



Impacts of travel bans and travel intention changes on aviation emissions due to Covid-19 pandemic

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Abstract

The Covid-19 pandemic negatively affected many sectors including aviation and travel. Travel bans and forced lockdowns prevented transportation activity, especially air travel. Accordingly, huge amounts of emission reductions occurred. On the other hand, travel restrictions are not the only cause of emissions reductions. Changing travel intention in the era of Covid-19 is another important factor that affects aviation emissions. This paper aims to investigate the Landing/Take-Off (LTO) emission changes at Turkish airports. An emission inventory has been implemented for the years 2019 and 2020 to reveal the impacts of Covid-19 on aviation emissions. Domestic, international, and cargo flights have been included in the inventory. According to the results, total emissions of SO₂, CO₂, CO, NO_x, NMVOC, CH₄, N₂O, and PM_{2.5} have decreased in 2020 compared to 2019 by 49.8%, 49.7%, 41.0%, 52.6%, 40.0%, 33.8%, 49.8%, and 50.3%, respectively. Total CO₂ reductions in the Q2, Q3, and Q4 periods of 2020 compared to that of 2019 are 87%, 50% and 43%, respectively. Another aim of this paper is to find the underlying reasons for emission reductions. For Turkish airports, emission reductions have resulted from travel bans in Q2. After the relaxation of restrictions with the declaration of the “New Normal” in Turkey, flight traffic rebounded to a certain level but was lower than 2019 levels. Therefore, changing travel intention is the main cause of emission reductions in Q3 and Q4 of 2020. The results of this study contribute to both the areas of air pollution and tourism management.

Keywords Aviation · Covid-19 · Emission inventory · Landing/Take-Off (LTO) · Travel bans · Travel intention changes · Turkey

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1 Introduction

The occurrence of health risk crises such as pandemics reduces the intention of travel and tourism movements (Chua et al., 2021; Matiza & Kruger, 2021). Passenger volumes decreased between 57.0% and 77.6% in affected airports during SARS (March–May 2003). Similarly, from March to May 2009, due to the Swine Flu, the number of airline passengers dropped by 4.12–7.88% (Gallego & Font, 2021). Before the Covid-19 pandemic, aviation was a rapidly growing sector. The size of the global commercial aircraft fleet has doubled every 20 years (Higham et al., 2019). Revenue passenger kilometers (RPK), the multiplication of revenue paying passengers by distance traveled, is used to express the air traffic (Masiol & Harrison, 2014). There existed a nine-time increase in RPK between 1970 and 2010, and global air travel passenger demand had grown 5–6% annually (Higham et al., 2019). With the spread of the Covid-19 pandemic, many countries adopted travel bans, lockdowns, stay-at-home orders, closing borders, or introduced quarantine periods for international travelers. Airlines suspended flights and airports were closed (Gössling et al., 2020). As a result of pandemic precautions year to year revenue passenger kilometers (RPK) has dropped by 85.3% on international routes from January to December 2020 (IATA Economics 2021). The impact of the Covid-19 pandemic on the aviation sector was quite catastrophic. Airlines and airports adopted new screening and boarding procedures and in-flight operations (Sun et al., 2021). Continuous cabin cleaning, distribution of hygiene kits (masks and disinfectants) during passenger boarding, and reduction or elimination of catering services are some examples of adaptations against Covid-19 (Ertaş & Yağcı, 2020). In addition, airlines applied new policies, such as flying with 50% capacity, to maintain the social distance between passengers. Some of the companies had to request financial aid, and some declared bankruptcy (Gössling et al., 2020). Suspension of international flights, closure of airports, travel bans for foreigners, and forced quarantine periods for travelers dramatically reduced tourism demand and international tourist flow (Haryanto, 2020). Gallego and Font (2020) analyzed Skyscanner data on 30 April 2020 for the May to September 2020 period and reported that the desire to travel (flight search) has dropped by 29.7%, while the intention to travel (flight pick) reduced by 37.3% globally. Although travel restrictions and border closures limited tourism movements, the environment benefited from lockdown measures and emissions are reduced. Matthias et al., (2021) indicated that travel restrictions caused quite amount of emission reductions especially from air and road transportation in spring 2020 in Europe. Nagaj & Žuromskaitė (2021) reported that arrivals at accommodation establishments and greenhouse emissions from tourism activities are decreased in all Central and Eastern European due to the Covid-19 pandemic. Monteiro et al., (2021) mentioned that tourism suffered the most while air quality improvements are highest in Lisbon in 2020.

The share of tourism in global carbon emissions is 5% and 40% of these emissions result from air transport (Chen et al., 2018; Higham et al., 2019; Liao et al., 2021). Kerosene-type fuels are used as fuel in aircraft and carbon dioxide (CO₂), water vapor (H₂O), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x), unburned hydrocarbons (HC) and particulate soot are the exhaust emissions of aircraft engines (Masiol & Harrison, 2014). Hydrocarbon emissions include methane (CH₄) and non-methane volatile organic compounds (NMVOC). Aviation emissions can be divided into two categories. Landing/Take-Off (LTO) emissions occur at airports and influence the air quality of the surrounding area. Climb/Cruise/Descent (CCD) emissions are important for regional air quality (Liao

et al., 2021). There was an increasing trend in aviation emissions until the Covid-19 pandemic. Before the pandemic, projections of aviation emissions had indicated a doubling of emissions by 2050 (Higham et al., 2019). Transportation emissions significantly declined because of the Covid-19 outbreak. Muhammad et al., (2020) pointed out that mobility was reduced by up to 90% and environmental pollution decreased by up to 30% during the first Covid-19 lockdown period of 2020. According to the International Civil Aviation Organization, 12 airline companies stopped flights internationally and 20 companies stopped flights both nationally and internationally at the end of March 2020 (Xue et al., 2021). Due to confinements, aviation activity decreased by 75% (60 to 90%), and consequently, CO₂ emissions were reduced by 60% (44 to 76%) at the beginning of April 2020 (Le Quéré et al., 2020; Jiang et al., 2021) estimated a 70% decrease in aircraft emissions in southern California during the Covid-19 lockdown period (19 March to 23 April 2020). In 2020, domestic aviation traffic in 4 Chinese airports reduced by 67.8% compared to 2019, resulting in CO₂, SO_x, NO_x, and CO emission reductions ranging from 62 to 15% during the year (Xue et al., 2021).

To reveal the impacts of the Covid-19 pandemic on aviation-related emissions, it is required to prepare an emission inventory. In Turkey, there is a growing interest in the development of inventory for aviation emissions. Zeydan & Yıldız Şekertekin (2022) summarized the studies covering LTO emissions at Turkish airports for the last two decades. Moreover, the most recent papers focused on the emissions of Iğdır Airport (Gürçam et al., 2021), Hasan Polatkan Airport (Akdeniz, 2021), Ordu- Giresun Airport (Orhan, 2021) in Turkey. On the other hand, all these studies implemented inventories for the pre-Covid-19 era. Deveci et al., (2022) investigated the economic impacts of the pandemic on the Turkish civil aviation industry. To our knowledge, there exist only a few studies revealing the effects of Covid-19 on aviation emissions in Turkey. Akyüz (2022) studied the LTO emissions of Van Ferit Melen Airport before and during the pandemic. Keskin & Yalçiner Ercoşkun (2021) investigated the LTO emissions of İzmir Adnan Menderes Airport and compared only two days of 2019 and 2020 to make a comparison. Ekici et al., (2021) examined the January-August period for four years (2017–2020) and compared the monthly emissions of CO, CO₂, HC, and NO_x to observe the effects of the pandemic. However, their calculations are based only on the Turkish Airlines fleet. Unlike the cited literature, in this study, the impacts of the Covid-19 pandemic on aviation emissions have been studied in detail for Turkish airports. LTO emissions of 56 Turkish airports have been included in the emission inventory for the years 2019 and 2020. The changes in emissions in the latter year are tried to be explained with travel restrictions and behavior changes of tourists. Therefore, this article aims to investigate LTO emission changes at airports in Turkey and the underlying reasons for emission reductions. This paper contributes to the literature in three folds. The development of an emission inventory is a requirement to reveal the environmental effects of the aviation sector. Also, the results of this inventory are important to see the impacts of the pandemic. Furthermore, our findings are beneficial to the tourism industry since most international tourists use airlines to travel to Turkey. Revealing the underlying reasons for emission reduction during the pandemic is the novelty of this study.

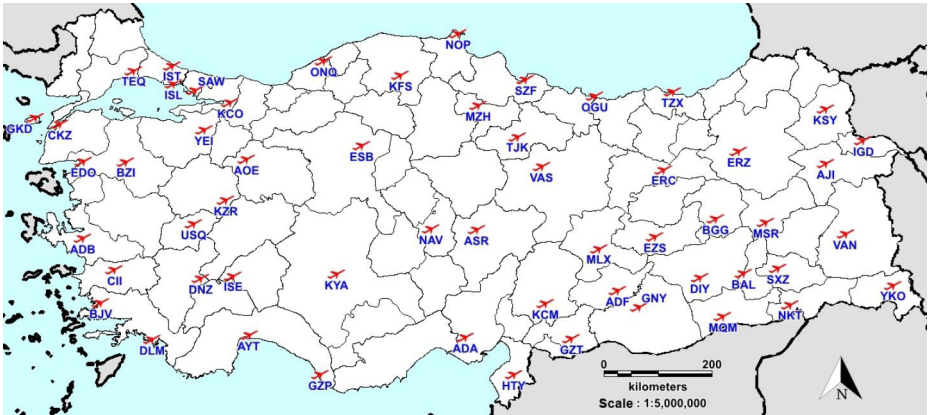


Fig. 1 Map of Turkish Airports at the end of 2020

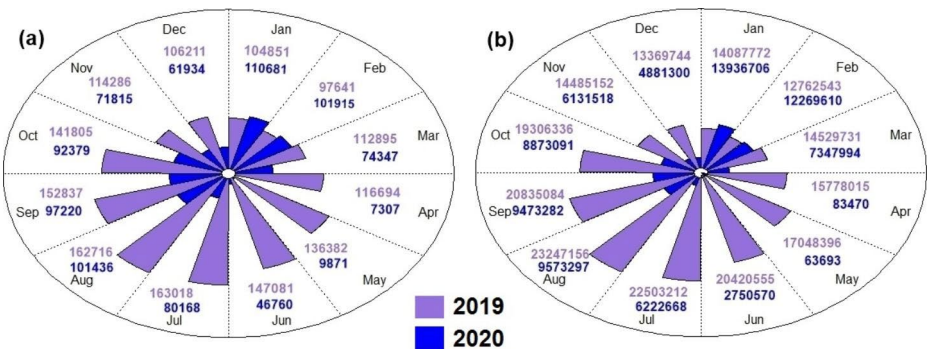


Fig. 2 (a) Number of flights and (b) number of passengers in Turkish airports for 2019 & 2020

2 Materials and methods

2.1 Aviation data

In Turkey, there exist 56 airports whose locations are represented in Fig. 1. Eight of them are served for only domestic flights in 2020, and the rest are used for both domestic and international flights. Flight and passenger data are downloaded from the website of the General Directorate of State Airports Authority of Turkey (GDSAA) for the years 2019 and 2020. Yearly total flight (commercial plus cargo flights) numbers are provided in Supplement 1. A total of 1,558,436 flights are made in 2019 at Turkish airports. The total number of flights has dropped to 857,853 in 2020 which indicates about a 45% reduction. The total number of passengers was 208,375,715 in 2019 while, only 81,609,219 passengers arrived in Turkey by airlines (61% decrease). The total number of flights and the total number of passengers arriving at Turkish airports are represented in Fig. 2 monthly for both years. Flight movements start to increase in May, highest in the summer months, and decrease in October regarding with tourism season in Turkey. With the spread of the Covid-19 pandemic and the



Fig. 3 Timeline of suspension and resumption of flights in Turkey in 2020

first reported case in Turkey, flight and passenger numbers abruptly dropped in the April - June period of 2020.

2.2 Covid-19 impacts on international flights and turkish tourism

Turkey is one of the leading destinations in tourism (UNWTO 2019). According to the tourism statistics published by the Turkish Ministry of Culture and Tourism, about 75% of international tourists prefer airlines to come to Turkey (MCT 2021). More than 45 million foreign tourists had come to Turkey in 2019. After the occurrence of the pandemic, some international flights are canceled to several countries. The first flight ban began on February 3 to China. Then, with the announcement of reported cases in Iran, commercial flights from and to Iran were suspended on February 23, 2020. After the spread of the pandemic to Europe, flights to and from Italy were called off. In March, Turkey started to suspend more flights in both directions in more countries as given in Fig. 3. The first case was reported in Turkey on 11 March 2020. To prevent the spread of the pandemic, Turkey started to cancel international flights. At the end of March, all international flights are suspended (Günay et al., 2020). As a result of travel bans, international tourist flow dramatically decreased (Table 1). International tourist arrivals were even devastating to Turkish tourism in April and May 2020 compared to 2019. To sustain tourism, the “Safe Tourism Certification Program” has been launched in May and became mandatory for accommodation facilities with 50 and more rooms (this number has been reduced to 30 at the beginning of 2021) (Zeydan & Gürbüz, 2021). Turkey has declared a “New Normal” starting from the 1st of June and has loosened some of the restrictions including travel bans. Flights to 31 countries have been started again on the 11th of June 2020. On the 1st of August, flights from Russia have been started. Russian flights were especially important in terms of Turkish tourism, as most foreign tourists came from Russia in 2020. At the end of 2020, the total number of international tourist arrivals was 12,734,213. This means that there was a 71% decrease in foreign tourist numbers in 2020 compared to 2019 (MCT 2021).

Table 1 International tourist arrivals to Turkey (2019–2020)

Months	International Tourist Arrivals		
	2019	2020	Change (%)
January	1,539,496	1,787,435	16.11
February	1,670,238	1,733,112	3.76
March	2,232,358	718,097	-67.83
April	3,293,176	24,238	-99.26
May	4,022,254	29,829	-99.26
June	5,318,984	214,768	-95.96
July	6,617,380	932,927	-85.90
August	6,307,508	1,814,701	-71.23
September	5,426,818	2,203,482	-59.40
October	4,291,574	1,742,303	-59.40
November	2,190,622	833,991	-61.93
December	2,147,878	699,330	-67.44
Total	45,058,286	12,734,213	-71.74

2.3 Risk perception and changing travel intentions

Perceived risk refers to the consumers' perception of all negative effects (expected damage or possible loss) of action beyond acceptable levels. Perceived risk in travel and tourism is the potential adverse outcomes that will happen in the case of the consumption of tourism products (Matiza & Kruger, 2021; Sonmez & Graefe, 1998) defined the dimensions of perceived risks in tourism as crimes, terrorism and political stability, equipment, financial, physical, psychological, satisfaction, social, time, and health risks. Health risks include being infected by a disease or feeling sick during traveling (Sujood et al. 2021). When tourists perceive health risks due to pandemics, avoidance behavior is observed (Sánchez-Cañizares et al., 2021). Tourists' intention to travel has decreased. Tourists may postpone or cancel their travels (Altınay Özdemir & Yıldız, 2020; Chua et al., 2021). Previous pandemics such as SARS and avian flu impacted the travel intention of tourists more than the financial crisis (Golets et al., 2021). Tourists also avoid crowds and mass tourism. They could prefer less populated destinations (Zenker & Kock, 2020). Travel intention may also be affected by the economic implications of the pandemic. Potential tourists may have a lower income or may completely lose their jobs during the pandemic, which may lead to not traveling (Altınay Özdemir & Yıldız, 2020). During the disease threat, tourists may tend to support local economies and may choose inbound destinations instead of international travel (Zenker & Kock, 2020). Furthermore, tourist may travel domestically because of the international flight restrictions. Additionally, travelers feel safer when choosing closer destinations (Ivanova et al., 2021). Because of the likelihood of infection, mass transit vehicles such as planes, ships, trains, and buses are not the preferred way of transportation. Personal cars seem to be the safest method of transportation (Page et al., 2006).

2.4 Emission inventory for aviation

An emission inventory is implemented for the years 2019 and 2020 to reveal the effects of the Covid-19 pandemic on aviation emissions in Turkey. There exist three approaches to the development of inventory: Tier 1, Tier 2, and Tier 3. The Tier 1 approach requires LTO fuel consumption. If information about aircraft types is available, Tier 2 methodology can

Table 2 Fuel consumption rates and emission factors for LTO activities

Flight type	Fuel Consumption (kg/LTO)	Pollutant Emission Factors (kg/LTO)							
		SO ₂	CO ₂	CO	NO _x	NM VOC	CH ₄	N ₂ O	PM _{2.5}
Domestic	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
International - Short Haul (<500 nm)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
International - Medium Haul (≥500 nm and ≤3000 nm)	1617	1.6	5094	6.1	26	0.2	0	0.2	0.15
International - Long Haul (>3000 nm)	3400	3.4	10,717	19.5	56.6	1.7	0.2	0.3	0.32

Note: 1 Nautical mile (nm)=1.852 kilometers (km)

be applied. In both methods, only LTO emissions at airports can be calculated. However, in the Tier 3 approach, in addition to LTO emissions, CCD emissions could be determined if the origin and destination of the flight are known (Tier 3 A) or if exact trajectory information is available (Tier 3B) (Kurniawan & Khardi, 2011). As stated in Sect. 2.1, flight data is obtained from GDSAA for the years 2019 and 2020. However, only the number of LTOs was available from GDSAA statistics. GDSAA does not provide any information about flight routes, flight numbers, or aircraft types. For this reason, the Tier 1 approach is implemented to calculate aviation emissions. Default Tier 1 emission factors and fuel consumption rates for the average fleet are obtained from EMEP/EEA Emission Inventory Guidebook 2013, published by European Environmental Agency (note that the latest version of this document does not provide Tier 1 emission factors). Fuel consumption rates and emission factors for LTO activities are listed in Table 2. The amounts of SO₂, CO₂, CO, NO_x, NMVOC, CH₄, N₂O, and PM_{2.5} emissions are determined for both domestic and international flights. The emissions of cargo flights are also included in the calculations. LTO fuel consumption and pollutant emissions are determined by using Eqs. 1 and 2 (EEA 2013; Kurniawan & Khardi, 2011).

$$LTO_{fuel} = \text{number of LTOs} \times \text{fuel consumption per LTO} \tag{1}$$

$$E_{pollutant} = AR_{fuel\ consumption} \times EF_{pollutant} \tag{2}$$

Where;

E_{pollutant}: annual emission of pollutant for each of the LTO and cruise phases of domestic and international flights,

AR_{fuel consumption}: activity rate by fuel consumption for each of the flight phases and trip types,

EF_{pollutant}: emission factor of pollutant for the respective flight phase and trip type.

As seen in Table 2, emission factors for international flights are classified into three categories: short, medium, and long hauls. Cruise distance shorter than 500 nm (926 km) is classified as short-haul whereas, long-haul flights have a cruise distance longer than 3000 nm (5556 km). To use these emission factors, flight distances must be known. International flight distances are retrieved from the Skyscanner website for the five busiest airports in the last week of 2020 (Skyscanner 2020). A total of 1846 flights were analyzed for 483 different routes. The flight ratios of short, medium, and long hauls are calculated and repre-

Table 3 The flight ratios of the five busiest airports for international flights (last week of 2020)

Departure Airport	Short Haul			Medium Haul			Long Haul		
	Routes	Flights	Flight Ratio	Routes	Flights	Flight Ratio	Routes	Flights	Flight Ratio
IST	32	135	10.7	259	994	79.1	36	127	10.1
SAW	10	42	9.0	95	425	91.0			
ESB				16	40	100.0			
ADB				9	12	100.0			
AYT	1	4	5.6	25	67	94.4			
Average of SAW, ESB, ADB, AYT			3.7			96.3			

Table 4 Fuel consumptions and LTO emissions of domestic flights in Turkish airports (2019 & 2020)

Year	Airport	Fuel C. (tonnes/year)	Domestic Flights' Emissions (tons/year)							
			SO ₂	CO ₂	CO	NO _x	NM VOC	CH ₄	N ₂ O	PM _{2.5}
2019	IST	68,007	65.9	214325.8	972.7	684.2	41.2	8.2	8.2	5.8
	SAW	111,542	108.2	351527.8	1595.4	1122.2	67.6	13.5	13.5	9.5
	ESB	65,069	63.1	205064.6	930.7	654.6	39.4	7.9	7.9	5.5
	ADB	49,227	47.7	155139.4	704.1	495.3	29.8	6.0	6.0	4.2
	AYT	42,500	41.2	133939.0	607.9	427.6	25.8	5.2	5.2	3.6
	Others	356,567	345.8	1123727.8	5100.0	3587.3	216.1	43.2	43.2	30.3
	Total	692,913	671.9	2183724.4	9910.7	6971.1	419.9	84.0	84.0	58.8
2020	IST	49,367	47.9	155581.4	706.1	496.7	29.9	6.0	6.0	4.2
	SAW	69,136	67.0	217882.6	988.9	695.5	41.9	8.4	8.4	5.9
	ESB	34,167	33.1	107676.4	488.7	343.7	20.7	4.1	4.1	2.9
	ADB	29,948	29.0	94380.0	428.3	301.3	18.2	3.6	3.6	2.5
	AYT	24,754	24.0	78013.0	354.1	249.0	15.0	3.0	3.0	2.1
	Others	267,220	259.1	842147.8	3822.1	2688.4	162.0	32.4	32.4	22.7
	Total	474,591	460.2	1495681.2	6788.1	4774.7	287.6	57.5	57.5	40.3
% Decrease	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	

sented in Table 3. These ratios are used in emission calculations. It was witnessed that, long haul international flights only departed from İstanbul Airport (IST). The short, medium, and long-haul ratios for IST are determined as 10.7%, 79.1%, and 10.1%, respectively. For other airports, most of the flights are medium-haul. Excluding IST and taking the averages of the four busiest airports, flight ratios of short and medium hauls are calculated as 3.7% and 96.3%, respectively. These two ratios are implemented for the rest of the airports.

3 Results and discussion

3.1 Emission inventory results

The results of the emission inventory are given for domestic and international flights separately in Tables 4 and 5. Fuel consumption values and emissions amounts are given for the five busiest airports in Turkey. The sum of other airports' emissions is listed as others. Total emissions and fuel consumption rates are provided separately for each airport in Supple-

Table 5 Fuel consumptions and LTO emissions of international flights in Turkish airports (2019 & 2020)

Year	Airport	Fuel C. (tones/year)	International Flights' Emissions (tons/year)							
			SO ₂	CO ₂	CO	NO _x	NM VOC	CH ₄	N ₂ O	PM _{2.5}
2019	IST	423,347	419.4	1333840.0	1993.9	6723.9	94.9	7.6	49.3	39.2
	SAW	155,367	153.6	489456.9	664.7	2453.2	22.8	0.9	19.2	14.4
	ESB	32,940	32.6	103769.9	124.3	529.6	4.1	0	4.1	3.1
	ADB	38,672	38.3	121828.1	145.9	621.8	4.8	0	4.8	3.6
	AYT	253,201	250.4	797663.0	1033.5	4026.5	34.9	0.9	31.3	23.4
	Others	259,195	256.4	816541.1	1030.3	4137.6	34.5	0.6	32.0	24.0
	Total	1,162,721	1150.6	3663099.0	4992.5	18492.7	195.9	10.1	140.7	107.6
2020	IST	215,214	213.2	678074.5	1013.6	3418.2	48.2	3.9	25.1	19.9
	SAW	65,749	65.0	207130.8	281.3	1038.2	9.7	0.4	8.1	6.1
	ESB	14,490	14.3	45647.3	54.7	233.0	1.8	0	1.8	1.3
	ADB	15,680	15.5	49396.5	59.2	252.1	1.9	0	1.9	1.5
	AYT	64,787	64.1	204098.8	264.4	1030.3	8.9	0.2	8.0	6.0
	Others	83,160	82.3	261980.2	330.6	1327.5	11.1	0.2	10.3	7.7
	Total	459,080	454.4	1446328.1	2003.7	7299.2	81.6	4.7	55.2	42.5
% Decrease	60.5	60.5	60.5	59.9	60.5	58.3	53.3	60.8	60.5	

ment 2. According to Table 4, the annual rate of fuel consumption for domestic flights in 2019 is found to be 692,913 tons/year. For the year 2020, it is determined as 474,591 tons/year. In 2019, LTO-related SO₂, CO₂, CO, NO_x, NMVOC, CH₄, N₂O, and PM_{2.5} emissions are determined as 671.9 tons/year, 2183724.4 tons/year, 9910.7 tons/year, 6971.1 tons/year, 419.9 tons/year, 84.0 tons/year, 84.0 tons/year, and 58.8 tons/year, respectively. For the same pollutants, the emission amounts are calculated as 460.2 tons/year, 1495681.2 tons/year, 6788.1 tons/year, 4774.7 tons/year, 287.6 tons/year, 57.5 tons/year, 57.5 tons/year, and 40.3 tons/year in 2020. In domestic flights, both fuel consumption and LTO emissions amounts are reduced by 31.5% in 2020 compared to 2019. İstanbul Sabiha Gökçen Airport (SAW) has the highest contribution in emissions in terms of domestic flights in 2019. İstanbul (IST) and Ankara Esenboğa (ESB) Airports follow SAW. İzmir Adnan Menderes (ADB) and Antalya (AYT) Airports have 4th and 5th ranks in emission amounts. In 2019, the contribution of these five busiest airports to the LTO emissions of domestic flights is about 49%. For 2020, the ranking of airports in terms of pollution amounts remains the same for the five busiest airports. However, their contribution to LTO emissions is determined as 44%. Therefore, it can be concluded that some of the air traffic in domestic flights moved from these airports to others in 2020. Changing flight schedules and travel restrictions due to the Covid-19 pandemic may be the reason for this shift. Furthermore, people may avoid using crowded airports due to perceived health risks. Smaller airports may be chosen in case of direct flights are available (Page et al., 2006).

For LTO activities of international flights, the annual fuel consumption rates are determined as 1,162,721 tons/year and 459,080 tons/year for 2019 and 2020, respectively (Table 5). The amount of total fuel consumed on international flights is decreased by 60.5% due to the Covid-19 travel restrictions and changes in travel behavior. In 2019, LTO-related SO₂, CO₂, CO, NO_x, NMVOC, CH₄, N₂O, and PM_{2.5} emissions from international flights are calculated as 1150.6 tons/year, 3663099.0 tons/year, 4992.5 tons/year, 18492.7 tons/year, 195.9 tons/year, 10.1 tons/year, 140.7 tons/year, and 107.6 tons/year, respectively. In 2020, 454.4 tons SO₂, 1446328.1 tons CO₂, 2003.7 tons CO, 7299.2 tons NO_x, 81.6 tons

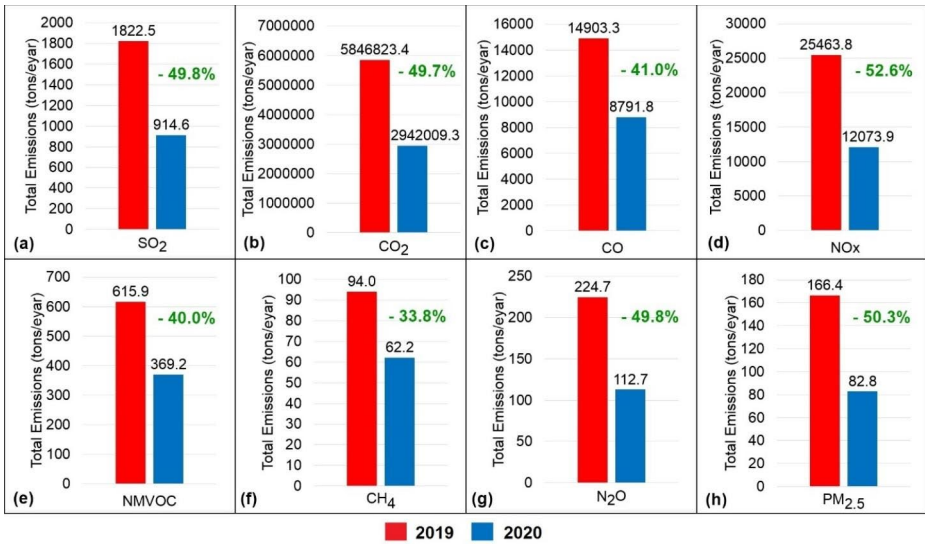


Fig. 4 Comparison of 2019 and 2020 total LTO emissions (tons/year) of SO₂ (a), CO₂ (b), CO (c), NO_x (d), NMVOC (e), CH₄ (f), N₂O (g) and PM_{2.5} (h)

NMVOC, 4.7 tons CH₄, 55.2 tons N₂O, and 42.5 tons PM_{2.5} are released to the atmosphere due to the LTO related activities. In international flights, about 60% reduction occurred in emissions except for CH₄. Emission reduction amounts for international flights are nearly two times higher than that of domestic flights. So, it can be deduced that international flights are more affected by travel bans or restrictions because of the pandemic. IST has most of the international air traffic among the Turkish airports. Also, long-haul flights depart from only IST. For these reasons, IST airport has the highest fuel consumption rate and emissions in both years. Antalya Airport (AYT) has the second rank in terms of fuel consumption and LTO-related pollutant emissions in 2019, whereas AYT dropped to the third place and came after SAW in 2020. Antalya is the leading city in Turkish tourism and AYT Airport plays an important role in reaching this destination. So, one can conclude that the international tourist flow to Antalya had been affected dramatically by the Covid-19 travel restrictions and the changes in tourist travel intentions in 2020. The contribution of the five busiest airports in international flights' LTO emissions is approximately 78% except NMVOC (82%) and CH₄ emissions (94%) in 2019. Their contribution to emissions has risen to about 82% apart from NMVOC (86%) and CH₄ emissions (96%) in 2020. Therefore, it can be said that international flights have shifted from other airports to these five airports.

The total amount of fuel consumption for LTO activities, including domestic and international flights in 2019 was 1,855,634 tons. This value dropped to 933,671 tons in 2020 showing a 49.7% reduction. The sum of domestic and international LTO emissions of Turkish airports is represented in Fig. 4 for 2019 and 2020. The red color shows the total emission amounts in 2019 whereas emissions for 2020 are given in blue color. In addition, emission reduction ratio is written in green text. The annual amount of SO₂ released from LTO activities is 1822.5 tons in 2019. On the other hand, in 2020 the total SO₂ emission is calculated as 914.6 tons which indicates a 49.8% reduction (Fig. 4-a). In 2019, 5846823.4 tons of CO₂ are emitted into the atmosphere from LTO activities, while this amount decreased to

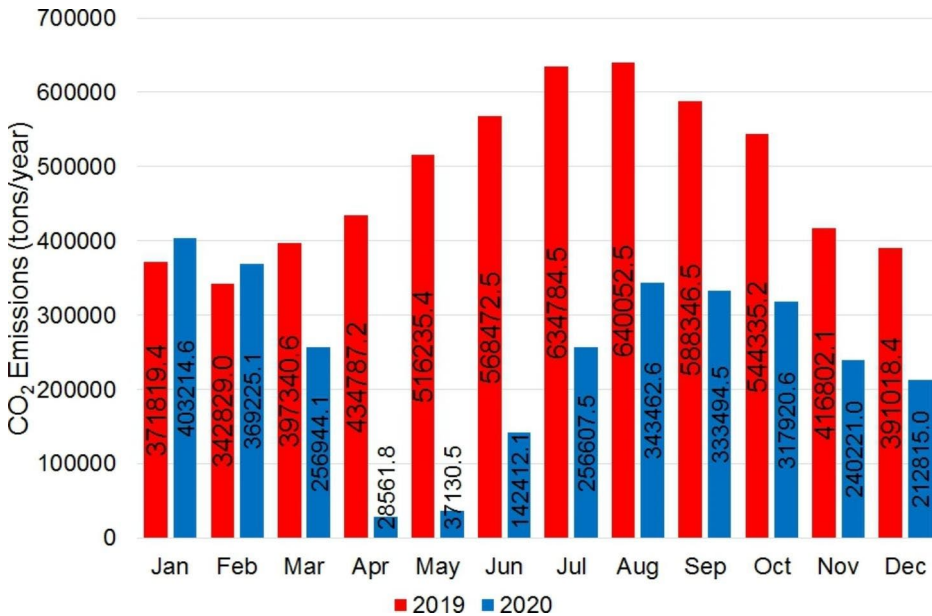


Fig. 5 Total CO₂ emissions (tons/year) in 56 Turkish airports for 2019 and 2020

2942009.3 tons in 2020 (49.7% decrease) (Fig. 4-b). The CO emission amount dropped by 41.0% in 2020 (8791.8 tons) as compared to the 2019 level (14903.3 tons) (Fig. 4-c). The highest reduction amount is observed for NO_x emissions by 52.6%. In 2019, LTO-related NO_x emission is 25463.8 tons, whereas it is determined as 12073.9 tons in 2020 (Fig. 4-d). The total NMVOC emission is reduced by 40.0% in 2020 (369.2 tons) compared to that of 2019 (615.9 tons) (Fig. 4-e). The lowest amount of emission reduction is calculated for CH₄ emission by 33.8%. 94.0 tons of CH₄ is released into the atmosphere because of LTO activities in 2019, while this amount decreased to 62.2 tons in 2020 (Fig. 4-f). The total N₂O emission amount is reduced from 224.7 tons in 2019 to 112.7 tons representing a 49.8% fall (Fig. 4-g). Lastly, LTO-related PM_{2.5} emissions decreased by 50.3% in 2020. The calculated amounts of PM_{2.5} emissions are 166.4 and 82.8 tons annually for the years 2019 and 2020, respectively (Fig. 4-h).

3.2 Impacts of Covid-19 pandemic on aviation emissions

So far, annual amounts of emissions have been discussed. To better understand the impacts of the Covid-19 pandemic on aviation emissions, this section provides monthly CO₂ emissions. The total CO₂ emissions at 56 Turkish airports are provided in Fig. 5 for 2019 and 2020. The number of flights and resulting emissions in Turkey are quite related to the country's tourism movements. Karamustafa & Ulama (2010) reported that international tourist arrivals show one-peak seasonality in the summer months for Turkey. Accordingly, aviation emissions represent a similar pattern in 2019. However, the data for 2020 are completely different. In March 2020, with the reported Covid-19 cases in Turkey and due to flight bans, emissions started to decrease. All commercial passenger flights were suspended on March

28. In April and May, apart from cargo flights, some necessary flights have been performed for the evacuation of Turkish citizens working or studying abroad. For these reasons, CO₂ emissions were at the lowest values in April and May. Ekici et al., (2021) found that more than 99% decrease in both domestic and international flights' emissions for the same period. Our results are in line with their findings. As represented in Fig. 5, about a 93% emission drop has been observed in total CO₂ emissions for April and May 2020. The 6% difference between these two studies may be the result of the selection of datasets. Ekici et al., (2021) included only the flight activity of Turkish Airlines (the largest fleet in Turkey), however, we used the entire LTO data published by GDSAA. The total CO₂ reductions are 87% and mainly because of travel restrictions in the Q2 period of 2020 compared to 2019. In the Q3 and Q4 periods of 2020, travel restrictions were relaxed, and flight traffic rebounded to a certain level but lower than 2019 levels. Consequently, the decreases in total CO₂ emissions are 50% and 43% in Q3 and Q4, respectively. Some other studies in the literature mentioned similar findings. For example, a study conducted in China indicated that fuel consumption and emissions of CO₂, SO_x, NO_x, and CO dropped by about 62% in Q1 and Q2 of 2020 compared to the same quarter of the previous year. In Q3 and Q4 of 2020, reduction ratios of fuel consumption and emissions of CO₂ and SO_x were approximately 17% and 13% compared to that of 2019, respectively. The decrease in NO_x and CO emissions was slightly lower (Xue et al., 2021). In another study, Hu et al., (2021) examined the emissions in China between 1 and 2020 and 29 February 2020. They reported that aviation activity decreased by 52% and 71% during the lockdown and resumption periods, respectively when compared to pre-lockdown duration.

In order not to lose tourism revenue, a "New Normal" has been declared in Turkey starting on 1 June 2020. With the new normal, the travel restrictions have been loosened. On 11 June, flights to 31 countries have started again. Therefore, changes in emissions in Q2 (March, April, and May) can be explained by travel restrictions. However, travel restrictions are not the only cause of emission reductions in the Q3 and Q4 periods of 2020. Ekici et al., (2021) mentioned that international flights in July and August did not increase much depending on the tourism demand in Turkey. This situation can be explained by the risk perception of tourists and changing travel intentions (Chua et al., 2021; Ivanova et al., 2021).

There exist many studies focusing on travel intention during the Covid-19 era. Bratić et al., (2021) stated that Covid-19 risk perception affects vacation plans, including not traveling at all. Liu et al., (2021) reported that the perception of Covid-19 has a significantly negative impact on the post-pandemic outbound travel intention of Chinese residents. Sujood et al. (2021) mentioned that perceived risk negatively impacted travel intention. The travel intentions of Brazilians are negatively impacted by perceived Covid-19 severity and perceived probability of infection (Golets et al., 2021; Seong & Hong, 2021) stated that the number of visitors to national parks in Korea has dropped in 2020 compared to 2019 because of Covid-19 risk perception. A survey performed in Malaysia indicated that perceived travel risk has a direct and negative effect on travel intention (Aziz & Long, 2021). Another study conducted in Turkey revealed that Covid-19 risk perception has a negative impact on travel intention (Garipağaoğlu Uğur et al., 2021). Turkey did not apply quarantine periods for international tourists, and this also caused domestic tourists not to travel (Yenişehirlioğlu & Salha, 2020). Bratić et al. 2021 revealed that due to Covid-19 some tourists plan to travel only domestically. In the light of cited literature, it can be deduced that Covid-19 risk perception negatively impacted tourists' travel intentions. Although travel restrictions were relaxed in the

Q3 and Q4 of 2020 in Turkey, potential tourists did not intend to travel due to Covid-19 risk perception and this resulted in lower emissions in flights.

Till the end of 2020, Covid-19 vaccines (especially mRNA-based ones) were in the development stage and most of the world population was unvaccinated. The first vaccine was applied in Turkey on 14 January 2021. Then, a mass vaccination campaign was initiated accordingly. It is reported that travel and vacation inquiries raised about 25% in Denver, the USA after vaccination (Zaman et al., 2021). Recent studies indicated that trust in the vaccine decreased the perceived risk of Covid-19 and increased travel intention (Fan et al., 2022; Kırlar-Can & Ertaş, 2022). Additionally, the safe travel certification programs applied by airlines may increase the trust and change the travel intention of tourists. For example, Çetin & Coşkuner (2021) mentioned that Turkish Airlines received the “Diamond Health and Safety” status from APEX (Airline Passenger Experience Association) and SimpliFlying assessment, and this could increase the confidence levels of passengers. The number of passengers in Turkish Airlines started to increase in the first half of 2021 and doubled in the second half of 2021 (Supplement 3).

4 Conclusion

Travel and air transportation are among the sectors most affected by the Covid-19 pandemic. To prevent the spread of the virus, travel bans, and force lockdowns have been implemented and this resulted in immediate emission reductions. Before this paper, the work of Ekici et al., (2021) examined the emission changes in Turkey until August 2020 with some assumptions. In our study, LTO changes emissions due to the Covid-19 pandemic in 56 Turkish airports are investigated. To the best of our knowledge, this paper is the most detailed study which indicates the impacts of the Covid-19 pandemic on aviation emissions in Turkey. According to the result of this study, total LTO-related emissions of SO₂, CO₂, CO, NO_x, NMVOC, CH₄, N₂O, and PM_{2.5} have decreased in 2020 compared to 2019 by 49.8%, 49.7%, 41.0%, 52.6%, 40.0%, 33.8%, 49.8%, and 50.3%, respectively. The total CO₂ reductions in the Q2, Q3 and Q4 periods of 2020 compared to that of 2019 are 87%, 50%, and 43%, respectively. Travel restrictions played an important role in the emission reductions in Q2, and the change in travel intention due to the perception of Covid-19 risk is the main cause of emission reductions in Q3 and Q4 of 2020.

As mentioned by Gössling et al., (2021), the pandemic has resulted in an unexpected reduction in aviation emissions. The main reasons for this decline are travel bans and travel intention changes of tourists. When the pandemic is over, flight numbers and, accordingly, emissions may rebound and return to pre-pandemic levels (Gössling & Lyle, 2021). Aviation emissions can be reduced by operational improvements to minimize LTO time at airports (Kesgin, 2006), using alternative jet fuels (Masiol & Harrison, 2014), applying transportation policies (Gössling & Lyle, 2021), and renewing the fleet (Pham et al., 2010). Also, behavioral changes of consumers such as flight avoidance, choosing other ways of transport, and carbon offsetting may help to decrease aviation-related emissions (Gössling & Dolnicar, 2022).

4.1 Policy implications

During the first two years of the global pandemic, the perception of Covid-19 risk has led travelers to avoid or cancel their vacations even during the relaxation periods of travel restrictions. To avoid losing customers, airline companies should implement safety and hygiene protocols. Also, trust plays an important role in tourism and travel marketing. To minimize risk perception during the pandemic period, airline companies should increase the passengers' trust. Trust increases when passengers feel safe during travel. This is achieved by ensuring social distancing and providing hygienic conditions. Taking passengers to the plane according to their seat numbers, leaving empty seats among passengers, and increasing the number of kiosks (touch screens) for check-in will reduce the contact of passengers. Disinfecting the aircraft after each flight, giving a hygiene kit to passengers during boarding, announcing changing the air filter on the plane, and the cabin crew wearing masks will make the passengers feel safe (Semercioğlu & Abay, 2021).

4.2 Limitations

This present study has certain limitations. First, it is limited by its geographical scope. It has been performed in Turkey and for the years 2019 and 2020. Only the LTO emissions of Turkish airports were included in the calculations. Climb, Cruise, and Descent emissions of aircraft were excluded in this study. During inventory calculations, default Tier 1 emissions factors were used. These emissions factors assume certain taxi times. Any deviations from default times were not considered in this study. The results are only applicable to Turkish airports. Therefore, it cannot be generalized to any other airport. Moreover, travel intentions are only valid for passengers coming to / going from Turkey and traveling inside Turkey. The cultural differences of travelers should be taken into account for other countries.

4.3 Further studies

In this paper, we only focused on the 2019 and 2020 years, and emission changes are calculated accordingly. However, the Covid-19 pandemic has affected the world also in 2021 and 2022. For this reason, similar emission inventory calculations are required for these years. Additionally, travel intention changes of travelers need further investigations. For example, virtual meetings have already replaced some air travel. Will it be the same after the pandemic and what will be the impact of this shift on aviation emissions? The change in travel intention in the era of the post-pandemic period is a quite important topic that should be focused on. Furthermore, the effect of vaccination on travel intentions needs further studies. Similarly, the effect of the safe travel policies implemented by airline companies should also be examined.

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Declarations

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