent; the growth of aviation was expected to be the largest of all transportation sectors throughout the 21st century (Clewlow, Sussman & Balakrishnan, 2014).

However, underneath the growth paths of aviation in the past there have been always variations differentiated by time and space due to various developments and single events. A couple of factors determined air traffic dynamics in Europe before the pandemic:

- Following the deregulation of the air transport market in Europe since the late 1980s, the spatial network concentration of European airlines on a small number of central national airports as home base was amended by a wave-like temporal concentration of the flights in those airports to generate multiple transfer opportunities (Burghouwt & de Wit, 2005). Spatial and temporal concentrations are the main characteristics of the hub-and-spoke network system yielding cost and demand advantages in a deregulated market.

- Also as a consequence of the deregulation, European Low Cost Carriers (LCC) entered the aviation market, starting with the domestic markets in the UK and Ireland and then expanding throughout Europe as deregulation advanced (Allroggen, Wittman & Malina, 2015). LCC operate point-to-point networks based on low operating costs and a low price basis (Burghouwt & de Wit, 2005). LCC serve in particular more remote or secondary airports, particularly in tourist destinations, bring air connectivity to regions with lower GDP which are less served by traditional Full Service Carriers (FCC) (Allroggen et al., 2015; Calzada & Fageda, 2019) and contribute to an overall increase in air traffic in Europe (Clewlow et al., 2014).
- European political integration with the enlargement of the European Union, particularly in 2004 and 2007 has led to additional growth of air transport in Europe. This is based on numerous reasons such as the deregulation of the air transport market in the new member states, intensified trade relationships in the enlarged common European market and increasing levels of GDP and personal income in the accession states (Allroggen et al., 2015).
- The evolving European high-speed rail network with sharp reductions of rail travel times on several city-to-city relationships have resulted in reductions in short-distance air travel demand and services (Behrens & Pels, 2012; Dobruszke, Dehon & Givoni, 2014; Albalate, Bel & Fageda, 2015). However, the effect on system-wide air travel demand is only modest (Clewlow et al., 2014). There are different spatial ranges mentioned in the literature to which rail is able to substitute air travel (Reiter, Voltes-Dorta & Suau-Sanchez, 2022). The ranges mentioned are between 200 and 800 km and depend on characteristics of the cities and their airports. The rail impact on air demand seems to go down beyond 2 or 2.5 h travel time by high-speed rail; the operation of LCC on the same relationship as high-speed rail reduces the number of rail passengers (Dobruszkes et al., 2014).
- Seasonality is a common feature of temporal variation in air traffic demand. There is a strong link between leisure and tourism seasonality and aviation seasonality. More than a third of the airports worldwide, but having only about 15% of global seat capacity, is facing high seasonality (Dobruszkes et al., 2022).
- Before the pandemic, videoconferencing was not seen as something that could have a substantial impact on business air travel unless air fares would increase tremendously (Denstadli, Gripsrud, Hjorthol & Julsrud, 2013). Although it was expected that some modest travel might be substituted by video-meetings, the advantages of face-to-face contacts seemed to be overwhelming.

In addition to those long-term factors of influence on air traffic, the European aviation market has also seen a couple of events of rather disruptive characteristics (Dobruszkes & van Hamme, 2011). Economic crises alone such as the financial crises from 2008 onwards, geopolitical crises such as the first gulf war in 1991, or the combination of economic crises with the terrorist attack on September 11 in 2001 (Alderighi & Cento, 2004) had severe impacts on air transportation. In addition, there have been volcanic eruptions, natural disasters, security threats in numerous countries, IT failures or air traffic control problems with the effects of temporary disruption of the air network in some parts of the world (Budd, Ison & Adrienne, 2020). Common to all these earlier crises is that the impact on the number of passengers was always relatively short-term and hardly visible in yearly statistics, however, the crises had long-term impacts such as increased full-efficiency as consequence of the oil crises in 1973, safety and security procedures following the terrorists attacks or consolidation among carriers and introduction of optional fees and upgrades after economic crisis (Sun, Wandelt & Zhang, 2022). It is interesting to note that earlier outbreaks of diseases did not have a sustainable effect on the air sector and its procedures with the result that the COVID-19 pandemic hit a largely unprepared industry (Sun et al., 2022).

The COVID-19 pandemic has had tremendous impacts on the air market in a magnitude never seen before. This initiated a vast number of scientific studies on the effects of the pandemic on the aviation sector and its components. In the early months of 2020, the literature focussed on how transport flows would allow predicting the arrival of the virus in a specific region, how control measures such as travel restriction would limit the spreading of the virus, and what impacts it has on air transport supply, demand and regulations (Sun, Wandelt & Zhang, 2021). Sun et al. (2022) later analysed more than 200 published papers along eight categories: airlines, airports, passengers, workforce, markets, contagion, sustainability and economics. Related to the issue of this paper, the impact of the pandemic on air transport flows in Europe, the following can be summarised from the literature:

- The government reactions to the pandemic threat with travel bans, lockdowns, shutdowns and other social distancing measures as well as mandatory quarantine requirements led to the collapse of aviation (Albers & Rundshagen, 2020). Airlines in Europe and around the world were faced with a huge decline in demand and consequently revenues. The basic response was to avoid or reduce direct and indirect operating costs by grounding aircrafts, by leaving certain airports, by sharply diminishing the number of flight frequencies and destinations served, by reducing staff costs, and to ask national governments for financial support (Budd et al., 2020). In Europe, a survey of 40 airlines has yielded that 32 of them completely suspended freight operation for an average period of 80 days in spring 2000; the remaining 8 reduced capacity by more than 90% (Budd et al., 2020).
- In terms of service reduction, domestic air travel was less affected than international and in particular intercontinental aviation (Budd et al., 2020; Andreana, Gualini, Martini, Porta & Scotti, 2021; Sun et al., 2022). However, most countries seem to have reacted too late to cut down air travel despite the contribution of aviation to disease spreading was well-known long before this pandemic; and, reduction of domestic air travel was even more delayed (Sun et al., 2021).
- LCC seemed to be slightly more resilient to the aviation crises, their reduction in the number of available seats was less than of Full Service Carriers (FSC) (Andreana et al., 2021). In terms of departures from EU airports, LCC as well as regional and pure leisure airlines recovered faster during the summer periods in 2020 and 2021 than FSC (Ennen & Wozny, 2022).
- The spatial and temporal changes in supply or demand for passenger aviation before and during the pandemic are mostly measured in terms of connectivity. A range of papers addressed the changes in the global aviation network (Li, Zhou, Kundu & Zhang, 2021a; Sun et al., 2021; Zhou, Kundu, Qin, Goh & Sheu, 2021; Rybenská, Socha & Vittek, 2022). Outcomes are typically related to the vastly varying number of operating airports, connections and flights in the global network, to the different paths of global and local connectivity, to the stable position of most critical airports in a centrality ranking or to the more significant flight variation in international flighty compared to domestic (Li, Zhou, Kundu & Sheu, 2021b). An analysis focussing on Europe shows that the initial reduction in the flight departures per route was larger than the reduction in the number of routes, i.e. destinations were more often kept but served much less frequently, and that by the end of 2021 the number of routes served was about pre-pandemic level, but the number of flights per route were still about 30% down (Ennen & Wozny, 2022). A connectivity study focusing on the 24 largest airports in Europe shows that most of the airports performed very similar over time in their downwards and upwards movement of their centrality, however, some airports deviated from the general path (Macurová, Vittek & Pecherková, 2022). The decline of Milan and Rome airports started earlier than the average due to the early severe emergence of the pandemic in Italy. The airports of Palma de Mallorca, based on connections to

Germany, and of Athens, based on domestic connections, recovered in autumn 2020 to higher centrality indices than the average; on the other hand, London Heathrow recovered much more slowly due to lacking intercontinental flights as well as Stockholm Arlanda due to less frequent intra-Nordic flights.

- Air cargo was less affected than air passenger transportation (Andreana et al., 2021; Sun, Wandelt & Zhang, 2023). Cargo volumes went down during the first lockdown period in spring 2020 mainly because the freight capacity of passenger aircrafts was not available due to the grounding of substantial parts of the fleets. But the impact on full-cargo traffic was the opposite due to the rapid growth of e-commerce during the pandemic, the fact that governments protected the shipments of food and medical supplies.

The novelty of the analysis presented in this paper compared to other reflections on air transport in COVID-19 times is that it not only looks at total volumes of air transport in Europe, European countries and single airports, but also focuses on the spatial interaction between European regions in terms of air transport flows for passenger and freight. To do so, the spatial and temporal dynamics of Europe's interregional relationships by air are related to the context of the COVID-19 pandemic's temporal development, lockdowns, travel warnings and bans, and other restrictions as well as the gradual opening of countries and regions to air transport. The analysis presents which interregional relationships have been hit hardest, which took longest to recover, and which did not recover at all — in other words, which interregional flows in Europe are robust and which are less resistant. To the best of our knowledge, this is the first study covering impacts of the COVID-19 pandemic on air transport flows for the whole of Europe in a geographically very detailed resolution at regional scale.

More general, the basic research objective addressed by this analysis was to establish up-to-date territorial evidence on the impacts of the COVID-19 pandemic on passenger and freight air transport flows with a high spatial and temporal resolution by first generating reliable and consistent flow datasets and then by describing and analysing the different paths of the air passenger and air freight flows in the context of the crises.

For this, the COVID-19 pandemic had to be operationalised by using comprehensive classifications of its development and measures taken to fight against it. A specific challenge was to grasp the dynamics involved in cause and effects.

The analysis presented in this paper originated in the ESPON IRiE project which dealt with interregional relationships in Europe (Velasco Echeverría et al., 2022). In this project, matrix databases for different kinds of flows between European regions have been established at NUTS 2 level, including trade, transport, migration, touristic, financial and knowledge flows. Those different kinds of flows were analysed, visualised, typologised and explained individually, but also in comprehensive approaches across all flows. Of this, freight and passenger transport flows by mode were one building block of the overall analysis (Schwarze, Spiekermann, Llano Verduras, Pérez-Balsalobre & Gallego López, 2022; Schwarze & Spiekermann, 2022a). The nature of the project was, and this was heavily influenced by the availability of – in most cases yearly – data, that it had to put attention on the last decade, i.e. a period before the COVID-19 pandemic. The analysis of the impacts of the COVID-19 pandemic on air transport was a case study of the ESPON IRiE project which required a high spatial and temporal resolution (Schwarze & Spiekermann, 2022b). The detailed air passenger and freight database of Eurostat allowed a relatively timely analysis.

## Data and methodology

This section on data and methodology contains the different approaches used to generate the necessary data and to further analyse them. The spatial levels of analyses are national total air transport developments, country-to-country air transport flows and region-to-region air transport flows. This section describes the procedures to obtain air flow data with an appropriate temporal resolution, the operationalisation of the COVID-19 pandemic and the way the analyses was performed.

The main method for the analysis of the COVID-19 pandemic on air transport flows in Europe is to make the developments visible through appropriate maps and other graphics and to give verbal explanation of the outcomes. Most of the maps and diagrams have been generated by customising the so-called *FlowMapper* developed for analytical process in the ESPON IRiE project (Schwarze & Spiekermann, 2022c) in a way, that the development paths of air transport during the pandemic become transparent in their spatial and temporal dimensions. The *FlowMapper* is a (carto)graphical tool especially designed and customised to visualise flows of any kind between NUTS 2 regions in Europe in different types of flow maps and flow diagrams.

### Air flow data with an appropriate temporal resolution

For the creation of an air passenger and air freight transport database covering the number of people flying and the amount of freight carried between NUTS 2 regions in Europe, Eurostat offers several datasets at different spatial resolutions such as countries, regions or individual airport (Eurostat, 2022). Besides the number of flights, the data contain the number of passengers, the available capacity as number of seats and the amount of freight expressed in tons. They also include totals for arrivals and departures for the different spatial entities as well as flow data between countries and between individual airports. All countries in the ESPON space are covered by appropriate data.

The main advantage of Eurostat's air transport database is its high temporal resolution, i.e. the data are provided on a monthly base. The second advantage of the air transport data compared to other flow data is their relatively timeliness. At the time of the analytical work for this paper, i.e. by the beginning of 2022, there were – with a few exceptions – already monthly air passenger and freight flow data available at the level of airports that reach until the summer of the year 2021, i.e. cover about the first one year and a half of the COVID-19 pandemic. The temporal data coverage was sufficient to analyse the effects of the lockdowns and the recovery processes in temporal and spatial detail, so as to reflect the rapidly changing development of the pandemic and its related policies. The main disadvantage of the database is that there seems to be no data clearance. The flow data is based on national reporting to Eurostat. However, there are often different figures reported for the same flow of people or freight by the countries being origin or destination of an air flow. For the purpose of this analysis, a rather pragmatic approach was taken to overcome such inconsistencies, i.e. simply the higher figure was taken to represent the flow in the database.

For the monthly country-to-country air transport flow matrices the Eurostat datasets containing flows between countries have been used. The monthly region-to-region air transport flow matrices were generated by aggregating the more detailed airport-to-airport datasets. The data has been aggregated to air transport flows between NUTS 2 regions by assigning each airport's flows to the NUTS 2 region where it is located. If there is more than one airport in a region, the flows of the individual airports have been summed up. As a result, region-to-region air transport flows at NUTS 2 level have been aggregated from airport flows forming a homogeneous air transport flow database for the months of the years 2019, 2020 and as far as data availability allowed for 2021. Thus, the database used in this study contains monthly flow matrices at the country-to-country

level and at the region-to-region level for the part of the European territory that is part of the ESPON 2020 Programme (EU27, UK, Switzerland, Iceland, Liechtenstein and Norway). Matrices have been generated for air passenger as well as for air freight. The generation of the matrices was data-driven, i.e. modelling techniques did not come into operation.

It has to be noted that the air transport dataset utilised here is probably the only non-modelled flow dataset available that covers Europe-wide mobility and freight transport impacts of the COVID-19 pandemic in a timely manner.

### Operationalisation of the temporal development of the COVID-19 pandemic and counter-measures

The COVID-19 pandemic is characterised by strong differences between countries concerning its measurement so that comparisons often have some bias. For instance, different test strategies for detecting infections might have led to different percentages of all current cases detected, i.e. there is some bias in the comparability of data. The same applies to measures against the spread of the pandemic. However, over time some international reference sources became available of which one is used here to operationalise basic characteristics of the pandemic and related measures.

For describing the spread of the COVID-19 pandemic, the cumulative number of newly recorded cases during the last seven days per 100,000 population is being used. This information is taken from the COVID-19 Government Response Tracker of the Blavatnik School of Government, University of Oxford (Hale et al., 2021; OxCGRT 2022a).

The classification of the measures aimed to control the spread of the pandemic is also taken from the same source, i.e. the COVID-19 Government Response Tracker. For the classification of international travel controls during the COVID-19 pandemic, OxCGRT (2022b) introduces five categories:

- no restrictions,
- screening arrivals,
- quarantine arrivals from some or all regions,
- ban arrivals from some regions,
- ban on all regions or total border closure.

For the classification of the restrictions on internal movement during the COVID-19 pandemic, OxCGRT (2022b) gives three categories:

- no measures,
- recommend not to travel between regions/cities,
- internal movement restrictions in place.

As with all aggregate classifications of a wide range and intensity of measures taken in a certain situation, the classification of OxCGRT might be criticised for an over-simplification and thus wiping-out of specific ways of implementing measures. However, and that is the reason that the data was used here and in numerous other studies, it has the huge advantage to provide a somewhat comparable classification across countries that would otherwise not be possible.

## The COVID 19 pandemic and mobility restrictions

The development of the COVID-19 pandemic in regions and countries is predominantly described with the use of one indicator that gives the number of new reported COVID-19 cases in a cer-

tain time period standardised with population. Despite all critique concerning underlying different measurement methods based on different COVID-19 test strategies in different countries, the incidence of COVID-19 cases is, together with indicators on death rates, hospitalisation and intense care rates of COVID-19 patients and later on vaccination rates, the most important indicator not only of comparison, but also for the definition and implementation of all kind of policy measures to fight the pandemic.

The development of new COVID-19 cases for the years 2020 and 2021 is presented in Figure 1 (left column) for the 32 countries considered. The first infection wave is visible in the early months of the year 2020 in almost all European countries. This is followed by a period of low infection rates in many countries during summer 2020. But then, compared to the first wave, the incidences rose to much higher values in the different waves to come. The diagrams might give the impression of a common rhythm of the pandemic. However, looking more closely at the development over time, it becomes obvious that there are substantial differences between countries in terms of timing and magnitude of the different waves.

As a reaction to the COVID-19 pandemic European countries introduced a wide range of measures to fight further spreading of the virus. Several of those measures aimed at influencing the mobility behaviour and spatial interaction pattern of the society. The basic principle behind was to sharply reduce the action space of individual persons to diminish contact opportunities.

Internal movement restrictions were introduced in almost all European countries during the first COVID-19 infection wave in spring 2020 (Fig. 1, right hand column of diagrams). This might include overall or localised lockdowns, overall or localised curfews, restrictions (e.g. quarantines) for specific categories of individuals or movement only for specific purposes (Stefan & Luk, 2021), Later on in the pandemic, such measures were not or only for short periods kept up by all countries, but a substantial number of countries had long-time internal travel restrictions as mean to fight the pandemic.

In addition, most European countries introduced different kinds of restrictions to cross-border mobility. 'The resulting picture is a web of dynamic, multi-layered measures, ranging from the reintroduction of internal border controls at specific land, sea and air borders, to intra-EU travel bans and an extra-EU travel ban' (Carrera & Luk, 2020, p. 8). The country diagrams in the middle column of Figure 1 show the development of international travel restriction over time as classified by the Blavatnik School of Government, University of Oxford (OxCGRT, 2022b). Beyond these classifications there is a wide amount of differentiation of the measures in terms of definition, scope, comprehensiveness, change over time and way and strictness of implementation.

Most of the international travel restriction measures of the individual countries were not universal, but often had a clear territorial orientation, meaning they are defined in relation to a certain country or in relation to a group of countries. Such cross-border mobility restrictions 'range from outright entry bans (more specifically, entry bans for people coming from certain countries, or for symptomatic travellers) and restrictive entry conditions (such as a pre-entry medical document certifying a negative (PCR) test result for COVID-19 and completion of a Passenger Locator Form (PLF)), to mandatory testing and/or quarantine after entry, as well as a combination of the above' (Stefan & Luk, 2021, p. 21). Even travel restrictions in only one country might had huge impacts on travelling abroad, because it applied either on the outward or return journey. Again, all measures taken were rather dynamic in scope and time and differ between countries or even regions of countries.

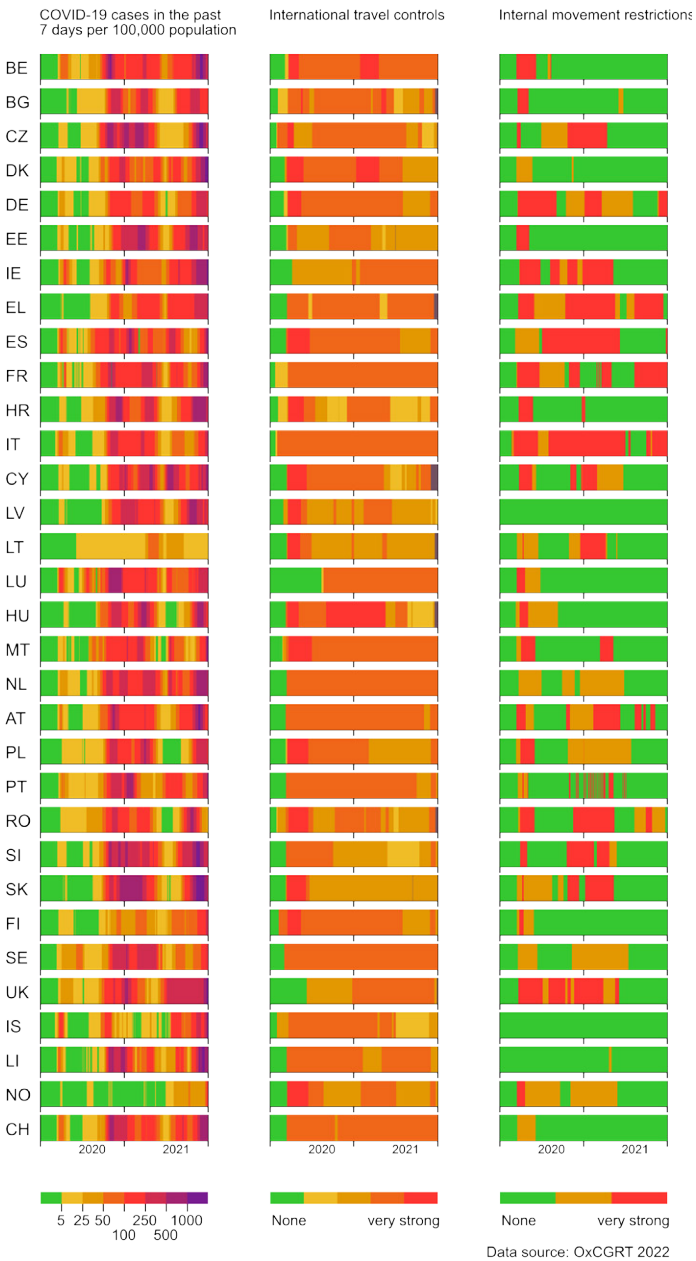


**Figure 1**. COVID-19 cases and travel restriction measures by country

The COVID-19 pandemic did not develop in all regions and countries the same way at the same time. There were always changes and huge differences in the measures taken by individual countries or regions. The main purpose of Figure 1 is to display the rather complex, somehow interwoven picture of the evolution of the pandemic and related policy responses in the

32 countries considered. At the same time, the three characteristics of the COVID-19 pandemic, i.e. incidences and internal and international restrictions on movements, can be considered important for the development of air transport during the first two years of the pandemic.

The dynamic interplay of these developments of the pandemic and related mobility measures had on the one hand a massive impact on the perception of potential air passengers how the COVID-19 pandemic might evolve in Europe and its regions, i.e. how safe travelling would be. A large uncertainty existed about what travel restrictions might be in place in a couple of weeks or months ahead. When travelling to other countries this had been a twofold uncertainty, i.e. there might be measures in the destination country, but there might be also measures when travelling back home. On the other hand, this had a tremendous influence on the air sector which also had to anticipate how travel restriction measures and demand would develop.

## Impacts of the COVID-19 pandemic on air passenger flows in Europe

This section addresses how air passenger flows in Europe were affected by the COVID-19 pandemic during its first two years. It commences with an analysis at the national level and continues with the regional level.

### Impacts at the national level

The impact of the COVID-19 pandemic on air passenger traffic was dramatic with reductions in numbers that have never been seen before since flying became a mass mode for medium and long-distance travel in Europe. The losses European countries experienced in 2020 compared to the previous year were in the range of between 67 and 84%, i.e. the relative impact was rather homogeneously distributed over the European territory.

Going into the temporal dynamics of the consequences of the COVID-19 pandemic and related measures on air passenger traffic at national level, it becomes apparent that also the development over time had a somehow similar path for all countries considered (Fig. 2). The single diagrams show national air passenger volumes for the two pandemic years 2020 and 2021 compared to the transport volumes of the respective months in 2019, i.e. seasonality of air transport is wiped out here, and map it against the development of the recorded COVID-19 infection rates. All curves follow roughly a comparable pathway, i.e. a complete breakdown in spring 2020, followed by a rather modest recovery in summer 2020, followed by another reduction or at least stagnation between autumn 2020 and spring 2021 leading to a renewed recovery in summer 2021 which is higher than a year before, but far from the 'normal' air passenger volumes. In some countries, the development path seems to be somewhat in relationship with the pandemic situation, in other countries, it seems not to be the case.

To discuss some typical developments in more detail, some countries were selected:

- Germany's air passenger volumes dropped as everywhere in Europe to almost zero in March/April 2020. During summer 2020 it recovered somewhat to about 25% of the pre-pandemic summer volume, however, rising COVID-19 cases in other countries and the classification of an increasing number of other countries as risk areas led to a renewed decrease. The second (winter 2020/21) and third (spring 2021) infection waves in Germany and related measures kept air

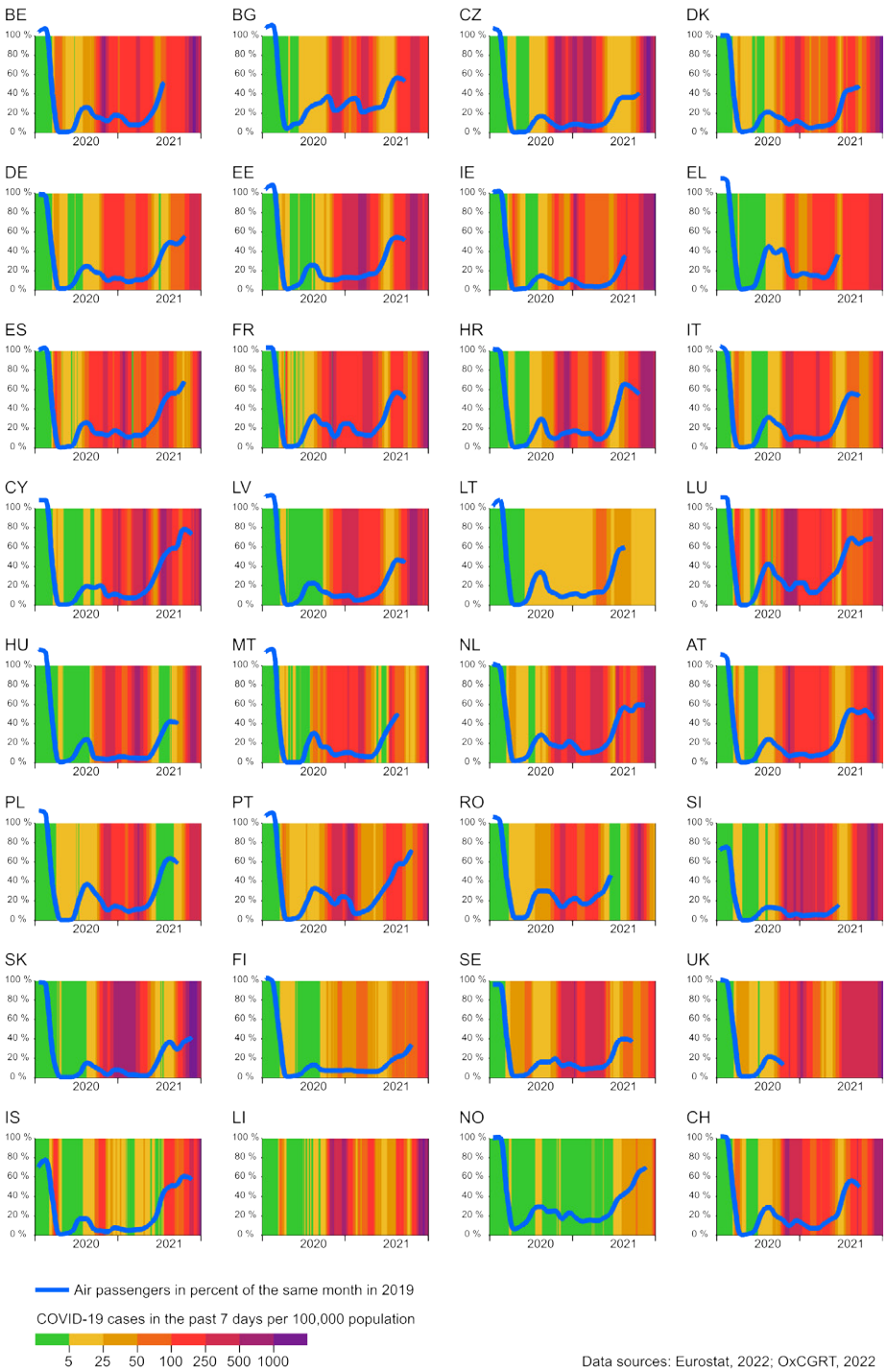


**Figure 2**. Change of monthly air passenger traffic during the COVID-19 pandemic by country

passenger volumes down at about 10% of previous levels for those periods. Low infection rates in summer 2021 resulted in an increased number of air passengers, however, figures were only at about 50% of pre-pandemic volumes in summer 2021 and at about 60% in autumn 2021. Interesting to note is that the number of passengers on domestic flights did not rise as international air passengers did until autumn 2021, a consequence of the sharp decline in business travel within Germany and in contrast to the faster recovery of domestic air travel in other countries.

- In Spain, the year 2020 began with higher air passenger volumes in the first two months than in the same period in 2019. The total spring breakdown was followed by a very slight recovery during summer 2020. Peak of total air passengers reached only about 25% of levels in 2019. However, domestic flight passengers in Spain reached almost 60%. Air passenger numbers dropped again strongly with the upturn of the second strong infection wave in autumn 2020. The period of slightly lower infection rates in-between the two infection wave peaks in autumn 2020 and beginning of the year 2021 saw a slight recovery of air transport of a few percentage points. Since spring 2021 there was a steady recovery of air passenger transport volumes in Spain. This was almost not influenced by another infection peak in summer 2021, but was in line with a relief of international and intra-national travel restrictions. Air transport volumes in autumn 2021 were at an overall level of about 70% of the pre-pandemic year. In Spain, domestic air transport was little less affected than international air passenger figures. Domestic flight passengers during summer 2021 were even at a level of 90% of the year in that period in 2019.
- Overall, Poland's development of air passengers during the pandemic took a comparable path to that of other countries. However, in terms of recorded infection rates Poland was much less affected by the pandemic than other countries in most of the time considered. But due to the international travel restrictions almost everywhere in Europe, but also in Poland, air passenger numbers that started very high into the year 2020 dropped to zero in spring. An intermediate peak of up to 40% of pre-pandemic levels in summer 2020, the rapidly rising number of infections in Poland in autumn 2020, followed by a second strong wave in spring 2021 kept air passenger numbers down at a level of 10 to 20% of the year 2019. With decreasing infection rates and a relief of travel restrictions, air passenger figures rose again to a level of about 65% towards summer 2021.
- The path of air passenger development in Sweden is somewhat different than those of other countries. Although Sweden had less travel and other restrictions than other countries, air passenger volumes did not recover as much as in other countries. In particular, the high infection rates in winter 2020/21 and spring 2021 came along with a level of only little more than 10% air passengers during those periods in the year 2019. Also, the recovery in summer 2021 was only to a level of 40% of the pre-pandemic year. The relative level of domestic flight passenger was only little bit above the international flight passengers.

Another way to depict the dramatic changes and the downs and ups of air passenger flows in Europe is to use chord diagrams (Fig. 3). For reasons of comparability over time, the two chord diagrams are scaled in the same way, which differs from common use of that diagram type. The diagrams display air passenger flows between European countries as well as the domestic flight volumes for the two months July 2019 and July 2020, another demonstration of the collapse of the air passenger market even for a month which showed some signs of recovery. The first chord diagram displays the exchange of air passengers between European countries typical for a 'normal' summer month before the pandemic. Many relationships see more than half a million people travelling between two countries. In particular, the flows of tourists from the larger European countries in the centre to the southern destinations such as Portugal, Spain, Italy and Greece, but also between those countries become evident.

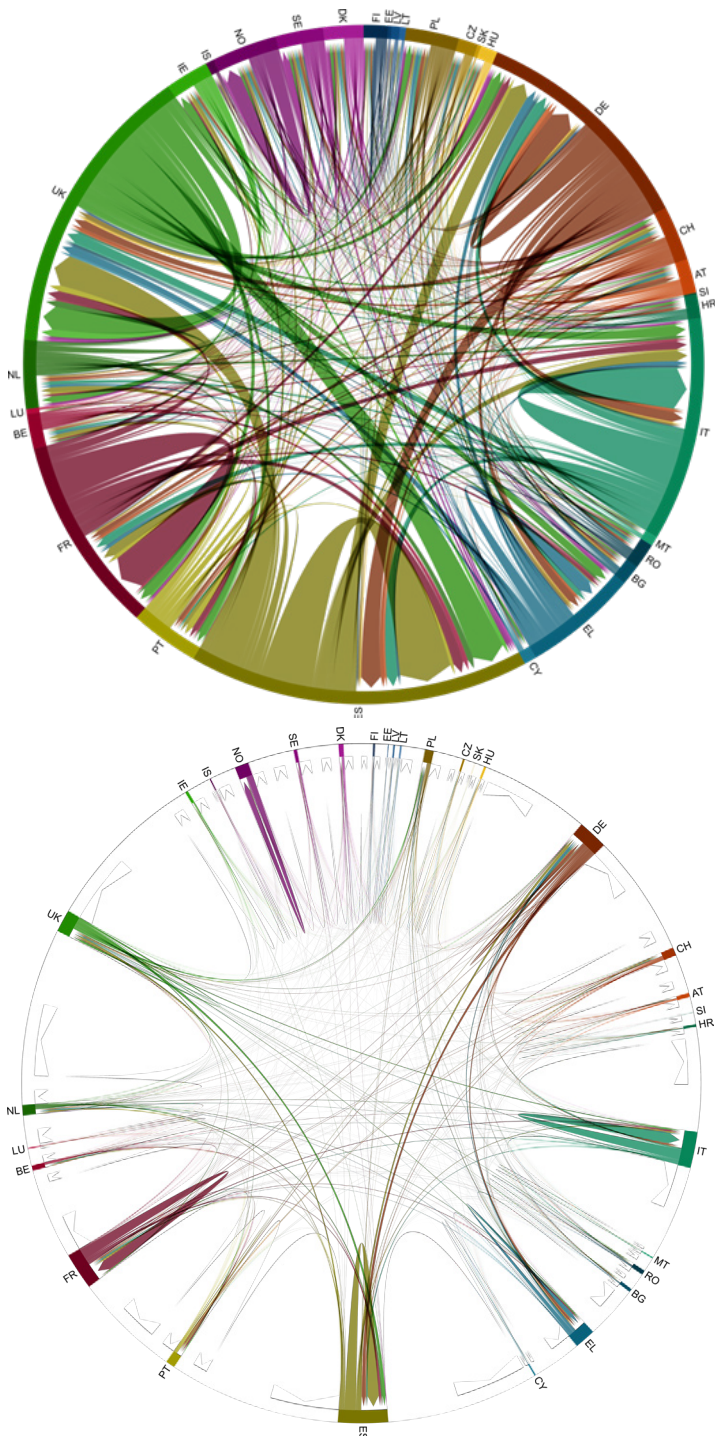


**Figure 3**. Air passenger flows between European countries, July 2019 (top) and July 2020 (bottom)

One year later, air passenger flows clearly shrunk everywhere. All relationships between countries lost an enormous amount of passengers in July 2020 compared to one year before. Most relations between two countries that had several hundred thousand air passengers in July 2019 had only a few ten thousands in July 2020. Of the many relations that previously saw more than half a million air passengers, only three had so in 2020. In this way UK-Spain, Germany-Spain and Germany-Greece mark the most important air passenger tourist flows although the absolute numbers dramatically decreased. Also of note are some domestic air passenger volumes during this period of the pandemic in Italy, Greece, Spain, France, the UK and Norway.

## Impacts at the regional level

Naturally, at regional level the overall consequences of the COVID-19 pandemic together with the measures taken did closely follow the temporal pattern demonstrated in the previous section at the national level. This section presents this as well as some peculiarities embedded.

For selected months in the years 2019, 2020 and 2021, a time series of air passenger flows between regions in Europe is given in Figure 4. For the pre-pandemic months in 2019, the high passenger numbers to the main touristic destinations in southern Europe as well as a dense mesh of highly used air connections in most parts of Europe are visible.

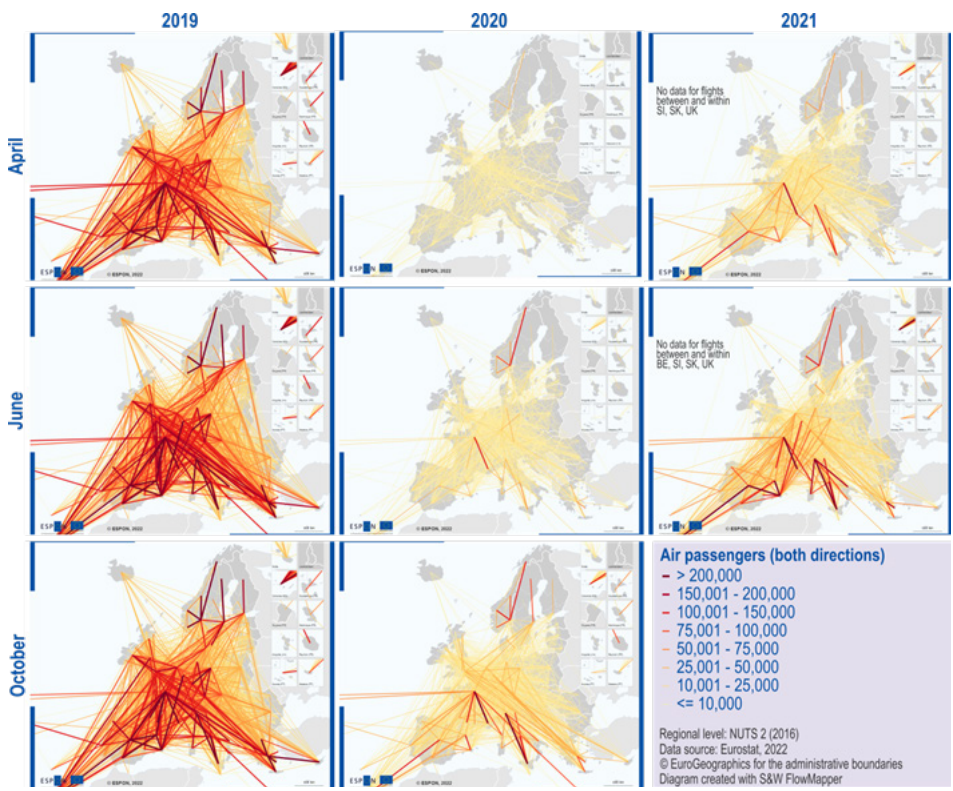


**Figure 4**. Regional air passenger flows, June 2019 to June 2021

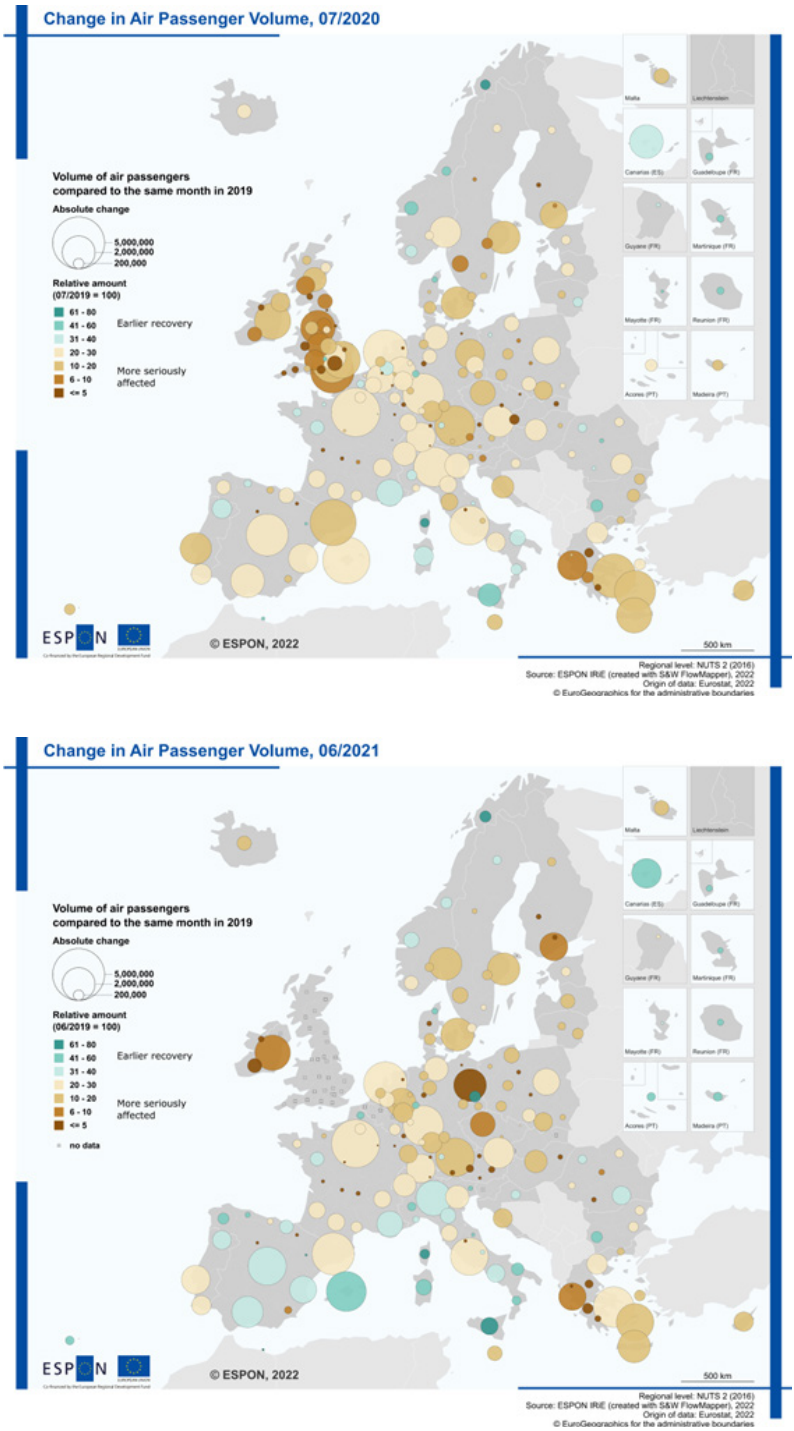


**Figure 5**. Change in regional air passenger volume, July 2020 and June 2021

With the pandemic in place, the monthly maps show the almost complete closure of air travel in April 2020, and the rather modest recovery in the following summer and autumn. However, flight volumes on most relationships are only a 'shadow' of what was recorded a year before. Regional linkages of several 10 thousands or even 100 thousands of passengers disappeared widely from the map. Highest passenger numbers were recorded on intra-national connections, most of which is an outcome of tourist flows concentrating mainly on domestic destinations during that summer. This occurred within Spain with the Balearic and Canary Islands as main destinations, within France with flows from Paris to the French Mediterranean regions, Corse and also to the outermost regions, within Italy with flows from the main metropolitan regions to southern regions and the islands of Sardinia and Sicily, within Greece, but also within Norway with substantial passenger numbers between Oslo and the more remote regions. The figure also displays that the slight recovery in spring and summer 2021 was not only based on domestic travel within the main tourist destination countries, but also on slightly higher numbers of people travelling south for instance from France, Germany or the Netherlands.

The decrease of air passenger volumes in the regions of Europe during the COVID-19 pandemic is dramatic in absolute and in relative terms. Figure 5 gives the absolute and relative changes of air passenger volumes for two sample summer months, July 2020 and June 2021, compared to the same months in the year 2019. In summer 2020, the level of air passengers has fallen down to 10 to 20% almost everywhere in Europe. It is even lower in the UK because of strict travel bans and lack of intercontinental flights and related passengers. It is also lower in Greek regions, but higher in some southern touristic regions, in particular islands such as Canary Islands, Corse, Sardinia, Sicily. Absolute air passenger losses could have reached up to 5 million per month. The situation in June 2021 is far away from the pre-pandemic air passenger traffic volumes, but is not as worse as one year earlier. In absolute numbers, passenger losses can add up to several million people in a month, but seen relatively, the level in many southern European touristic destinations was between 30 and 50% of June 2019. Other more northern regions in Europe reached only between 10 and 30% of previous levels. Several smaller airports were substantially affected by air traffic drop downs. Even in June 2021 several regional airports, in particular in Spain, France, Ireland, Germany, Austria and Greece had only around 10% of its passenger volumes the same month two years before. The low relative value in Berlin is an artefact of the closure of Berlin-Tegel and the opening of the new Berlin airport in the Brandenburg region.

## Impacts of the COVID-19 pandemic on air freight flows in Europe

This section presents briefly to what degree air freight transport flows in Europe have been disturbed by the COVID-19 pandemic. With higher temporal resolution, e.g. monthly data, air freight transport comes along much more volatile over the years than air passenger traffic. This is true even at the national level; at the same time, it makes it much more difficult or even impossible to assess whether regional changes are due to external influence such as the pandemic or the usual fluctuation over the years. Therefore, the analysis is only done at the national level.

The single diagrams of Figure 6 show national freight transport volumes for the two pandemic years compared to the transport volumes of the respective months in 2019 together with the recorded COVID-19 infection rates. Basically, two groups of countries can be distinguished. One group experienced a more or less clear decrease of air transport volumes in the beginning of the pandemic, mostly down to 40 to 60% of the previous level. Countries such as Bulgaria, Denmark, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Poland, Portugal, Finland, UK or Switzerland

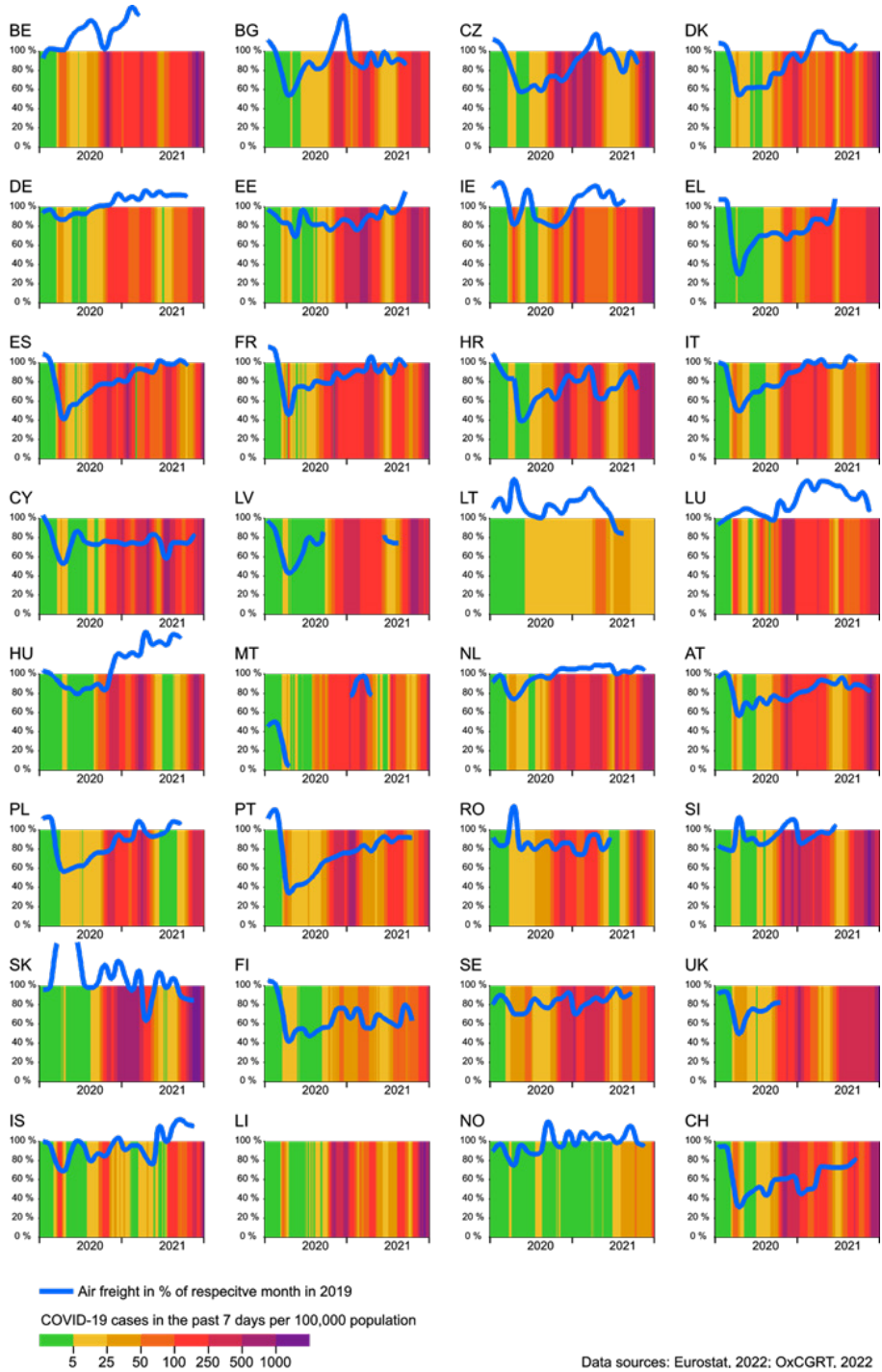


**Figure 6**. Change of monthly air freight volume during the COVID-19 pandemic by country

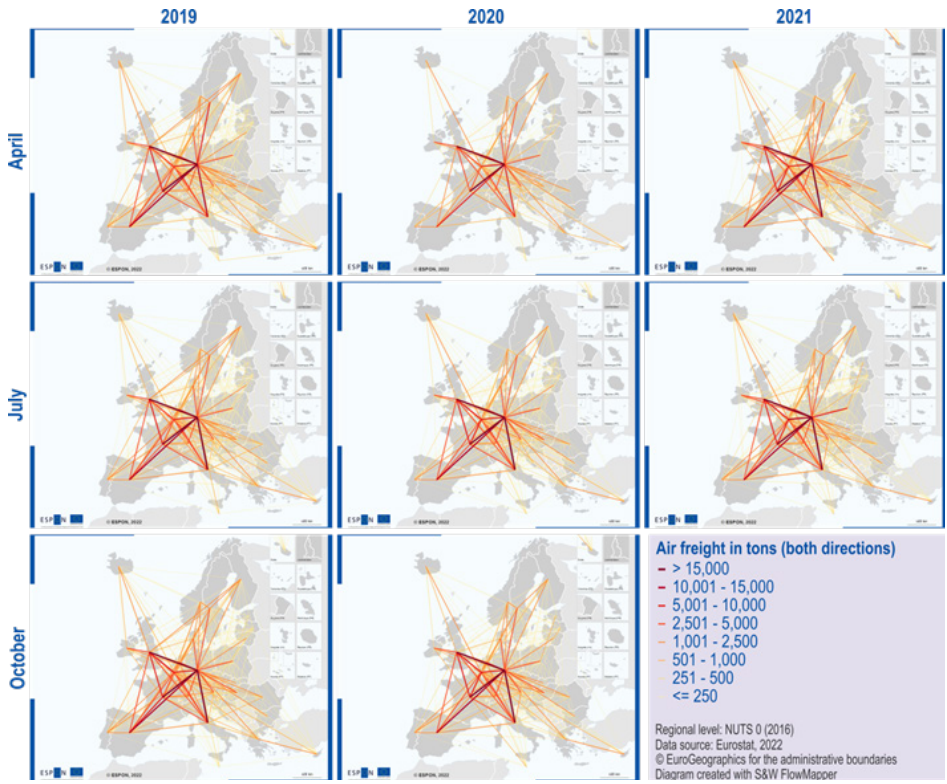


**Figure 7**. National air freight transport flows, April 2019 to July 2021

belong to this group. On the other hand, countries that have major international air freight hubs such as Belgium, Germany, Ireland, Luxembourg, Netherlands and some other have experienced clearly growing air freight volumes during the COVID-19 pandemic. In summer 2021 most countries have monthly air freight transport volumes that are around the level of those months in 2019 or even above.

The spatial pattern of air freight transport flows between countries in Europe appears to be rather not been affected by the COVID-19 pandemic (Fig. 7). Even in spring 2020 where some countries experienced some losses of transport volumes, the pattern and magnitude of the stronger flows is hardly reduced. This is also true for the other months of the pandemic.

## Conclusions

The impact of the COVID-19 pandemic on air passenger traffic during its first two years was dramatic with reductions in numbers that have never been seen before since flying became a mass mode for medium and long-distance travel in Europe. All countries experienced losses in 2020 of between 67 and 84% in air passenger traffic, i.e. the relative impact at country level was rather homogeneous distributed over the European territory. However, freight and mail transport by air were much less affected by the COVID-19 pandemic and related measures than air passenger transport.

The downs and upturns of air passenger traffic happened wave-like relatively similar in most regions. However, touristic destinations in southern Europe seemed to be the leaders in the upwards turns. July 2021, a month in which the data availability was not complete at time of the analysis, gives an indication of a re-growth of air passengers almost everywhere in Europe compared to the previous months, but by far not compared to the pre-pandemic levels. However, regional airports in several countries did not give signs of passenger recovery during the period considered.

The overall variation of the impact of the COVID-19 pandemic on air transport flows of different types of regions or countries such as cohesion policy regions or member states grouping by geographical area (EC, 2022) is relatively low or non-existing. This is in line with earlier findings on the potential regional impacts of COVID-19 policy responses which 'differ substantially to the usual geographical patterns of regional development. COVID-19 and the policy responses produce multifaceted and complex impacts on regional development' (Böhme et al., 2020, p. 16).

In general, the development of air transport, in particular air passenger transport, during the COVID-19 pandemic, is an outcome of the integrated network characteristics of this transport mode together with a high complexity of measures and traveller perception. Changes in travel demand in one regional part of the European air network either induced by travel restriction or cautious potential travellers has effects all over the network and destinations. Travel restrictions have an immediate impact on the number of people travelling. However, there was not always a clear link between new infection cases and travel restrictions (IATA, 2022). And, in the course of the pandemic, there was not always a clear link between infection cases, travel restrictions on the one hand and number of people travelling by air. This was clear at the beginning of the pandemic during spring 2020. However, later on, even in times where travel restrictions were lower or infection rates decreased or increased, the direct influence of the current situation of the pandemic on passenger numbers was less clear. This has to do with the fact that potential air travellers have a certain perception of the risks involved in travelling by air, in travelling to other countries with potentially higher infection risks or risks of quarantine there and afterwards at home (Lamb, Winter, Rice, Ruskin, & Vaughn, 2020; Garaus & Hudáková, 2022). The perceived threat is a clear loss of confidence of many travellers in using an air plane; similar observations have been made during the pandemic regarding other collective means of travel. Based on this, in particular tourists made rather often the decision, not to travel by air to other countries but to stay for holidays in their home countries. However, tourists were also the first to start flying again with the effect of southern tourist destination regions were first on the path of recovery towards pre-pandemic air passenger numbers.

During the COVID-19 pandemic, the aviation sector has received an enormous amount of state aid to compensate for its economic losses. Starting with the almost full lockdown in spring 2020, many European airlines asked for state aid in the form of loans, equity injections, tax deferrals, subsidies or state guarantees (Albers & Rundshagen, 2020; Sun et al., 2022); in Europe, this state aid has accumulated to almost 200 billion Euro already in March 2021 (Rodrigues, Sandri; Antonucci; Knezevic & Teoh, 2021). This form of government aid was considered essential for airline operators to stay in market and to maintain their air transport services despite dramatic decreases of revenues.

However, in a combination of behavioural changes of potential air travellers and strategies of the aviation sector as a consequence of the COVID-19 crises, there are a range of emerging trends that affect air transport in the medium and long-term after the pandemic as summarised in a recent study by Rodrigues et al. (2021):

- rising debt of the aviation sector is leading to stronger state involvement,
- business travel is recovering much slower than leisure travel,

- hub-and-spoke connectivity is shifting more towards point-to-point connectivity, in particular for domestic travel,
- continued digitalisation supports capacity and resilience of airport system and helps to restore traveller confidence,
- higher hygiene and sanitation standards are prerequisite for growing passenger numbers,
- air freight demand increases among others as a consequence of clearly rising e-commerce during the pandemic,
- flexibility and quick decision making needed in the aviation sector as response to changing travel restrictions of different countries,
- existing policy framework towards decarbonisation targets to be taken into account.

Based on these trends identified, the study by Rodrigues et al. (2021)came along with three basic fields of policy recommendations to EU policy makers to support the recovery of the aviation sector:

- **Rebuild passenger confidence in air transport**. This includes harmonised hygiene and sanitation standards throughout airport facilities and aircrafts; communication and coordination of travel restrictions; COVID tests and quarantine rules; an EU Digital COVID Certificate, campaigns for air travel and tourism.
- **Better support of the aviation sector**. This includes priorities of frontline aviation workers in vaccination plans etc., safe re-opening of borders using systematic COVID-19 vaccination and testing; EU harmonised and coordinated guidelines, fiscal measures that preserve employment, competition, business dynamics and maintains regional connectivity.
- **Strengthen existing policies defined for the sector**. This includes to ensure that pre-COVID plans and arrangements to meet sustainability objectives can be carried out or, if necessary, adapted given the industry's financial struggle; investments towards the entire aviation value chain, e.g. the development and use of sustainable aviation fuels, research activities on air traffic management and digitalisation to support the sustainability efforts of the sector.

These measures referred to above are probably the right steps to push the aviation sector towards its performance in pre-COVID times. They are probably also a possible path under an assumption that the recovery of the air transport sector would at the same time improve also the situation of up- and downstream economic sectors and thus those regions that are harmed by sharply reduced levels of air passenger transport as seen during the last years.

The COVID-19 crisis has induced a huge transformation of the way we are living, working, spending leisure time, travelling, communicating etc. A basic question therefore is whether all changes forced by the pandemic are bad or whether we might rethink some of the former personal and economic habits. This might be in particular important by anticipating one of the next crises to come, the climate crisis, much more than it is done so far.

Relating these considerations to air transport flows with a regional perspective, there might be more policy options in addition to the ones referred to above, but might also replace some of them:

- **Greenhouse gas emissions of air transport seriously to be taken into account**. Self-commitments of the air sector and wishful thinking about reducing passenger demand do not appear to be sufficient to get air transport on track to get greenhouse gas emissions down. Direct policy interventions could include fostering of technological innovations and regulatory legislation to replace conventional aircrafts with zero-emission aircrafts and also create zero-emission airports. This has to be accompanied by strong and steadily increasing economic disincentives for further greenhouse gas emissions from aviation. This is a basic requirement and policy direction that is also linked to most of the other options below.

- **Further develop other modes of transport**. A substantial part of air travel is short or medium distance, i.e. mobility demand that could be taken by other more sustainable modes of transport. The accelerated development of the TEN-T (high-speed) rail network would support such a modal shift also in regions of Europe such as eastern and south-eastern Europe where rail does not play an important rail today.
- **Promote domestic tourism**. There is an almost unlimited demand of the population to spend leisure times in other places than at the place of living. The travel restrictions, but also the uncertainties about possible travel restrictions, health and quarantine risks led to a huge revival of domestic tourism in many European countries. This was partly realised by flying to the domestic destination (as seen for instance in Spain or Italy) or by using other modes of transport (e.g. in Germany). A new appreciation of destinations nearby was in place that were of benefit to a substantial number of regions and partly extended the duration of the main touristic season from early spring to late autumn. This should be taken up by local and regional actors in tourist regions in order to have a more sustained flow of visitors.
- **Develop other regional assets**. The pandemic has hit regions the most that to a large degree are depending on foreign tourists that arrive by air. Such foci on one economic sector are always risky, but particular in times of crises. As other crises might come (or are already in place such as war again in Europe or the climate crisis) resilient regions need to have a diversified economic base.
- **Prepare for lower rates of business travel**. The pandemic has led to a forced flight into home office and an enormous increase in video conferences replacing physical travel to common place of work and to personal meetings somewhere in Europe or worldwide. It has been seen that in countries such as Germany in which business travel makes up two third of all domestic air passenger travel, the recovery of domestic air passenger volumes was much lower than international travel. It is probably not realistic that business travel will soon reach its pre-pandemic levels again. This is on the one hand a chance to reduce medium and long-distance travel, but at the same time it is a large economic problem for the aviation sector but also for regions benefitting from this type of travel. Measures to mitigate this are to be developed.
- **Prepare for problems of regional airports**. There are several regional airports that had economic problems already before the COVID-19 crisis due to insufficient air transport volumes and due to their dependencies on one or few low-cost carriers. These situations have not improved during the pandemic years. It might be expected that some of the regional airports, in particular if they are located closer to larger airports as it is the case for several regional airports in central regions of Europe might not survive. Regions should prepare for such possibilities.

## Acknowledgement

The research work presented here has been implemented in the course of the project ‘ESPON IRiE – Interregional Relations in Europe’ within the framework of the ESPON 2020 Cooperation Programme, partly financed by the European Regional Development Fund.
The authors would like to thank the two anonymous reviewers for their helpful suggestions and comments on an earlier version of this paper.

## References


Brenner, N. (1999). Globalisation as Reterritorialisation: The Re-scaling of Urban Governance in the Eu-Albalate, D., Bel, G., & Fageda, X. (2015). Competition and cooperation between high-speed rail and air transportation services in Europe. *Journal of Transport Geography*, *42*, 166–174. https://doi.org/10.1016/j.jtrangeo.2014.07.003

Albers, S., & Rundshagen, V. (2020). European airlines' strategic responses to the COVID-19 pandemic (January-May, 2020). *Journal of Air Transport Management*, *87*, 101863. https://doi.org/10.1016/j.jairtraman.2020.101863

Alderighi, M., & Cento, A. (2004). European airlines conduct after September 11. *Journal of Air Transport Management*, *10*(2), 97–107. https://doi.org/10.1016/S0969-6997(03)00053-X

Allroggen, F., Wittman, M.D., & Malina, R. (2015). How air transport connects the world – A new metric of air connectivity and its evolution between 1990 and 2012. *Transportation Research Part E: Logistics and Transportation Review*, *80*, 184–201. https://doi.org/10.1016/j.tre.2015.06.001

Andreana, G., Gualini, A., Martini, G., Porta, F., & Scotti, D. (2021). The disruptive impact of COVID-19 on air transportation: An ITS econometric analysis. *Research in Transportation Economics*, *90*, 101042. https://doi.org/10.1016/j.retrec.2021.101042

Behrens, C., & Pels, E. (2012). Intermodal competition in the London–Paris passenger market: High-Speed Rail and air transport. *Journal of Urban Economics*, *71*(3), 278–288. https://doi.org/10.1016/j.jue.2011.12.005

Böhme, K., Besana, F., Lüer, C., Holstein, F., Hans, F., Valenza, A., Caillaud, B., & Derszniak-Noirjean, M. (2020). Potential impacts of COVID-19 on regions and cities of the EU. Brussels: European Committee of the Regions.

Budd, L., Ison, S., & Adrienne, N. (2020). European airline response to the COVID-19 pandemic – Contraction, consolidation and future considerations for airline business and management. *Research in Transportation Business & Management*, *37*, 100578. https://doi.org/10.1016/j.rtbm.2020.100578

Burghouwt, G., & de Wit, J. (2005). Temporal configurations of European airline networks. *Journal of Air Transport Management*, *11*(3), 185–198. https://doi.org/10.1016/j.jairtraman.2004.08.003

Calzada, J., & Fageda, X. (2019). Route expansion in the European air transport market. *Regional Studies*, *53*(8), 1149–1160. https://doi.org/10.1080/00343404.2018.1548763

Carrera, S., & Luk, N.C. (2020). *In the Name of COVID-19: An Assessment of the Schengen Internal Border Controls and Travel Restrictions in the EU*. Brussels: Policy Department for Citizens' Rights and Constitutional Affairs, European Parliament.

Clewlow, R.R., Sussman, J.M., & Balakrishnan, H. (2014). The impact of high-speed rail and low-cost carriers on European air passenger traffic. *Transport Policy*, *33*, 136–143. https://doi.org/10.1016/j.tranpol.2014.01.015

Denstadli, J.M., Gripsrud, M., Hjorthol, R., & Julsrud, T.E. (2013). Videoconferencing and business air travel: Do new technologies produce new interaction patterns? *Transportation Research Part C: Emerging Technologies*, *29*, 1–13. https://doi.org/10.1016/j.trc.2012.12.009

Dobruszkes, F., & van Hamme, G. (2011). The impact of the current economic crisis on the geography of air traffic volumes: an empirical analysis. *Journal of Transport Geography*, *19*(6), 1387–1398. https://doi.org/10.1016/j.jtrangeo.2011.07.015

Dobruszkes, F., Decroly, J.-M., & Suau-Sanchez, P. (2022). The monthly rhythms of aviation: A global analysis of passenger air service seasonality. *Transportation Research Interdisciplinary Perspectives*, *14*, 100582. https://doi.org/10.1016/j.trip.2022.100582

Dobruszkes, F., Dehon, C., & Givoni, M. (2014). Does European high-speed rail affect the current level of air services? An EU-wide analysis. *Transportation Research Part A: Policy and Practice*, *69*, 461–475. https://doi.org/10.1016/j.tra.2014.09.004

EC (2022). *Cohesion in Europe towards 2050. Eighth report on economic, social and territorial cohesion*. DG Regio – European Commission Directorate-General for Regional and Urban Policy. Luxembourg: Publications Office of the European Union. https://doi.org/10.2776/624081

Ennen, D., & Wozny, F. (2022). COVID-19: Impacts on air fares and air connectivity in the European Union. *Transportation Research Procedia*, *65*, 265–274. https://doi.org/10.1016/j.trpro.2022.11.031

Eurostat (2022). *Air transport (avia)*. Retrieved from https://ec.europa.eu/eurostat/data/database?node_code=hlth

Garaus, M., & Hudáková, M. (2022). The impact of the COVID-19 pandemic on tourists' air travel intentions: The role of perceived health risk and trust in the airline. *Journal of Air Transport Management*, *103*, 102249. https://doi.org/10.1016/j.jairtraman.2022.102249

Hale, T., Angrist, N., Goldszmidt, R., Kira, B., Petherick, A., Phillips, T., Webster, S., Cameron-Blake, E., Hallas, L., Majumdar, S., & Tatlow, H. (2021). A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nature Human Behaviour*, *5*, 529–538. https://doi.org/10.1038/s41562-021-01079-8

IATA (2022). *Overview of air transport in 2021 and recent developments. Media briefing 25 January 2022*. Retrieved from https://www.iata.org/en/iata-repository/publications/economic-reports/overview-of-air-transport-in-2021-and-recent-developments/

Lamb, T.L., Winter, S.R., Rice, S., Ruskin, K.J., & Vaughn, A. (2020). Factors that predict passengers willingness to fly during and after the COVID-19 pandemic. *Journal of Air Transport Management*, *89*, 101897. https://doi.org/10.1016/j.jairtraman.2020.101897

Li, S., Zhou, Y., Kundu, T., & Zhang, F. (2021a). Impact of entry restriction policies on international air transport connectivity during COVID-19 pandemic. *Transportation research. Part E, Logistics and transportation review*, *152*, 102411. https://doi.org/10.1016/j.tre.2021.102411

Li, S., Zhou, Y., Kundu, T., & Sheu, J.-B. (2021b). Spatiotemporal variation of the worldwide air transportation network induced by COVID-19 pandemic in 2020. *Transport Policy*, *111*, 168–184. https://doi.org/10.1016/j.tranpol.2021.08.001

Macurová, M., Vittek, P., & Pecherková, P. (2022). Connectivity of the European air transport network during the Covid-19 pandemic. T*ransportation Research Procedia*, *65*, 208–215. https://doi.org/10.1016/j.trpro.2022.11.024

OxCGRT (2022a). *COVID-19 Government Response Tracker*. Retrieved from https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker

OxCGRT (2022b). *Codebook for the Oxford Covid-19 Government Response Tracker*. Retrieved from https://github.com/OxCGRT/covid-policy-tracker/blob/master/documentation/codebook.md

Reiter, V., Voltes-Dorta, A., & Suau-Sanchez, P. (2022). The substitution of short-haul flights with rail services in German air travel markets: A quantitative analysis. *Case Studies on Transport Policy*, *10*(4), 2025–2043. https://doi.org/10.1016/j.cstp.2022.09.001

Rodrigues, M., Sandri, E., Antonucci, B., Knezevic, L., & Teoh, T. (2021). *Relaunching transport and tourism in the EU after COVID-19. Part III Aviation sector*. Brussels: European Parliament, Policy Department for Structural and Cohesion Policies.

Rybenská, K., Socha, V., & Vittek, P. (2022). Adapting Connectivity Measure for Business Aviation – COVID-19 Case Study. *Transportation Research Procedia*, *65*, 172–179. https://doi.org/10.1016/j.trpro.2022.11.020

Schwarze, B., & Spiekermann, K. (2022a). *Interregional passenger transport flows in Europe*. IRiE – Interregional Relations in Europe, Annex 8. Luxembourg: ESPON. Retrieved from https://gis-portal.espon.eu/arcgis/apps/sites/#/irie-hub/pages/reports

Schwarze, B., & Spiekermann, K. (2022b). *Case study: COVID-19 impacts on air transport flows between European regions*. IRiE – Interregional Relations in Europe, Annex 20. Luxembourg: ESPON. Retrieved from https://gis-portal.espon.eu/arcgis/apps/sites/#/irie-hub/pages/reports

Schwarze, B., & Spiekermann, K. (2022c). *FlowMapper*. IRiE – Interregional Relations in Europe, Annex 30. Luxembourg: ESPON. Retrieved from https://gis-portal.espon.eu/arcgis/apps/sites/#/irie-hub/pages/reports

Schwarze, B., Spiekermann, K., Llano Verduras, C., Pérez-Balsalobre, S., & Gallego López, N. (2022). *Interregional freight transport flows in Europe*. IRiE – Interregional Relations in Europe, Annex 3. Luxembourg: ESPON. Retrieved from https://gis-portal.espon.eu/arcgis/apps/sites/#/irie-hub/pages/reports

Stefan, M., & Luk, N.C. (2021). *Limitations on Human Mobility in Response to COVID-19. CEPS Paper in Liberty and Security in Europe*. Retrieved from https://www.ceps.eu/download/publication/?id=34930&pdf=LSE2021-02_Limitations-on-Human-Mobility.pdf

Sun, X., Wandelt, S., & Zhang, A. (2021). On the degree of synchronization between air transport connectivity and COVID-19 cases at worldwide level. *Transport Policy*, *105*, 115–123. https://doi.org/10.1016/j.tranpol.2021.03.005

Sun, X., Wandelt, S., & Zhang, A. (2022). COVID-19 pandemic and air transportation: Summary of Recent Research, Policy Consideration and Future Research Directions. *Transportation Research Interdisciplinary Perspectives*, *16*, 100718. https://doi.org/10.1016/j.trip.2022.100718

Sun, X., Wandelt, S., & Zhang, A. (2023). A data-driven analysis of the aviation recovery from the COVID-19 pandemic. *Journal of Air Transport Management*, *109*, 102401. https://doi.org/10.1016/j.jairtraman.2023.102401

Velasco Echeverría, X., Izquieta Rojano, S., Sola Torralba, I., Salinas Sole, C., Llano Verduras, C., Moral Carcedo, J., Pérez García, J., Ángel Almazán, M., Pérez-Balsalobre, S., Pardo Fernández, J., Gallego López, N., Kallioras, D., Tsiapa, M., Rasvanis, E., Manetos, P., Adamakou, M., Topaloglou, L., Petrakos, G., Viseu Cardoso, R., Dabrowski, M., Uyttebrouck, C., Spiekermann, K., Schwarze, B., Rauhut, D., Halme, J., Kahila, P., Fritsch, M., Komornicki, T., Rosik, P., Wiśniewski, R., Szejgiec-Kolenda, B., Wójcik, J., Cerić, D., Czapiewski, K., Mazur, M., & Pomianowski, W. (2022). *IRiE – Interregional Relations in Europe*. Luxembourg: ESPON. Retrieved from https://gis-portal.espon.eu/arcgis/apps/sites/#/irie-hub/pages/reports

Zhou, Y., Kundu, T., Qin, W., Goh, M., & Sheu, J.-B. (2021). Vulnerability of the worldwide air transportation network to global catastrophes such as COVID-19. *Transportation research Part E: Logistics and transportation review*, *154*, 102469. https://doi.org/10.1016/j.tre.2021.102469