Heathrow Airport Airfield Emission Inventory 2021

Report for Heathrow Airport Limited

ED16779 | Issue Number 1 | Date 20/10/2023

Customer:

Heathrow Airport Limited

Customer reference:

HAL1008237PO

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20 October 2023

Ricardo Energy & Environment reference:

Ref: ED16779- Issue Number 1

Table of contents

Glossary

APU Auxiliary Power Unit

ATM Air Transport Movement

BA British Airways

AUWR All Up Weight Return – Heathrow's database that provides information on aircraft engine fits and maximum take-off weights

CAEP Committee on Aviation Environmental Protection

CO_2 Carbon dioxide

EFPS Electronic Flight Processing Strips

GSE Ground Support Equipment

HGV Heavy Goods Vehicle

ICAO International Civil Aviation Organisation

LTO Landing and Take-Off

LGV Light Goods Vehicle

mppa million passengers per annum

NAEI National Atmospheric Emissions Inventory

NATS National Air Traffic Services

NO_x Nitrogen Oxides

NTK Noise and Track-Keeping

nvPM non-volatile Particulate Matter

OPR Overall Pressure Ratio

OSI Operational Safety Instruction

PCA Pre-Conditioned Air

PM Particulate Matter

PM_{10} Inhalable particles with diameters that are generally 10 µm and smaller

$PM_{2.5}$ Inhalable particles with diameters that are generally 2.5 µm and smaller

1 Introduction

This report presents the results of an emission inventory study of Heathrow Airport for the year 2021, concentrating on airfield emissions. It is based on the methodology of an inventory and dispersion modelling study for 2013[i] and it aligns with inventories for 2015 to 2018 that were produced for the Airport Expansion Consultation[ii] and developed further to include inventories for 2019 to 2020 for annual "Business as Usual" reporting[iii].

In line with the Heathrow Expansion project inventories, this assessment encompasses all airfield sources including:

- Aircraft and APU
- Ground Support Equipment (GSE)
- Stationary sources (heating plant and Fire training ground)

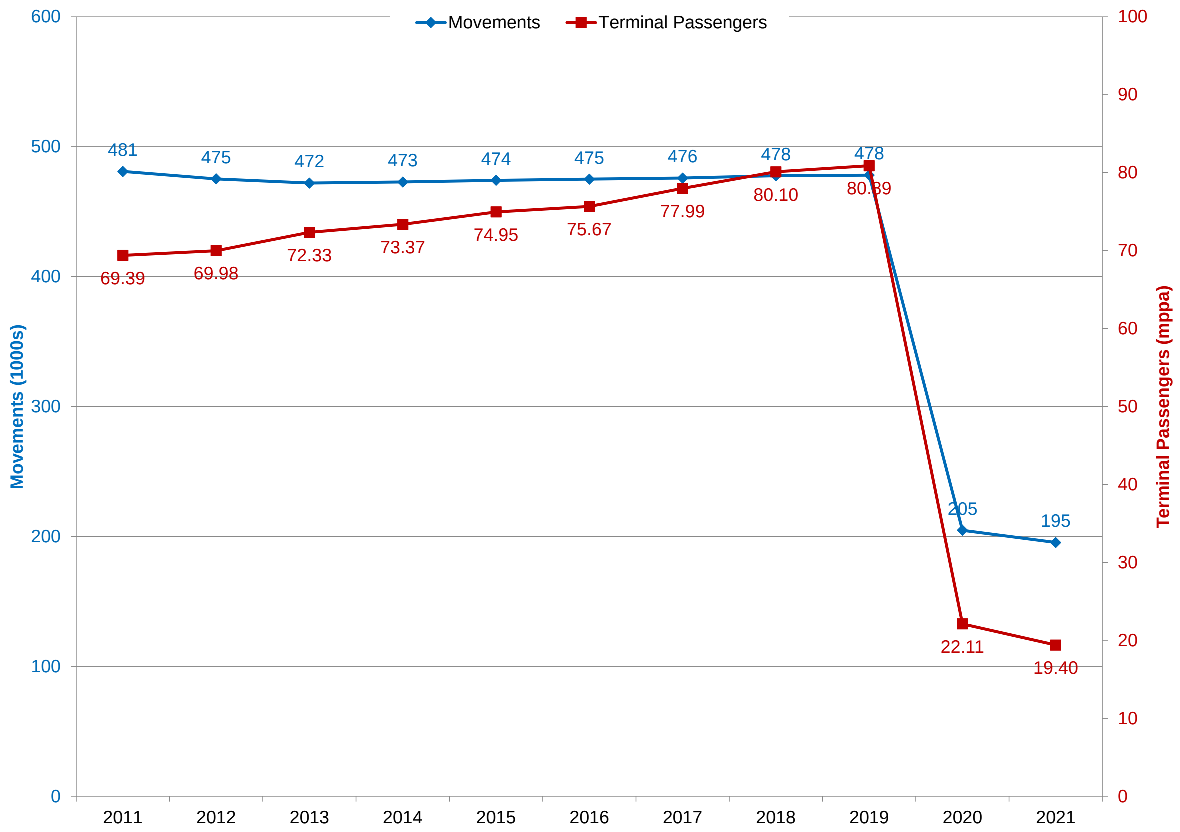
The Heathrow Expansion project also assessed emissions from surface access, including the airport car parks and landside road network. However, these sources are beyond the scope of this study.

2 Input data

2.1 Movements and passenger numbers

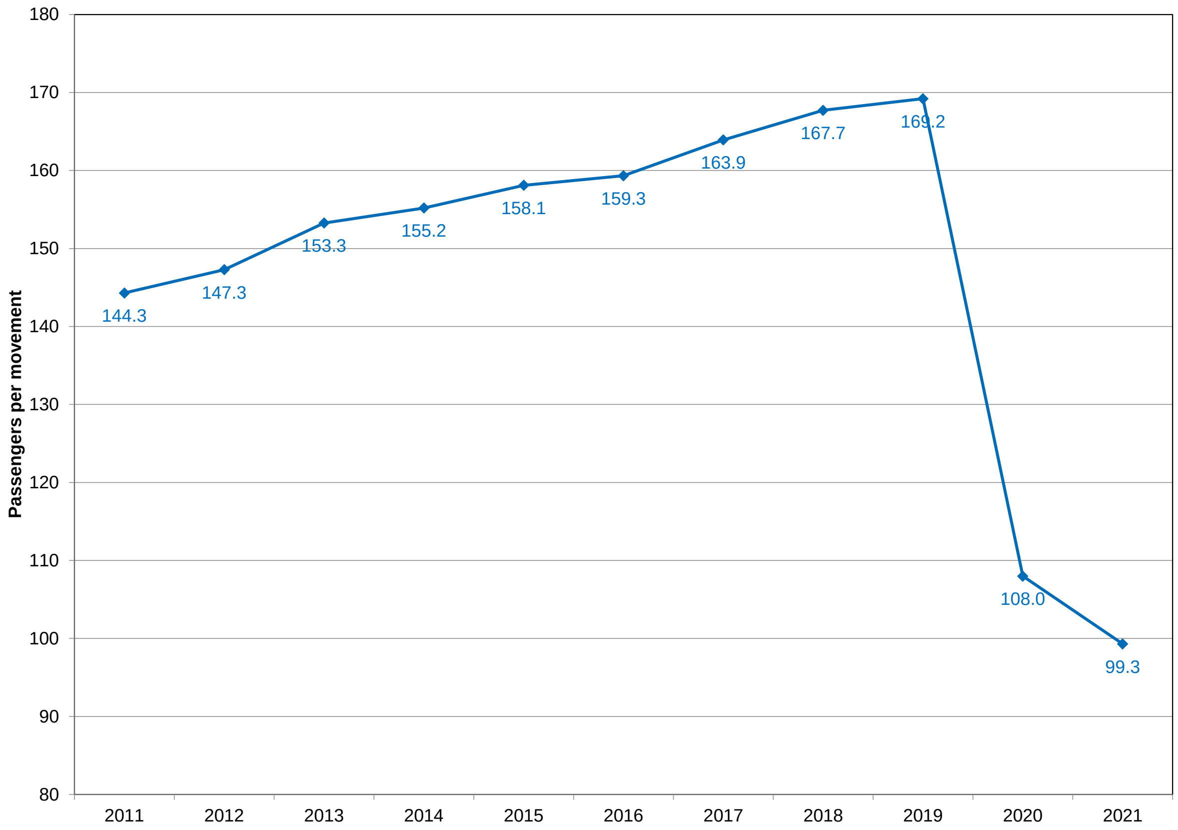
Figure 1 shows the trend in the number of aircraft movements and passengers over the last ten years. Up until 2019, the number of aircraft movements remained broadly constant, reflecting the fact that the airport was operating close to maximum capacity. However, the number of passengers rose steadily over the same period, accommodated by a larger number of passengers per movement on average (Figure 2). In 2020, there was a dramatic downturn in both movements and passengers due to the COVID-19 pandemic. This downturn continued into 2021. Figure 2 also shows a dramatic downturn in passengers per movement in 2020, which also continued into 2021. This reflects the reduced passenger load factors seen during the pandemic.

Figure 1 Aircraft movement[1] and passenger numbers[2]



[1] ATMs and non-ATMs
[2] Terminal passengers

Figure 2 Average number of passengers[1] per movement[2]



[1] Terminal passengers
[2] ATMs and non-ATMs

2.2 Aircraft data

Aircraft movement data were provided by Heathrow Airport as an extract from their Power BI/HDS information. For each aircraft movement, the following data fields are used in the emission inventory calculations:

- aircraft registration number (which allows an engine type to be assigned to the movement)
- flight date and time (which allows effects of meteorological parameters on emissions to be calculated)
- runway identifier and whether arrival or departure
- stand number

The last two items are used to determine taxiing and other times-in-mode.

The inventory includes emissions from both Air Transport Movements (ATMs) and non-ATMs (for example, positioning movements and private flights).

Table 1 gives a breakdown of the movements by aircraft type for each year 2015 to 2021.

Table 1 Aircraft movements[1] by aircraft type: 2015 to 2021

Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	3,586	2,504	4,268	5,189	9,407	2,387	1,906
Medium	294,843	289,774	284,982	284,151	283,738	108,913	95,058
A318/A319	84,352	81,196	81,371	80,179	72,503	27,334	18,686
A320	141,169	140,303	141,347	141,556	142,594	55,842	55,137
A321	42,765	43,040	38,541	39,283	48,171	16,721	12,269
B737	18,376	18,712	15,174	14,003	10,758	4,836	5,175
Others	8,181	6,523	8,549	9,130	9,712	4,180	3,791
Heavy	160,869	164,435	168,182	171,739	168,919	88,951	96,046
A350	58	714	2,809	5,037	7,571	10,503	12,261
B747	25,662	20,668	20,564	20,277	18,893	4,473	1,134
B767	28,342	25,949	23,749	16,575	9,191	3,583	3,760
B777	62,611	61,241	61,306	63,234	60,611	30,521	30,963
B787	15,601	27,591	36,484	41,266	45,423	29,772	35,388
Other	28,595	28,272	23,270	25,350	27,230	10,099	12,540
A380	14,826	18,265	18,483	16,696	15,996	4,481	2,330
Total	**474,124**	**474,978**	**475,915**	**477,775**	**478,060**	**204,732**	**195,340**

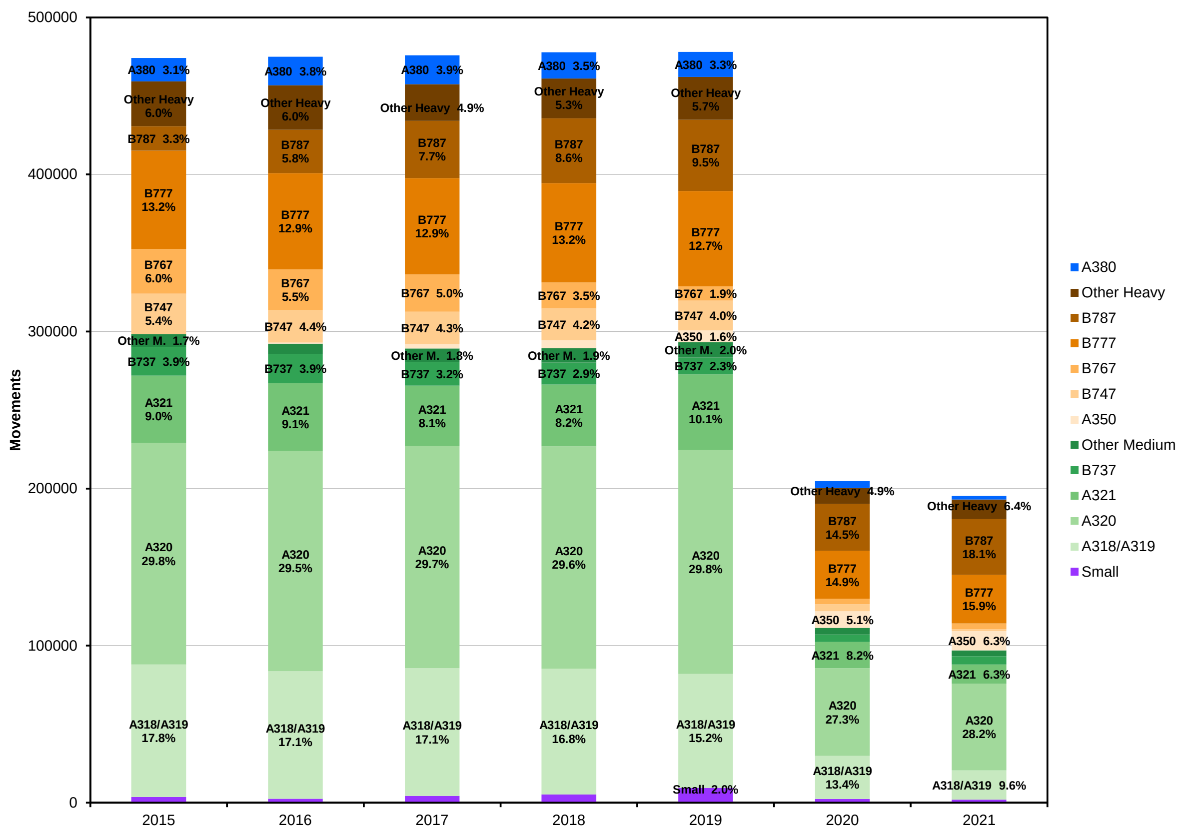
[1] ATMs and non-ATMs

Figure 3 shows the trend in the number of aircraft movements broken down by aircraft type. There have been some significant changes to the fleet mix between 2015 and 2021. The Boeing 787 (B787) has increased its share from 3.3% of the movements in 2015 to 18.1% of the movements in 2021. Also, the A350 entered the fleet in 2016 and in 2021 had a 6.3% share of the movements. These increases appear to have been partially at the expense of the Boeing 767 (B767), whose share has reduced from 6.0% in 2015 to 1.9% in 2021 and the Boeing 747 (B747), whose share has reduced from 5.4% in 2015 to 0.6% in 2021. However, there has been a general shift from medium sized aircraft to heavies[1]. In 2015 medium sized aircraft represented 62.2% of the fleet and heavies

[1] In essence, medium-sized aircraft are single-aisle airliners, excluding regional jets and turboprops, while heavies are twin-aisle airliners. The most common types under each category are shown in Table 1

(excluding the A380) represented 33.9%. By 2021 the medium share had reduced to 48.7% and heavies (excluding the A380) had increased to 49.2%. It should be acknowledged that movement numbers in both 2020 and 2021 were heavily affected by the COVID-19 pandemic. However much of the changes to the fleet were also evident in 2019. The shift towards a heavier fleet can be seen in the data to 2019 that are presented in Figure 2 (average passengers per movement). The 2020 and 2021 data in Figure 2 are affected by reduced passenger load factors to such an extent that the shift towards a heavier fleet is concealed.

Figure 3 Number of movements[1] by aircraft type: 2015 to 2021

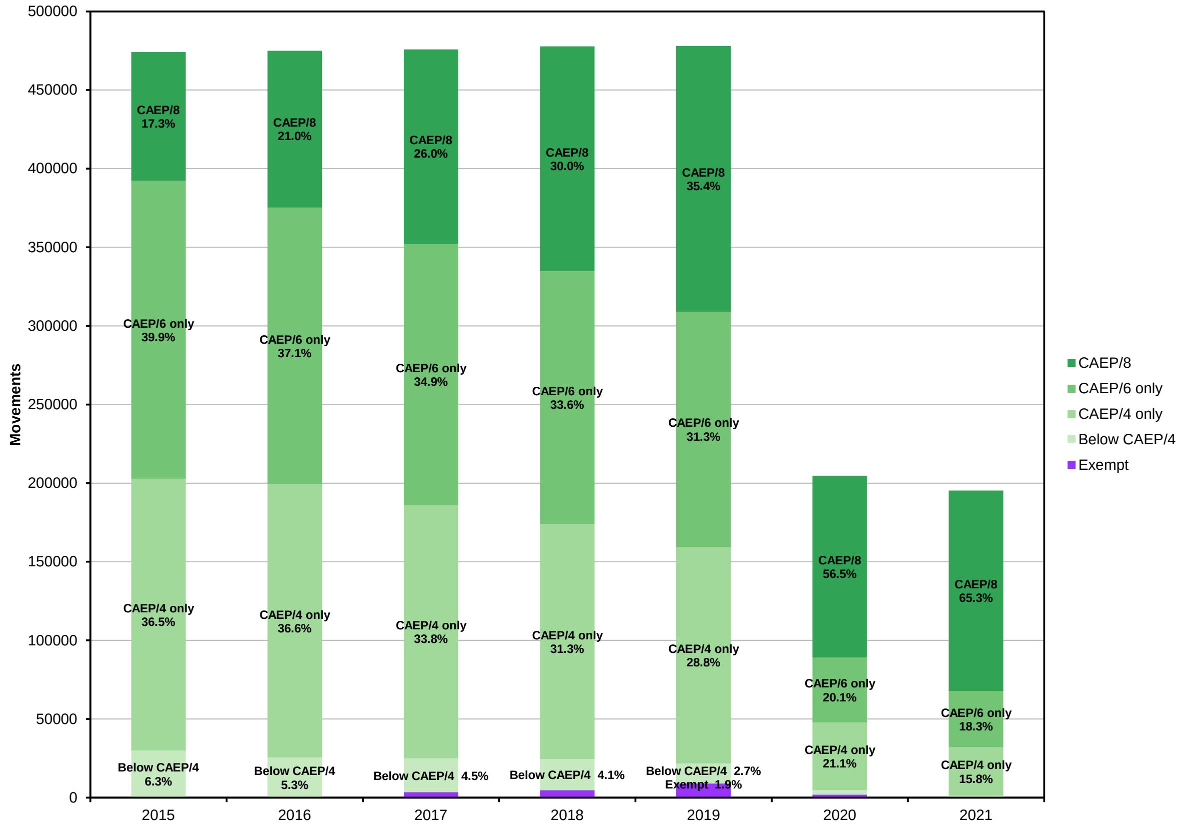


[1] ATMs and non-ATMs

2.3 Engine assignment

Aircraft engine assignments have been taken directly from the airlines via Heathrow's AUWR database. Figure 4 shows the trend in the number of movements by aircraft meeting the various CAEP emission standards.

Figure 4 Total movements[1] by CAEP standard[2]



[1] ATMs and non-ATMs
[2] "CAEP/4 only" means engines that meet the CAEP/4 standard but not the CAEP/6 standard. Similarly, "CAEP/6 only" means engines that meet the CAEP/6 standard but not the CAEP/8 standard. Jet engines below 26.7 kN (6,000 lb) thrust and turboprops are exempt from the CAEP regulations.

Up until 2019, these results show a continuing trend of an increasing number of aircraft that meet the most recent CAEP NO_x standards (CAEP/6 and CAEP/8) and a reducing number of aircraft that only meet the older standard (CAEP/4). This is the natural result of normal fleet replacement as more modern aircraft are more likely to meet the latest standards. (All newly manufactured jet engines[2] since 1st January 2013 must comply with the CAEP/6 standard, while all new jet engine[2] types since 1st January 2014 must comply with the CAEP/8 standard). In 2020 and 2021 there is a significant increase in the percentage of aircraft meeting CAEP/8, indicating a selective removal of older aircraft as demand reduced due to the COVID-19 pandemic.

Between 2016 and 2019 there is also a noticeable increasing number of exempt aircraft. This reflects growth in the number of turboprop aircraft, which are not covered under the CAEP regulations. This trend did not continue into 2020 and 2021, apparently due to the demise of De Havilland Canada Dash 8 aircraft movements on domestic routes.

[2] Rated 26.7 kN (6,000 lb) thrust and above

2.4 Times in mode

2.4.1 Ground-based modes

Taxiing times for are taken from Heathrow's ground radar system OPAS. In previous years similar data were extracted from a NATS database that was populated using electronic flight processing strips (EFPS).

For departures, the OPAS data recorded times of off-blocks, runway entry, start of roll and wheels up to a precision of 1 second. Unlike the EFPS data used in previous years, the OPAS data did not distinguish taxi-out from hold. Therefore taxi-out, hold and line-up times have now been combined. Taxi-out and hold times were obtained by subtracting the off-blocks times from runway entry times. Similarly, line-up times were obtained by subtracting the runway entry times from the from the start of roll times. Additionally, take-off roll times[3] were obtained by subtracting the start of roll times from the wheels up.

For arrivals, the OPAS data recorded times of touchdown, runway exit and on-blocks to a precision of 1 second. Taxi-in times were obtained by subtracting the runway exit times from the on-blocks times. Similarly, landing-roll times[4] were obtained by subtracting the touchdown from the runway exit times.

It was possible to match the vast majority of departures with an OPAS record so that they had individual taxi-out and hold and take-off roll times, and similarly, for arrivals so that they had individual taxi-in and landing roll times. For the other movements that could not be matched, times were taken from tables of times by runway/apron combination derived by averaging the OPAS data.

Table 2 shows taxi-in times derived from data for the years 2015 to 2021, by runway and terminal. Table 3 shows similar data for taxi-out and hold (including line-up) combined.

Table 2 Aircraft taxi-in times: 2015 to 2021

Runway	Terminal	Taxi-in (s)						
		2015	2016	2017	2018	2019	2020	2021
09L	T1[a]	256	300	N/A	N/A	N/A	N/A	N/A
09L	T2	449	421	449	474	476	431	360
09L	T3	426	438	469	504	494	449	397
09L	T4	732	707	718	741	737	550	534
09L	T5	495	473	463	533	502	453	464
09L	Cargo	709	684	681	757	764	584	597

[3] Previously, sample OPAS data were analysed to provide average take-off roll time by aircraft type and runway block (with the latter being required to account for intersection take-offs)

[4] Previously, sample OPAS data were analysed to provide average landing roll times by aircraft type and runway exit block.

Runway	Terminal	Taxi-in (s)						
		2015	2016	2017	2018	2019	2020	2021
09R	T1[a]	452	489	N/A	N/A	N/A	N/A	N/A
09R	T2	332	334	328	363	346	340	270
09R	T3	442	450	490	472	472	429	321
09R	T4	297	292	296	296	284	314	212
09R	T5	603	599	656	630	598	520	448
09R	Cargo	340	288	308	336	292	373	282
27L	T1[a]	513	581	3062	N/A	N/A	N/A	N/A
27L	T2	382	355	378	421	406	412	358
27L	T3	340	368	387	430	447	428	317
27L	T4	375	362	362	376	367	361	303
27L	T5	438	461	447	475	475	438	394
27L	Cargo	219	200	219	225	215	271	171
27R	T1[a]	290	366	517	N/A	N/A	N/A	N/A
27R	T2	531	508	526	546	544	499	447
27R	T3	382	403	411	443	446	422	333
27R	T4	745	774	748	740	743	718	563
27R	T5	414	434	410	447	442	400	375
27R	Cargo	677	653	644	667	669	605	550

[a] Terminal 1 was closed during 2015. However, there were a few movements from remote stands associated with T1 during 2016 and 2017, which yield some unusually long taxi times.

Table 3 Aircraft taxi-out and hold[1] times: 2015 to 2021

Runway	Terminal	Taxi-out and hold[1] (s)						
		2015	2016	2017	2018	2019	2020	2021
09L	T1[a]	625	N/A	N/A	N/A	N/A	N/A	N/A
09L	T2	1432	1152	1262	1216	1490	1064	1010
09L	T3	1258	1102	1098	1318	1436	935	917
09L	T4	1741	1477	1641	1373	1984	1068	1179
09L	T5	1308	1027	1189	1588	1221	892	934
09L	Cargo	1437	1619	1242	1362	1478	1132	1175
09R	T1[a]	1431	1577	1634	N/A	N/A	N/A	N/A
09R	T2	1242	1300	1321	1298	1316	983	926
09R	T3	1303	1353	1350	1360	1356	1043	875
09R	T4	1269	1314	1312	1312	1321	1018	889
09R	T5	1216	1237	1228	1321	1288	929	834
09R	Cargo	1059	1041	1095	1145	1113	796	712
27L	T1[a]	1171	1282	1509	N/A	N/A	N/A	N/A
27L	T2	1015	1049	1063	1050	1076	867	676
27L	T3	1282	1328	1337	1309	1336	1180	869
27L	T4	1095	1131	1129	1124	1133	981	767
27L	T5	1405	1450	1453	1465	1501	1230	1026
27L	Cargo	1207	1209	1196	1207	1217	963	813

Runway	Terminal	Taxi-out and hold[1] (s)						
		2015	2016	2017	2018	2019	2020	2021
27R	T1[a]	1055	1138	978	N/A	N/A	N/A	N/A
27R	T2	1102	1149	1133	1129	1152	951	762
27R	T3	1325	1356	1350	1343	1352	1226	902
27R	T4	1339	1382	1369	1361	1386	1272	1033
27R	T5	1410	1397	1403	1456	1448	1183	980
27R	Cargo	1425	1400	1473	1467	1503	1187	1075

[1] Includes time for line-up and pilot reaction.
[a] Terminal 1 was closed during 2015. However, there were a few movements from remote stands associated with T1 during 2016 and 2017, which yield some unusually long taxi times.

Table 4 shows average taxi and hold times weighted over all movements for the years 2015 to 2021. Generally, there is only modest year-on-year variation in taxi and hold times. However, the variation is more apparent for individual runway and terminal pairings. For 2020, there is a significant reduction in hold times, due to the lower movement numbers seen during the COVID-19 pandemic. For 2021, the data do not distinguish taxi-out from hold. However, there are further reductions in the combined taxi-out and hold times, again due to the COVID-19 pandemic.

Table 4 Weighted average taxi and hold[1] times

Mode	Time (s)						
	2015	2016	2017	2018	2019	2020	2021
Taxi-In	451	453	447	491	480	440	389
Taxi-Out	661	655	662	688	688	646	889
Hold[1]	609	648	643	631	640	433	

[1] Includes time for line-up and pilot reaction.

2.4.2 Airborne modes

Times in approach, initial climb and climb-out are taken from Heathrow's noise and track keeping system (NTK). These have been analysed to provide average approach, initial climb, and climb-out times by aircraft type for each year.

Table 5 shows approach times derived from data for the years 2015 to 2021 and Table 6 and Table 7 show the initial-climb and climb-out times, respectively.

Table 5 Approach times: 2015 to 2021

	Phase 1[a] (s)						
	2015	2016	2017	2018	2019	2020	2021
A318	92.4	77.3	83.8	87.1	79.5	n/a	74.3
A319	70.5	70.2	72.8	69.7	71.3	71.5	69.5
A320	70.5	69.8	73.5	69.7	70.8	71.8	68.7
A320 neo	n/a	n/a	n/a	n/a	70.6	71.7	71.0
A321	71.4	70.5	72.4	70.7	71.7	78.0	80.8
A321 neo	n/a	n/a	n/a	n/a	71.4	75.0	72.9
A350-900	n/a	79.4	80.0	80.4	75.5	83.4	76.0
A350-1000	n/a	n/a	n/a	81.2	79.8	75.4	70.4
B747-400	69.7	68.8	71.0	68.5	69.4	77.0	n/a
B777-200	70.8	68.8	71.6	67.1	68.3	71.1	68.0
B777-200LR	78.8	71.7	70.5	84.8	72.9	74.7	70.6
B777-300ER	72.9	73.9	75.7	73.1	71.8	75.8	71.8
B787-8	72.4	71.7	74.5	73.1	71.6	74.7	75.7
B787-9	69.3	69.2	71.4	68.9	69.8	71.5	69.7
B787-10	n/a	n/a	n/a	n/a	70.4	68.6	68.4
A380-800	74.3	73.6	74.9	71.6	72.5	75.4	79.6

	Phase 2[b] (s)						
	2015	2016	2017	2018	2019	2020	2021
A318	130.8	160.3	168.1	183.8	162.2	n/a	164.9
A319	129.8	160.9	167.5	161.6	164.6	166.7	165.7
A320	126.6	156.6	163.0	158.1	159.6	160.4	162.2
A320 neo	n/a	n/a	n/a	n/a	162.6	162.9	167.1
A321	129.2	153.4	157.6	155.1	155.6	152.7	153.9
A321 neo	n/a	n/a	n/a	n/a	159.1	167.8	162.9
A350-900	n/a	156.9	165.4	154.0	156.9	161.0	165.8
A350-1000	n/a	n/a	n/a	151.9	154.9	158.9	160.0
B747-400	117.0	150.4	151.9	150.5	153.2	144.8	n/a
B777-200	127.7	151.5	158.2	151.6	155.7	156.8	157.1
B777-200LR	139.4	150.0	155.4	149.8	155.1	155.8	153.6
B777-300ER	125.8	148.3	151.9	151.2	154.2	155.9	152.0
B787-8	138.0	152.7	156.4	150.9	154.5	159.1	154.4
B787-9	130.5	148.7	155.4	147.4	153.4	152.5	151.3
B787-10	n/a	n/a	n/a	n/a	153.8	148.1	154.9
A380-800	131.4	159.7	162.9	156.7	160.9	162.1	158.3

[a] from 3,000 feet to 2,000 feet altitude.
[b] from 2,000 feet altitude to threshold.

Table 6 Initial-climb times[1]: 2015 to 2021

	To 1,000 feet (s)						
	2015	2016	2017	2018	2019	2020	2021
A318	22.0	20.9	20.3	21.2	20.8	n/a	21.8
A319	23.9	22.2	21.6	22.0	21.5	22.2	22.4
A320	21.4	19.4	18.9	19.2	18.7	19.4	19.6
A320 neo	n/a	n/a	n/a	n/a	19.2	19.9	20.7
A321	21.0	18.8	18.0	18.4	18.4	21.6	21.3
A321 neo	n/a	n/a	n/a	n/a	19.7	20.6	21.4
A350-900	n/a	18.3	18.5	18.6	18.4	19.0	19.7
A350-1000	n/a	n/a	n/a	n/a	17.5	18.4	19.1
B747-400	35.3	34.4	33.8	35.1	34.8	n/a	n/a
B777-200	23.9	22.9	21.2	21.8	21.7	22.3	23.3
B777-200LR	21.1	20.9	17.5	20.0	18.7	n/a	22.4
B777-300ER	22.6	20.5	19.5	20.1	19.6	21.9	22.1
B787-8	28.8	25.8	23.8	23.7	23.5	25.6	26.5
B787-9	27.1	26.9	26.5	24.3	23.6	25.9	26.1
B787-10	n/a	n/a	n/a	n/a	23.6	23.8	25.4
A380-800	42.9	40.0	39.0	40.9	38.9	41.3	44.1

	To 1,500 feet (s)						
	2015	2016	2017	2018	2019	2020	2021
A318	34.0	32.9	33.4	34.3	32.3	n/a	34.9
A319	39.0	37.6	36.2	37.3	35.8	36.1	36.5
A320	36.1	33.8	32.6	33.4	32.0	31.6	32.9
A320 neo	n/a	n/a	n/a	n/a	33.6	33.5	35.7
A321	34.0	31.2	29.6	30.7	30.3	34.2	34.4
A321 neo	n/a	n/a	n/a	n/a	34.3	34.2	36.1
A350-900	n/a	35.2	32.7	34.2	33.5	31.7	33.1
A350-1000	n/a	n/a	n/a	n/a	31.9	32.0	33.9
B747-400	56.3	56.2	54.8	57.5	56.8	n/a	n/a
B777-200	37.9	37.9	35.2	36.2	35.4	36.3	38.2
B777-200LR	32.3	33.3	27.8	32.0	30.7	n/a	35.5
B777-300ER	33.8	32.0	30.7	31.8	30.9	33.7	34.2
B787-8	42.4	40.1	37.2	37.7	36.6	38.7	40.3
B787-9	41.5	41.2	40.5	38.3	36.4	39.6	39.8
B787-10	n/a	n/a	n/a	n/a	36.5	36.3	37.9
A380-800	72.0	68.9	62.9	64.2	62.8	62.9	68.0

[1] Times for cutback at 1,000 feet and 1,500 feet are given for aircraft types where either is used depending on operator.

Table 7 Climb-out times[1]: 2015 to 2021

	From 1,000 feet (s)						
	2015	2016	2017	2018	2019	2020	2021
A318	72.1	73.2	72.3	73.9	67.5	n/a	73.1
A319	69.4	69.1	67.9	69.1	67.2	65.0	65.1
A320	77.0	75.6	74.5	76.7	74.5	68.7	74.8
A320 neo	n/a	n/a	n/a	n/a	63.5	60.7	63.8
A321	74.2	73.1	70.4	74.0	73.5	68.7	70.7
A321 neo	n/a	n/a	n/a	n/a	64.1	62.8	64.6
A350-900	n/a	71.6	68.7	76.3	70.0	62.4	64.6
A350-1000	n/a	n/a	n/a	n/a	66.6	72.9	78.3
B747-400	69.2	66.0	64.0	65.7	65.0	n/a	n/a
B777-200	80.0	81.1	76.8	80.9	78.7	87.4	82.5
B777-200LR	54.0	56.1	47.8	53.5	54.5	n/a	69.1
B777-300ER	63.9	63.7	62.3	61.9	61.3	57.7	63.0
B787-8	64.4	65.2	61.5	61.7	67.2	68.7	68.2
B787-9	76.4	75.6	72.4	72.5	71.6	70.8	69.7
B787-10	n/a	n/a	n/a	n/a	70.0	57.8	70.5
A380-800	91.3	90.0	92.0	96.0	91.8	72.7	73.4

	From 1,500 feet (s)						
	2015	2016	2017	2018	2019	2020	2021
A318	60.1	61.3	59.2	60.8	55.9	n/a	60.0
A319	54.3	53.7	53.3	53.9	52.9	51.1	51.1
A320	62.3	61.2	60.8	62.4	61.2	56.4	61.5
A320 neo	n/a	n/a	n/a	n/a	49.1	47.1	48.8
A321	61.3	60.7	58.8	61.8	61.6	56.1	57.6
A321 neo	n/a	n/a	n/a	n/a	49.6	49.2	50.0
A350-900	n/a	54.7	54.5	60.7	54.9	49.7	51.2
A350-1000	n/a	n/a	n/a	n/a	52.2	59.3	63.5
B747-400	48.2	44.1	43.0	43.3	43.1	n/a	n/a
B777-200	66.0	66.1	62.9	66.6	65.0	73.3	67.6
B777-200LR	42.8	43.8	37.5	41.5	42.4	n/a	56.1
B777-300ER	52.6	52.2	51.1	50.1	49.9	45.9	50.8
B787-8	50.7	50.9	48.1	47.8	54.1	55.6	54.3
B787-9	62.1	61.4	58.5	58.6	58.8	57.1	56.0
B787-10	n/a	n/a	n/a	n/a	57.1	45.3	58.1
A380-800	62.2	61.1	68.1	72.6	68.0	51.1	49.5

[1] Times for cutback at 1,000 feet and 1,500 feet are given for aircraft types where either is used depending on operator.

2.4.3 APU running times

The APU running times are derived from observations of APU running times reported annually. The APU data were supplied by Heathrow Airport in the same form as they were provided for previous inventories. These data have been analysed using the same methodology as used in the previous work to extract average running times on arrival and on departure, for narrow and wide-bodied aircraft types. The Airbus A380 was analysed separately from other wide-bodied aircraft as its APU is generally run for longer and the number of APU running times recorded were significant enough to warrant separate analysis. (Heathrow's Operational Safety Instruction "OSI/21/11" allows for longer running times for the A380 compared with other wide-bodied aircraft.)

The 2013 inventory only considered APU use on-stand. However, if aircraft operate using reduced-engine taxi they usually keep their APUs running during taxiing. At the time of the 2013 inventory, no data were available regarding the deployment of reduced-engine taxi at Heathrow, so it was not considered in the inventory. However, as reduced-engine taxiing is now a standard component of the methodology, APU use off-stand is also accounted for.

Table 8 shows the APU on-stand running times derived from data for the years 2015 to 2021. APU use off-stand is not shown is the table as it is not recorded. It is, however, estimated from reduced engine taxi and OPAS data.

On-stand running times for narrow-bodied aircraft are broadly similar for all years. However, for wide-bodied aircraft (excluding the A380) there is more year-on-year variability. On-stand running times peaked in 2017, most likely due to issues with pre-conditioned air (PCA) use, which first became apparent in 2016.

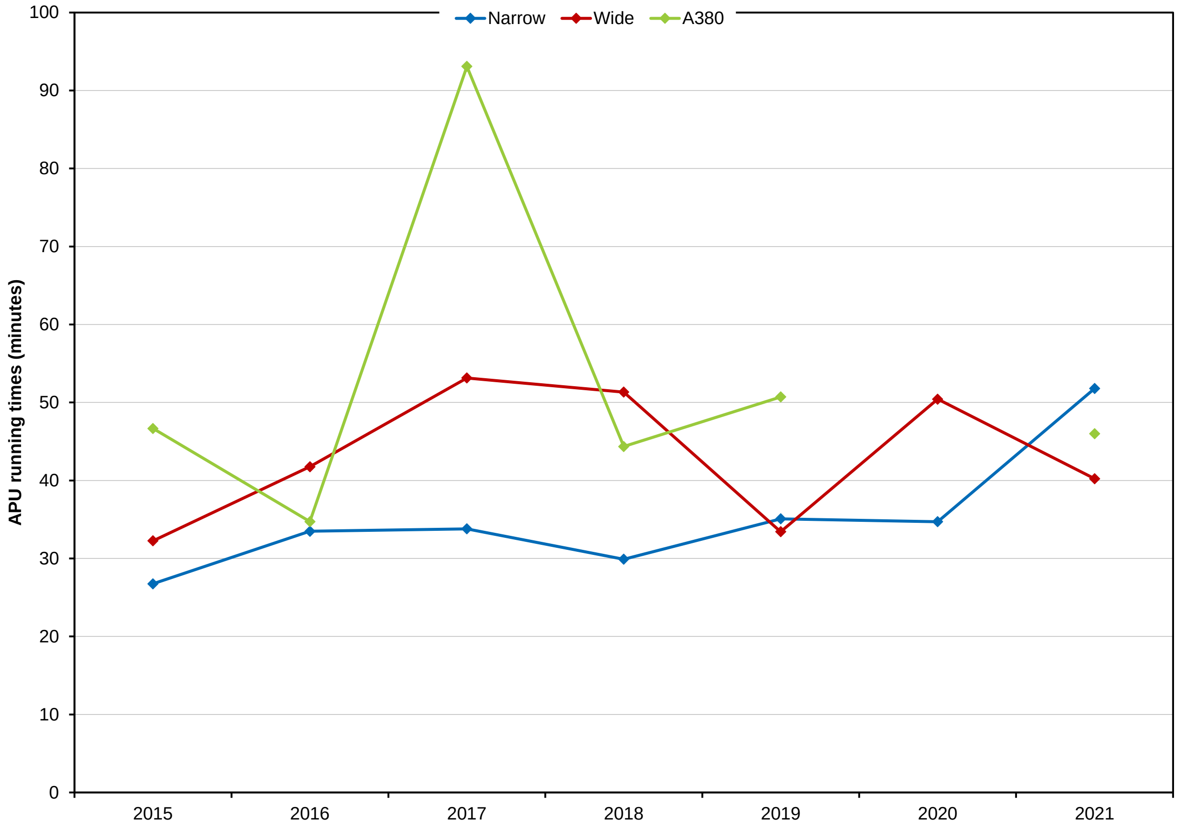
The large year-on-year variability seen for the A380 is likely to be an artefact of the smaller sample sizes involved. In 2021, there were very few observations made of A380 arrivals and departures, so 5-year average times were assumed.

Figure 5 shows the trend in the APU on-stand running times since 2015.

Table 8 APU on-stand running times: 2015 to 2021

		APU running time (minutes)						
		2015	2016	2017	2018	2019	2020	2021
Narrow-bodied	Arrival	6.9	9.9	9.2	9.3	10.9	12.0	15.1
	Departure	19.9	23.6	24.6	20.6	24.2	22.7	36.7
	Total	26.8	33.5	33.8	29.9	35.1	34.7	51.8
Wide-bodied	Arrival	8.2	11.2	10.6	11.6	14.9	14.1	15.5
	Departure	24.0	30.6	42.6	39.7	18.5	36.3	24.7
	Total	32.3	41.8	53.1	51.3	33.4	50.4	40.2
A380	Arrival	11.2	16.1	27.1	11.9	18.9	15.8	5.0
	Departure	35.5	18.7	66.0	32.4	31.8	N/A	41.0
	Total	46.7	34.7	93.1	44.3	50.7	N/A	46.0

Figure 5 APU running times



2.5 Take-off thrust

For commercial reasons, airlines have become reluctant to share the operational data required to estimate take-off thrusts[5]. Therefore, data from the 2013 study were pooled with the little data that were made available to the Heathrow Expansion project to provide estimates of average take-off thrust separately for twin-engined and four-engined aircraft.

The assumptions used for the inventories produced for the anticipated Heathrow Expansion Environmental Statement are shown in Table 9.

[5] As aircraft do not necessarily take off at their certificated maximum take-off weight (MTOM), they do not necessarily need to use full engine thrust for take-off. To reduce fuel consumption and engine maintenance costs, aircraft will normally take off using less than maximum engine thrust when feasible. The reduced take-off thrust used is normally expressed as a percentage of the maximum engine thrust.

Table 9 Take-off thrusts

Aircraft type	Reduced thrust setting (%)	Flights using 100% thrust (%)
Narrow-body, twin-engined	80.6	6
Wide-body, twin-engined	80.6	6
Wide-body, four-engined	84.1	14

2.6 Reduced engine taxiing

Table 10 shows the percentage arrivals and departures using reduced engine taxiing[6] for the years 2015 to 2021. There is a clear decline in reduced engine taxiing on departure. The reasons for this are unclear, but possible explanations are that for modern jets the practice is less beneficial. The Boeing 787 is incapable of using reduced engine taxiing due to its APU capabilities. There are also issues relating to warm up times on some A320 neo engines. These factors may be more widespread and affect other modern jets. It may also be possible that airlines have not found that the fuel savings outweigh the safety concerns of starting an engine during taxi-out.

For taxi-in, reduced engine taxi use is estimated from data from a survey that was undertaken for the 2017 update. Reduced engine taxiing has remained relatively constant. However, this may be an artefact of the survey that was done to establish its prevalence, and the fact that the survey has not been recently updated.

Table 10 Reduced engine taxi use: 2015 to 2021

	2015	2016	2017	2018	2019	2020	2021
Arrivals	80%	77%	78%	77%	78%	76%	74%
Departures	21%	17%	18%	13%	11%	6%	1%

3 Results

3.1 NO_x

Table 11 shows airfield NO_x emissions broken down by source category. For aircraft emissions these sources are the phases of the LTO cycle as reported in the 2013 inventory and dispersion modelling study and the subsequent annual updates.

Aircraft NO_x emissions increased year-on-year between 2015 and 2018, broadly in line with passenger numbers. However, in 2019 aircraft emissions were 5% lower than their 2018 peak despite continued passenger growth. This is mainly due to the propagating of newer low-NO_x aircraft types

[6] Taxiing with fewer than all main engines operating.

into the fleet, particularly the A320 neo and A321 neo. There is also some year-on-year variation due to meteorological effects and variations in operational data, such as APU running times and taxiing times, that influence emissions. Aircraft NO_x emissions in both 2020 and 2021 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

GSE emissions have fallen year-on-year since 2015. This is due to the ground fleet turnover, with older equipment being retired and replaced with either newer equipment with tighter emissions standards or with electric equipment. 2020 and 2021 were also heavily impacted by the COVID-19 pandemic.

NO_x emissions from stationary sources increased year-on-year between 2017 and 2020, due to increased use of biomass as a fuel. The savings achieved in net CO_2 emissions from biomass burning apparently come at a cost of increased NO_x emissions. In 2021, there was a significant reduction in biomass consumption and a corresponding increase in gas use. This resulted in lower NO_x emissions from stationary sources overall.

Table 11 Breakdown of airfield NO_x emissions by source category: 2015 to 2021

Source Category	Annual NO_x emissions (tonnes)						
	2015	2016	2017	2018	2019	2020	2021
Aircraft							
Ground-level							
Landing roll	48.67	61.85	68.85	40.20	39.28	19.01	20.31
Taxi-in	136.78	138.30	137.62	150.74	143.80	59.23	48.51
Taxi-out	245.44	243.67	246.21	259.81	253.33	104.45	134.92
Hold	231.03	246.00	243.74	242.47	239.14	69.92	
Take-off roll	761.82	776.15	798.02	1017.97	970.91	435.82	427.68
APU	253.39	314.13	332.49	299.29	257.59	135.01	125.42
Engine testing[1]	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Total ground-level	**1679.94**	**1782.89**	**1829.73**	**2013.29**	**1906.85**	**826.23**	**759.63**
Elevated							
Approach	503.45	591.20	619.62	611.20	605.09	272.94	253.71
Initial climb	719.60	670.83	663.13	688.11	638.01	273.80	247.57
Climb out	1418.53	1442.37	1522.38	1607.21	1507.57	644.91	614.82
Total elevated	**2641.58**	**2704.39**	**2805.14**	**2906.53**	**2750.68**	**1191.64**	**1116.10**
Total aircraft	**4321.52**	**4487.28**	**4634.87**	**4919.82**	**4657.52**	**2017.87**	**1875.74**

Source Category	Annual NO_x emissions (tonnes)						
	2015	2016	2017	2018	2019	2020	2021
GSE[2]	**156.03**	**143.73**	**127.82**	**122.00**	**95.07**	**52.39**	**44.04**
Stationary sources[3]							
Gas	N/A	N/A	N/A	N/A	19.31	15.32	23.88
Gas-oil	N/A	N/A	N/A	N/A	10.45	8.37	6.85
LPG	N/A	N/A	N/A	N/A	0.04	0.00	n/a
Biomass	N/A	N/A	N/A	N/A	35.12	42.42	4.55
(BA gas)	N/A	N/A	N/A	N/A	34.14	34.14	34.14
Total stationary	**74.92**	**55.64**	**50.64**	**76.54**	**99.06**	**100.24**	**69.42**
Total airfield	**4552.48**	**4686.65**	**4813.33**	**5118.36**	**4851.65**	**2170.50**	**1989.20**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018.

Table 12 shows the values of annual aircraft LTO NO_x emissions normalised by the number of passengers and movements. The NO_x per passenger is highest in 2021. However, 2020 and 2021 are heavily affected by reduced passenger load factors due to the COVID-19 pandemic. Prior to 2020, the NO_x per movement increased year-on-year between 2015 and 2018 in line with the shift towards larger aircraft. However, this trend did not continue into 2019, mainly due to the propagating of newer cleaner aircraft types into the fleet

Table 12 LTO NO_x emissions per passenger and per movement: 2015 to 2021

	2015	2016	2017	2018	2019	2020	2021
LTO NO_x (tonnes per year)	4321.52	4487.28	4634.87	4919.82	4657.52	2017.87	1875.74
Passengers[1] (mppa)	74.95	75.67	77.99	80.10	80.89	22.11	19.40
LTO NO_x (g per passenger[1])	57.66	59.30	59.43	61.42	57.58	91.27	96.70
Movements[2] (1000s)	474.09	474.96	475.78	477.60	478.06	204.73	195.34
LTO NO_x (kg per movement[2])	9.12	9.45	9.74	10.30	9.74	9.86	9.60

[1] Excludes transit passengers
[2] ATMs and non-ATMs

From a local air quality perspective, emissions from aircraft on the ground have a greater impact than elevated emissions. The calculated value of ground-level aircraft NO_x emissions (including APU emissions and engine testing emissions) peaked in 2018 at the point where increasing emissions due to higher passenger numbers had not been sufficiently offset by the propagation of newer cleaner aircraft types in into the fleet (refer to Table 11).

Table 13 gives a breakdown of ground-level aircraft NO_x emissions (omitting APUs and engine testing) by aircraft type. The larger aircraft types (heavy and A380) together contribute almost 85% of the emissions in 2021, despite accounting for only a half of the total movements. Previously, they had contributed approximately three quarters of the emissions (four fifths in 2020) from less than half of the total movements in each year. Conversely, between 2015 and 2019 the A320 aircraft family (A318/A319, A320 and A321) only accounted for between a fifth and a quarter of the emissions despite accounting for more than half of the total movements. The contribution from the A320 family declined further in 2020 and again in 2021 by which time it accounted for only 14% emissions from 44% of the movements.

Table 13 also gives ground-level emissions per movement (excluding APU and engine testing emissions) for each aircraft type. There is variability in emissions from year-to-year, due to the changeable effects of ambient meteorological conditions. For a given aircraft type, the emissions per movement are also affected by changes to the distribution of sub-aircraft types and/or engine models, which have different emissions characteristics. The table shows that the values of ground-level emissions per movement for the large aircraft types (B747 and B777) are around a factor of five higher than the average for A318/A319/A320/A321 or B737 aircraft. Of course, the larger types carry more passengers than the A320/B737 families, but only around twice as many passengers, so the NO_x per passenger ratio is roughly double that of the A320/B737 families. The reasons for this are well understood and result from two main causes:

- The larger aircraft types tend to be operated on long-haul rather than short-haul flights, so fuel comprises a much greater proportion of the aircraft take-off mass, requiring significantly higher take-off thrust (per passenger).
- Engine manufacturers have previously concentrated their efforts on fuel efficiency on larger engines (as fitted to these larger aircraft types) as, globally, they consume more fuel than the

smaller types. A key technology for increasing fuel efficiency is the use of higher overall pressure ratios (OPR) and the CAEP standards allow engines with higher OPRs to emit more NO_x than those with lower OPRs (after normalising by the engine rated thrust).

Table 13 Breakdown of ground-level aircraft NO_x emissions[1] by aircraft type: 2015 to 2021

(a) annual emissions in tonnes per year

	NO_x emissions (tonnes/year)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	2.47	1.71	1.47	1.79	2.78	0.71	0.48
Medium	382.44	379.27	371.62	397.22	391.76	130.22	97.86
A318/A319	97.55	97.31	93.86	99.83	92.42	31.23	18.32
A320	176.20	175.08	178.76	186.64	181.18	61.63	54.45
A321	73.48	74.66	69.24	79.26	91.43	27.05	16.40
B737	21.85	21.95	17.81	18.39	14.27	5.62	5.30
Others	13.36	10.28	11.96	13.09	12.46	4.69	3.40
Heavy	897.20	909.59	946.32	1121.64	1071.90	510.95	509.21
A350	0.32	3.43	11.30	25.74	40.02	59.79	64.28
B747	185.74	151.92	160.11	187.61	175.04	36.02	7.26
B767	87.37	76.68	81.91	66.05	30.78	11.06	10.92
B777	412.84	399.47	400.17	497.55	455.61	215.05	214.52
B787	74.33	146.37	183.49	205.49	227.31	145.72	163.94
Other	136.59	131.71	109.33	139.21	143.13	43.31	48.30
A380	141.64	175.38	175.02	190.55	180.01	46.55	23.86
Total	**1423.75**	**1465.96**	**1494.44**	**1711.20**	**1646.45**	**688.42**	**631.42**

(b) percentage of annual emissions by aircraft type

	NO_x emissions (%)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	0.2	0.1	0.1	0.1	0.2	0.1	0.1
Medium	26.9	25.9	24.9	23.2	23.8	18.9	15.5
A318/A319	6.9	6.6	6.3	5.8	5.6	4.5	2.9
A320	12.4	11.9	12.0	10.9	11.0	9.0	8.6
A321	5.2	5.1	4.6	4.6	5.6	3.9	2.6
B737	1.5	1.5	1.2	1.1	0.9	0.8	0.8
Others	0.9	0.7	0.8	0.8	0.8	0.7	0.5
Heavy	63.0	62.0	63.3	65.5	65.1	74.2	80.6
A350	0.0	0.2	0.8	1.5	2.4	8.7	10.2
B747	13.0	10.4	10.7	11.0	10.6	5.2	1.2
B767	6.1	5.2	5.5	3.9	1.9	1.6	1.7
B777	29.0	27.2	26.8	29.1	27.7	31.2	34.0
B787	5.2	10.0	12.3	12.0	13.8	21.2	26.0
Other	9.6	9.0	7.3	8.1	8.7	6.3	7.6
A380	9.9	12.0	11.7	11.1	10.9	6.8	3.8
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

(c) average emissions per movement by aircraft type

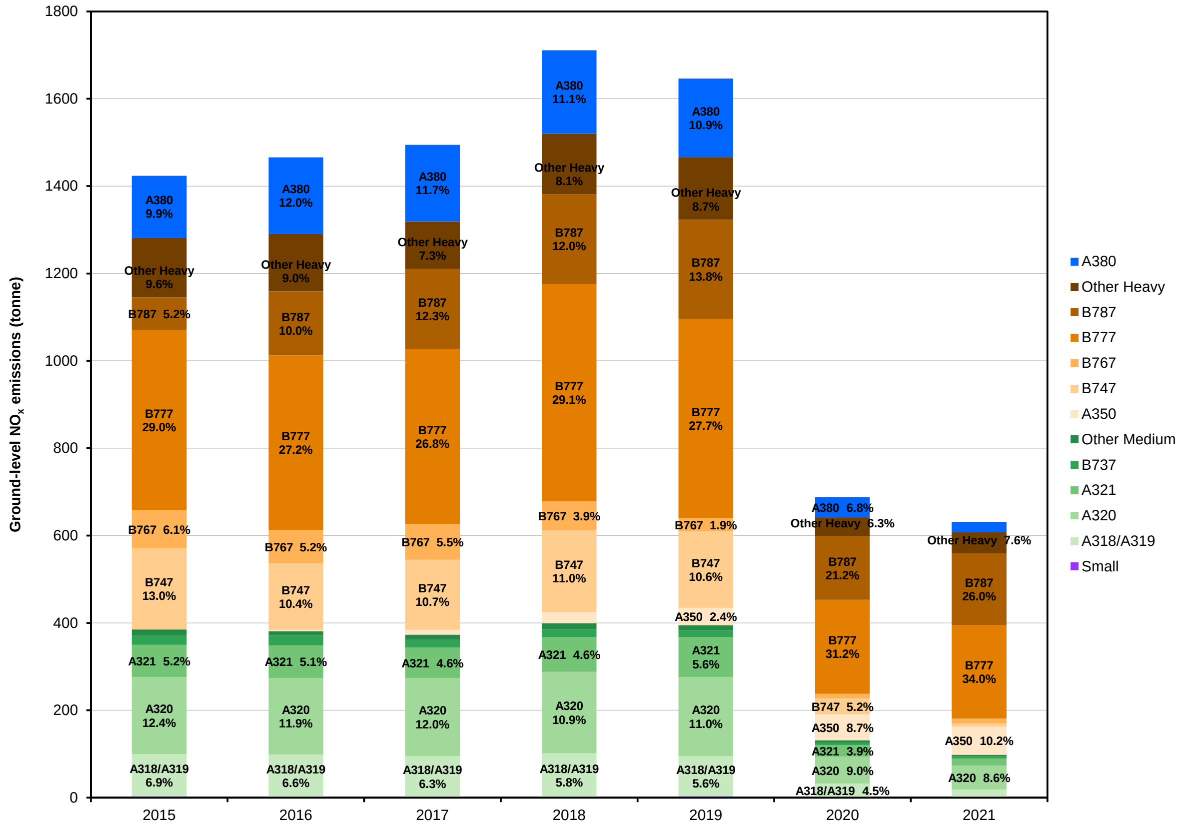
	NO_x emissions (kg/movement)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	0.69	0.68	0.35	0.35	0.30	0.30	0.25
Medium	1.30	1.31	1.30	1.40	1.38	1.20	1.03
A318/A319	1.16	1.20	1.15	1.25	1.27	1.14	0.98
A320	1.25	1.25	1.26	1.32	1.27	1.10	0.99
A321	1.72	1.73	1.80	2.02	1.90	1.62	1.34
B737	1.19	1.17	1.17	1.31	1.33	1.16	1.02
Others	1.63	1.58	1.40	1.43	1.28	1.12	0.90
Heavy	5.58	5.53	5.63	6.53	6.35	5.74	5.30
A350	5.59	4.80	4.02	5.11	5.29	5.69	5.24
B747	7.24	7.35	7.79	9.25	9.26	8.05	6.40
B767	3.08	2.96	3.45	3.98	3.35	3.09	2.90
B777	6.59	6.52	6.53	7.87	7.52	7.05	6.93
B787	4.76	5.31	5.03	4.98	5.00	4.89	4.63
Other	4.78	4.66	4.70	5.49	5.26	4.29	3.85
A380	9.55	9.60	9.47	11.41	11.25	10.39	10.24
Total	**3.00**	**3.09**	**3.14**	**3.58**	**3.44**	**3.36**	**3.23**

[1] Ground–level emissions from main engines only (omitting APU and engine testing)

Overall, the fleet-averaged value of ground-level aircraft NO_x emissions per movement, excluding APUs and engine testing, increased year-on-year between the 2015 and 2018, but, with the propagation of newer low-NO_x aircraft types into the fleet, they have decreased year-on-year since then.

Figure 6 shows the trend in ground-level aircraft NO_x emissions broken down by aircraft type.

Figure 6 Breakdown of ground-level aircraft NO_x emissions[1] by aircraft type: 2015 to 2021



[1] Ground–level emissions from main engines only (omitting APU and engine testing)

3.2 PM_{10} and $PM_{2.5}$

Table 14 and Table 15 show airfield PM_{10} and $PM_{2.5}$ emissions broken down by source category, respectively.

Aircraft PM_{10} emissions remained relatively constant between 2015 and 2019. Emissions in 2020 and 2021 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic. The $PM_{2.5}$ trend follows a very similar pattern to PM_{10}.

It should be noted that for aircraft exhaust emissions all the mass has been assumed to be associated with particles less than 2.5 µm in diameter (as it is widely understood that all particulate matter emitted by aircraft engines is smaller than this size), so PM_{10} and $PM_{2.5}$ exhaust emissions are the same. However, not all of the particulate matter generated by brake and tyre wear is associated with particles of less than 2.5 µm in diameter (see Reference i for details).

PM_{10} and $PM_{2.5}$ emissions from GSE have fallen year-on-year since 2015. This is due to the ground fleet turnover, with older equipment being retired and replaced with either newer equipment with tighter emissions standards or with electric equipment. 2020 and 2021 were also heavily impacted by the COVID-19 pandemic.

Emissions from stationary sources increased considerably in 2019, due to increased use of biomass as a fuel. The savings achieved in net CO_2 emissions from biomass burning come at a cost of increased PM emissions. In 2021, there was a significant reduction in biomass consumption that resulted in PM emissions from stationary sources reverting to the levels of 2018.

PM emissions in 2020 and 2021 were heavily impacted by the COVID-19 pandemic.

Table 14 Breakdown of airfield PM_{10} emissions by source category: 2015 to 2021

<table>
<tr><th rowspan="2">Source Category</th><th colspan="7">Annual PM_{10} emissions (tonnes)</th></tr>
<tr><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th></tr>
<tr><td>Aircraft</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ground-level</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Landing roll</td><td>0.46</td><td>0.50</td><td>0.50</td><td>0.41</td><td>0.39</td><td>0.18</td><td>0.20</td></tr>
<tr><td>Taxi-in</td><td>2.63</td><td>2.65</td><td>2.57</td><td>2.72</td><td>2.57</td><td>0.97</td><td>0.79</td></tr>
<tr><td>Taxi-out</td><td>4.61</td><td>4.60</td><td>4.57</td><td>4.70</td><td>4.57</td><td>1.74</td><td rowspan="2">2.20</td></tr>
<tr><td>Hold</td><td>4.45</td><td>4.74</td><td>4.63</td><td>4.42</td><td>4.30</td><td>1.18</td></tr>
<tr><td>Take-off roll</td><td>3.19</td><td>3.17</td><td>3.14</td><td>3.67</td><td>3.52</td><td>1.47</td><td>1.39</td></tr>
<tr><td>Brake wear</td><td>9.58</td><td>9.74</td><td>9.82</td><td>9.89</td><td>9.81</td><td>4.47</td><td>4.36</td></tr>
<tr><td>Tyre wear</td><td>6.38</td><td>6.51</td><td>6.59</td><td>6.64</td><td>6.57</td><td>3.05</td><td>3.00</td></tr>
<tr><td>APU</td><td>4.34</td><td>5.49</td><td>6.06</td><td>5.32</td><td>4.78</td><td>2.29</td><td>2.27</td></tr>
<tr><td>Engine testing[1]</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td></tr>
<tr><td>Total ground-level</td><td>35.69</td><td>37.45</td><td>37.94</td><td>37.83</td><td>36.55</td><td>15.39</td><td>14.26</td></tr>
<tr><td>Elevated</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Approach</td><td>4.52</td><td>5.25</td><td>5.33</td><td>5.07</td><td>4.90</td><td>2.11</td><td>1.90</td></tr>
<tr><td>Initial climb</td><td>2.45</td><td>2.24</td><td>2.14</td><td>2.12</td><td>1.97</td><td>0.78</td><td>0.70</td></tr>
<tr><td>Climb out</td><td>5.66</td><td>5.62</td><td>5.63</td><td>5.67</td><td>5.28</td><td>2.08</td><td>1.95</td></tr>
<tr><td>Total elevated</td><td>12.63</td><td>13.12</td><td>13.09</td><td>12.87</td><td>12.15</td><td>4.97</td><td>4.55</td></tr>
<tr><td>Total aircraft</td><td>48.33</td><td>50.57</td><td>51.03</td><td>50.69</td><td>48.71</td><td>20.36</td><td>18.81</td></tr>
</table>

Source Category	Annual PM_{10} emissions (tonnes)						
	2015	2016	2017	2018	2019	2020	2021
GSE[2]							
Exhaust	7.23	6.14	5.45	5.03	3.07	1.75	1.26
Fugitives	3.60	3.61	3.59	3.64	3.31	1.96	1.91
Total GSE	**10.83**	**9.75**	**9.04**	**8.67**	**6.37**	**3.71**	**3.16**
Stationary sources[3]							
Gas	N/A	N/A	N/A	N/A	1.05	0.90	2.25
Gas-oil	N/A	N/A	N/A	N/A	0.57	0.46	0.37
LPG	N/A	N/A	N/A	N/A	0.00	0.00	n/a
Biomass	N/A	N/A	N/A	N/A	37.66	45.48	4.88
(BA gas)	N/A	N/A	N/A	N/A	0.19	0.19	0.19
Total stationary	**8.68**	**6.29**	**4.85**	**7.80**	**39.47**	**47.03**	**7.70**
Total airfield	**67.83**	**66.61**	**64.92**	**67.16**	**94.55**	**71.11**	**29.68**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018.

Table 15 Breakdown of airfield $PM_{2.5}$ emissions by source category: 2015 to 2021

<table>
<tr><th rowspan="2">Source Category</th><th colspan="7">Annual $PM_{2.5}$ emissions (tonnes)</th></tr>
<tr><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th></tr>
<tr><td>Aircraft</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ground-level</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Landing roll</td><td>0.46</td><td>0.50</td><td>0.50</td><td>0.41</td><td>0.39</td><td>0.18</td><td>0.20</td></tr>
<tr><td>Taxi-in</td><td>2.63</td><td>2.65</td><td>2.57</td><td>2.72</td><td>2.57</td><td>0.97</td><td>0.79</td></tr>
<tr><td>Taxi-out</td><td>4.61</td><td>4.60</td><td>4.57</td><td>4.70</td><td>4.57</td><td>1.74</td><td rowspan="2">2.20</td></tr>
<tr><td>Hold</td><td>4.45</td><td>4.74</td><td>4.63</td><td>4.42</td><td>4.30</td><td>1.18</td></tr>
<tr><td>Take-off roll</td><td>3.19</td><td>3.17</td><td>3.14</td><td>3.67</td><td>3.52</td><td>1.47</td><td>1.39</td></tr>
<tr><td>Brake wear</td><td>3.81</td><td>3.88</td><td>3.91</td><td>3.94</td><td>3.90</td><td>1.78</td><td>1.74</td></tr>
<tr><td>Tyre wear</td><td>4.47</td><td>4.56</td><td>4.61</td><td>4.65</td><td>4.60</td><td>2.14</td><td>2.10</td></tr>
<tr><td>APU</td><td>4.34</td><td>5.49</td><td>6.06</td><td>5.32</td><td>4.78</td><td>2.29</td><td>2.27</td></tr>
<tr><td>Engine testing[1]</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td><td>0.06</td></tr>
<tr><td>Total ground-level</td><td>28.01</td><td>29.64</td><td>30.05</td><td>29.88</td><td>28.68</td><td>11.78</td><td>10.74</td></tr>
<tr><td>Elevated</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Approach</td><td>4.52</td><td>5.25</td><td>5.33</td><td>5.07</td><td>4.90</td><td>2.11</td><td>1.90</td></tr>
<tr><td>Initial climb</td><td>2.45</td><td>2.24</td><td>2.14</td><td>2.12</td><td>1.97</td><td>0.78</td><td>0.70</td></tr>
<tr><td>Climb out</td><td>5.66</td><td>5.62</td><td>5.63</td><td>5.67</td><td>5.28</td><td>2.08</td><td>1.95</td></tr>
<tr><td>Total elevated</td><td>12.63</td><td>13.12</td><td>13.09</td><td>12.87</td><td>12.15</td><td>4.97</td><td>4.55</td></tr>
<tr><td>Total aircraft</td><td>40.64</td><td>42.75</td><td>43.14</td><td>42.75</td><td>40.83</td><td>16.75</td><td>15.29</td></tr>
<tr><td>GSE[2]</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Exhaust</td><td>6.82</td><td>5.80</td><td>5.14</td><td>4.75</td><td>2.90</td><td>1.66</td><td>1.19</td></tr>
<tr><td>Fugitives</td><td>1.69</td><td>1.69</td><td>1.69</td><td>1.71</td><td>1.55</td><td>0.92</td><td>0.90</td></tr>
<tr><td>Total GSE</td><td>8.51</td><td>7.49</td><td>6.83</td><td>6.46</td><td>4.45</td><td>2.59</td><td>2.09</td></tr>
</table>

Source Category	Annual $PM_{2.5}$ emissions (tonnes)						
	2015	2016	2017	2018	2019	2020	2021
Stationary sources[3]							
Gas	N/A	N/A	N/A	N/A	1.05	0.90	2.25
Gas-oil	N/A	N/A	N/A	N/A	0.57	0.46	0.37
LPG	N/A	N/A	N/A	N/A	0.00	0.00	n/a
Biomass	N/A	N/A	N/A	N/A	36.87	44.53	4.78
(BA gas)	N/A	N/A	N/A	N/A	0.19	0.19	0.19
Total stationary	**6.36**	**4.83**	**N/A**	**N/A**	**38.68**	**46.08**	**7.60**
Total airfield	**55.51**	**55.07**	**N/A**	**N/A**	**83.96**	**65.42**	**24.98**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018. $PM_{2.5}$ emissions not calculated for 2017 or 2018.

Table 16 shows the values of annual aircraft LTO PM_{10} and $PM_{2.5}$ emissions normalised by the number of passengers and movements. PM_{10} and $PM_{2.5}$ emissions per passenger are highest in 2021. However, 2020 and 2021 are heavily affected by reduced passenger load factors due to the COVID-19 pandemic. PM_{10} and $PM_{2.5}$ per movement remained relatively constant over the period 2015 and 2021.

Table 16 LTO PM emissions per passenger and per movement: 2015 to 2021

	2015	2016	2017	2018	2019	2020	2021
LTO PM_{10} (tonnes per year)	48.33	50.57	51.03	50.69	48.71	20.36	18.81
LTO $PM_{2.5}$ (tonnes per year)	40.64	42.75	43.14	42.75	40.83	16.75	15.29
Passengers[1] (mppa)	74.95	75.67	77.99	80.10	80.89	22.11	19.40
LTO PM_{10} (g per passenger[1])	0.64	0.67	0.65	0.63	0.60	0.92	0.97
LTO $PM_{2.5}$ (g per passenger[1])	0.54	0.56	0.55	0.53	0.50	0.76	0.79
Movements[2] (1000s)	474.09	474.96	475.78	477.60	478.06	204.73	195.34
LTO PM_{10} (kg per movement[2])	0.10	0.11	0.11	0.11	0.10	0.10	0.10
LTO $PM_{2.5}$ (kg per movement[2])	0.09	0.09	0.09	0.09	0.09	0.08	0.08

[1] Excludes transit passengers
[2] ATMs and non-ATMs

From a local air quality perspective, emissions from aircraft on the ground have a greater impact than elevated emissions. The calculated value of ground-level aircraft PM_{10} emissions (including brake and tyre wear, APU and engine testing emissions) remained relatively constant between 2015 and 2019. Emissions in 2020 and 2021 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

For PM, non-exhaust emissions (aircraft brake and tyre wear) are a significant contributor to the ground-level aircraft emissions, together accounting for between 40% and 50% of the ground-level PM_{10} emissions (between 20% and 30% for $PM_{2.5}$).

Table 17 gives a breakdown of ground-level aircraft exhaust PM emissions (omitting brake and tyre wear, APUs and engine testing) by aircraft type. As expected from the movement breakdowns in Table 1, the A320 aircraft family (A318/A319, A320 and A321) account for a significant fraction of the emissions in all years. The larger aircraft types, B747, B777 and A380, together contribute 30% of the emissions in 2021, despite accounting for only 18% of the total movements. This is a slightly lower contribution than in previous years, but they also account for a smaller fraction of the movements than they did in previous years.

Table 17 also gives ground-level emissions per movement (excluding APU, engine testing and brake and tyre wear emissions) for each aircraft type. As explained in the NO_x discussion, this value may change over time even for a given aircraft type due to changes in sub-series and/or engine models in the fleet. Typically, the values for the larger aircraft types (B747, B777 and A380) are around a factor of two to three times those for the single-aisle jets. However, this pattern is changing, with newer aircraft types entering the fleet and fewer older aircraft remaining.

Table 17 Breakdown of ground-level aircraft PM[1] emissions[2] by aircraft type: 2015 to 2021

(a) annual emissions in tonnes

	PM emissions (tonnes/year)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	0.08	0.06	0.02	0.01	0.03	0.01	0.01
Medium	7.19	7.32	7.06	7.18	6.82	2.17	1.58
A318/A319	2.24	2.33	2.25	2.36	2.19	0.73	0.42
A320	3.34	3.35	3.32	3.28	3.04	1.03	0.96
A321	1.18	1.24	1.14	1.23	1.29	0.29	0.12
B737	0.29	0.29	0.23	0.21	0.18	0.07	0.05
Others	0.13	0.10	0.11	0.11	0.11	0.04	0.03
Heavy	7.10	7.04	7.13	7.54	7.36	3.06	2.85
A350	0.00	0.02	0.08	0.17	0.26	0.33	0.35
B747	1.83	1.51	1.59	1.70	1.62	0.36	0.07
B767	0.95	0.90	0.89	0.58	0.41	0.14	0.13
B777	2.89	2.86	2.89	3.20	3.00	1.24	1.16
B787	0.36	0.64	0.83	0.93	1.04	0.64	0.74
Other	1.08	1.11	0.85	0.97	1.04	0.35	0.40
A380	0.97	1.23	1.20	1.18	1.14	0.29	0.15
Total	**15.34**	**15.66**	**15.41**	**15.92**	**15.34**	**5.53**	**4.58**

(b) percentage of annual emissions by aircraft type

	PM emissions (%)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	0.5	0.4	0.1	0.1	0.2	0.1	0.2
Medium	46.9	46.8	45.8	45.1	44.4	39.2	34.5
A318/A319	14.6	14.9	14.6	14.8	14.3	13.3	9.2
A320	21.8	21.4	21.6	20.6	19.8	18.7	21.0
A321	7.7	7.9	7.4	7.7	8.4	5.3	2.5
B737	1.9	1.9	1.5	1.3	1.2	1.2	1.2
Others	0.9	0.7	0.7	0.7	0.7	0.8	0.7
Heavy	46.3	45.0	46.3	47.4	48.0	55.4	62.1
A350	0.0	0.1	0.5	1.1	1.7	5.9	7.7
B747	11.9	9.7	10.3	10.7	10.5	6.5	1.5
B767	6.2	5.8	5.8	3.6	2.6	2.5	2.7
B777	18.8	18.2	18.7	20.1	19.6	22.5	25.3
B787	2.3	4.1	5.4	5.8	6.8	11.7	16.1
Other	7.0	7.1	5.5	6.1	6.7	6.4	8.8
A380	6.3	7.9	7.8	7.4	7.4	5.3	3.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(c) average emissions per movement by aircraft type

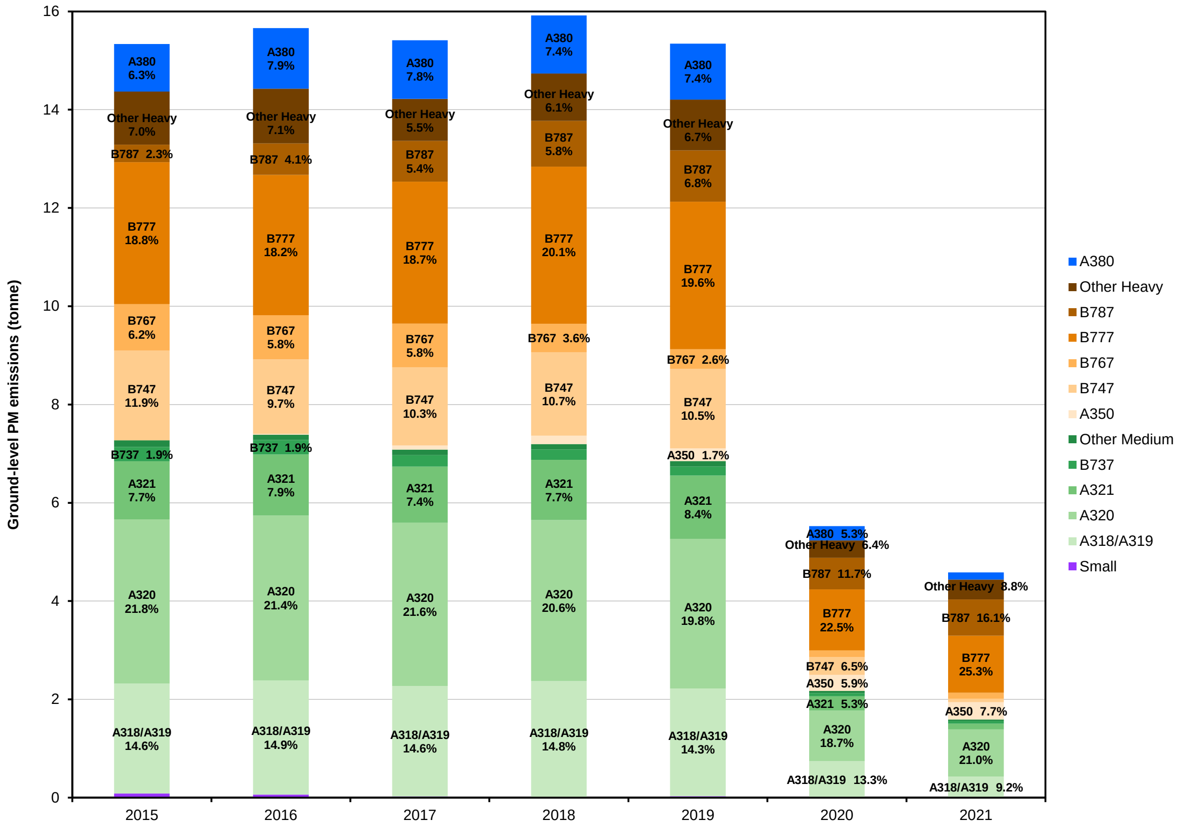
	PM emissions (g/movement)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	23.20	24.53	5.13	2.73	3.21	2.98	4.09
Medium	24.38	25.27	24.78	25.27	24.03	19.88	16.66
A318/A319	26.53	28.65	27.65	29.38	30.25	26.82	22.58
A320	23.68	23.90	23.51	23.15	21.35	18.48	17.43
A321	27.65	28.88	29.63	31.29	26.74	17.37	9.43
B737	15.72	15.71	15.38	14.89	16.74	13.81	10.40
Others	16.49	16.09	13.33	12.08	11.59	10.26	8.12
Heavy	44.11	42.83	42.42	43.91	43.56	34.40	29.63
A350	28.18	29.26	29.93	33.88	34.16	31.14	28.69
B747	71.15	73.27	77.40	83.72	85.50	80.56	59.76
B767	33.42	34.76	37.43	35.05	44.13	38.10	33.29
B777	46.09	46.63	47.11	50.55	49.51	40.65	37.48
B787	22.81	23.09	22.67	22.56	22.94	21.64	20.83
Other	37.78	39.39	36.71	38.07	38.03	34.79	32.19
A380	65.50	67.57	64.74	70.87	71.09	65.69	62.58
Total	**32.35**	**32.97**	**32.39**	**33.32**	**32.10**	**27.00**	**23.46**

[1] For exhaust emissions, PM_{10} and $PM_{2.5}$ have been taken to be the same.
[2] Ground–level emissions from main engines only (omitting APU, engine testing, brake wear and tyre wear)

Overall, the fleet-averaged value of ground-level aircraft PM emissions per movement, excluding APUs, engine testing, brake wear and tyre wear, remained relatively constant between 2015 and 2019, but reduced sharply in 2020 and 2021 (years that were heavily impacted by the COVID-19 pandemic). This contrasts with LTO PM emissions per movement (Table 16), which have remained relatively constant throughout. The reason for this is that LTO PM emissions include brake and tyre wear, which, per movement, rose sharply in 2020 and 2021 due to the increased average size of aircraft. This offset the reduction, per movement, in exhaust emissions.

Figure 7 shows the trend in ground-level aircraft PM emissions broken down by aircraft type.

Figure 7 Breakdown of ground-level aircraft PM[1] emissions[2] by aircraft type: 2015 to 2021



[1] For exhaust emissions, PM_{10} and $PM_{2.5}$ have been taken to be the same.
[2] Ground–level emissions from main engines only (omitting APU, engine testing, brake wear and tyre wear)

3.3 CO_2

In contrast to NO_x and PM, the emissions index (quantity of emission per kg of fuel burnt) for CO_2 is not a function of the engine type but is a constant[7] (3.15 kg/kg fuel). Therefore, the CO_2 emissions are calculated simply by multiplying the calculated fuel burn by that emissions index. Table 18 shows airfield emissions of CO_2 broken down by source category. For aircraft emissions these are the phases of the LTO cycle as reported in the 2013 inventory and dispersion modelling study and the subsequent annual updates.

The calculated total aircraft CO_2 emissions (up to 3,000 feet) increased year-on-year between 2015 and 2018, broadly in line with passenger numbers. However, in 2019 aircraft emissions were 4% lower than their 2018 peak despite continued passenger growth. This is mainly due to the propagating of newer more efficient aircraft types in into the fleet, particularly the A320 neo and A321 neo. There is also some year-on-year variation due to variations in operational data, such as APU running times and taxiing times, that influence emissions. Aircraft CO_2 emissions in both 2020 and 2021 were

[7] Strictly, the emissions index for CO_2 is a function of the chemistry of the fuel; it is slightly different for other fuels such as gasoline or diesel.

heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

GSE emissions remained relatively constant between 2015 and 2019. Emissions in 2020 and 2021 were heavily impacted by the COVID-19 pandemic.

CO_2 emissions from biomass burning are not included in the stationary source totals as they are not a fossil fuel. Emissions from other fuels remained relatively constant between 2015 and 2021. However, CO_2 emissions were not calculated for 2017 or 2018.

Table 18 Breakdown of airfield CO_2 emissions by mode: 2015 to 2021

Mode	Annual CO_2 emissions (kilotonnes)						
	2015	2016	2017	2018	2019	2020	2021
Aircraft							
Ground-level							
Landing roll	18.34	20.24	20.89	16.62	16.15	7.40	8.50
Taxi-in	92.62	93.84	92.44	99.71	95.66	38.84	32.39
Taxi-out	163.89	163.28	163.24	169.74	166.65	67.80	89.64
Hold	154.11	164.67	161.66	158.54	156.98	45.84	
Take-off roll	96.57	97.06	97.77	120.33	117.52	51.92	53.83
APU	84.32	103.00	118.63	104.30	90.70	44.61	40.24
Engine testing[1]	1.21	1.21	1.21	1.21	1.21	1.21	1.21
Total ground-level	**611.06**	**643.30**	**655.83**	**670.46**	**644.87**	**257.62**	**225.80**
Elevated							
Approach	152.66	177.16	182.40	176.54	175.12	77.36	72.91
Initial climb	76.05	69.80	67.33	68.30	64.65	27.39	26.38
Climb out	169.49	170.31	171.51	177.21	169.56	70.26	70.14
Total elevated	**398.20**	**417.27**	**421.23**	**422.05**	**409.34**	**175.01**	**169.43**
Total aircraft	**1009.26**	**1060.57**	**1077.07**	**1092.51**	**1054.21**	**432.63**	**395.23**
GSE[2]	**29.88**	**29.88**	**29.88**	**30.43**	**28.52**	**16.45**	**16.01**

Mode	Annual CO_2 emissions (kilotonnes)						
	2015	2016	2017	2018	2019	2020	2021
Stationary Sources[3]							
Gas	n/a	n/a	n/a	n/a	22.24	16.89	22.34
Gas-oil	n/a	n/a	n/a	n/a	1.61	1.29	1.05
LPG	n/a	n/a	n/a	n/a	0.04	0.00	n/a
Biomass	n/a	n/a	n/a	n/a	n/a	n/a	n/a
(BA gas)	n/a	n/a	n/a	n/a	17.36	17.36	17.36
Total Stationary	**38.76**	**37.45**	**n/a**	**n/a**	**41.23**	**35.53**	**40.75**
Total Airfield	**1077.89**	**1127.90**	**n/a**	**n/a**	**1123.97**	**484.62**	**451.99**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018. CO_2 emissions not calculated for 2017 or 2018. CO_2 emissions from biomass not included.

Table 19 shows the values of annual aircraft LTO CO_2 emissions normalised by the number of passengers and movements. The CO_2 per passenger is highest in 2021. However, 2020 and 2021 are heavily affected by reduced passenger load factors due to the COVID-19 pandemic. The CO_2 per movement increased year-on-year between 2015 and 2018 in line with the shift towards larger aircraft. However, this trend did not continue into 2019, mainly due to the propagating of newer cleaner aircraft types into the fleet

Table 19 LTO CO_2 emissions per passenger and per movement: 2015 to 2021

	2015	2016	2017	2018	2019	2020	2021
LTO CO_2 (kilotonnes per year)	1009.26	1060.57	1077.07	1092.51	1054.21	432.63	395.23
Passengers[1] (mppa)	74.95	75.67	77.99	80.10	80.89	22.11	19.40
LTO CO_2 (kg per passenger[1])	13.47	14.02	13.81	13.64	13.03	19.57	20.38
Movements[2] (1000s)	474.09	474.96	475.78	477.60	478.06	204.73	195.34
LTO CO_2 (tonnes per movement[2])	2.13	2.23	2.26	2.29	2.21	2.11	2.02

[1] Excludes transit passengers
[2] ATMs and non-ATMs

Table 20 gives a breakdown of LTO aircraft CO_2 emissions (omitting APUs and engine testing) by aircraft type. The B777 and B787 together contribute over half of the emissions in 2021, despite accounting for only a third of the total movements. Before 2020, they had contributed approximately a third of the emissions from a fifth of the total movements. Conversely, between 2015 and 2019 the A320 aircraft family (A318/A319, A320 and A321) only accounted for approximately 30% of the emissions despite accounting for more than half of the total movements. The contribution from the A320 family declined further in 2020 and again in 2021 by which time it accounted for only 22% emissions from 44% of the movements.

Table 20 also gives LTO emissions per movement (excluding APU and engine testing emissions) for each aircraft type. Emissions of CO_2 have global impacts on climate change, rather than the more local effects of pollutants such as NO_x and PM. Therefore, the values are presented for the complete movement (up to 3,000 feet altitude) rather than just the ground-level emissions as presented for the other pollutants. The table shows that the values of LTO emissions per movement for the large aircraft types (B747 and B777) are around a factor of four higher than the average for A318/A319/320/321 or B737 aircraft. Of course, the large types carry more passengers than the A320/B737 families, but only around twice as many passengers, so the CO_2 /passenger ratio is roughly double that of the A320/B737 families.

Table 20 Breakdown of LTO aircraft CO_2 emissions[1] by aircraft type: 2015 to 2021

(a) annual emissions in kilotonnes

	CO_2 emissions (kilotonnes/year)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	2.34	1.72	1.37	1.46	2.45	0.66	0.57
Medium	305.18	311.29	306.78	310.66	306.11	104.48	84.31
A318/A319	81.48	82.95	82.37	83.36	76.17	26.60	16.71
A320	143.97	148.34	151.19	151.98	149.20	51.96	49.25
A321	51.32	53.13	48.46	51.49	59.85	17.81	11.03
B737	18.67	19.03	15.54	14.54	11.62	4.63	4.53
Others	9.75	7.83	9.22	9.29	9.27	3.48	2.80
Heavy	530.69	536.04	544.08	575.88	559.81	257.01	256.52
A350	0.16	1.93	7.38	14.43	21.55	28.90	32.73
B747	122.82	101.93	102.84	105.14	98.90	21.59	4.73
B767	61.62	54.66	51.60	37.95	19.87	7.78	7.50
B777	220.66	221.56	222.54	240.29	227.17	104.17	102.39
B787	37.26	68.95	89.96	99.95	110.92	68.92	79.14
Other	88.17	87.02	69.76	78.14	81.41	25.66	30.03
A380	85.52	107.31	104.99	98.99	93.94	24.67	12.39
Total	**923.73**	**956.36**	**957.23**	**986.99**	**962.30**	**386.82**	**353.79**

(b) percentage of annual emissions by aircraft type

	CO_2 emissions (%)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	0.3	0.2	0.1	0.1	0.3	0.2	0.2
Medium	33.0	32.5	32.0	31.5	31.8	27.0	23.8
A318/A319	8.8	8.7	8.6	8.4	7.9	6.9	4.7
A320	15.6	15.5	15.8	15.4	15.5	13.4	13.9
A321	5.6	5.6	5.1	5.2	6.2	4.6	3.1
B737	2.0	2.0	1.6	1.5	1.2	1.2	1.3
Others	1.1	0.8	1.0	0.9	1.0	0.9	0.8
Heavy	57.5	56.0	56.8	58.3	58.2	66.4	72.5
A350	0.0	0.2	0.8	1.5	2.2	7.5	9.3
B747	13.3	10.7	10.7	10.7	10.3	5.6	1.3
B767	6.7	5.7	5.4	3.8	2.1	2.0	2.1
B777	23.9	23.2	23.2	24.3	23.6	26.9	28.9
B787	4.0	7.2	9.4	10.1	11.5	17.8	22.4
Other	9.5	9.1	7.3	7.9	8.5	6.6	8.5
A380	9.3	11.2	11.0	10.0	9.8	6.4	3.5
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

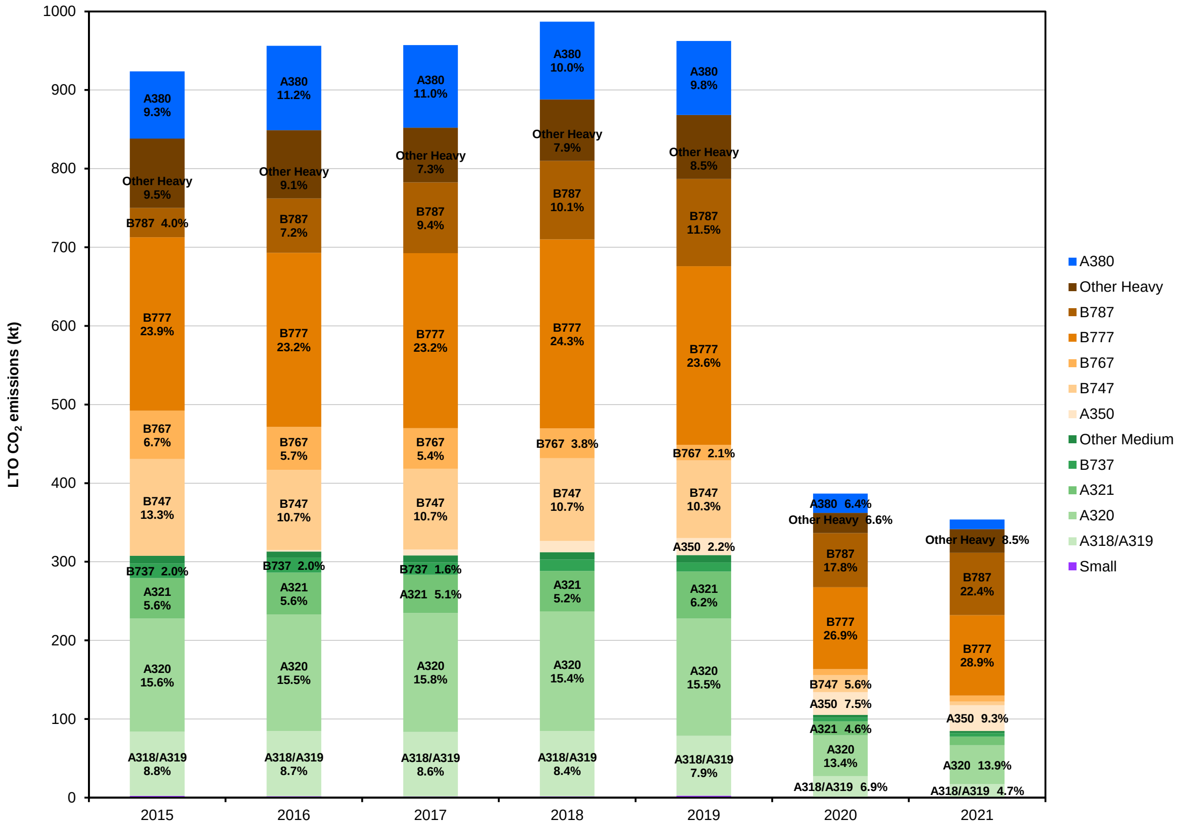
(c) average emissions per movement by aircraft type

	CO_2 emissions (tonnes/movement)						
Aircraft Type	2015	2016	2017	2018	2019	2020	2021
Small	0.65	0.69	0.32	0.28	0.26	0.28	0.30
Medium	1.04	1.07	1.08	1.09	1.08	0.96	0.89
A318/A319	0.97	1.02	1.01	1.04	1.05	0.97	0.89
A320	1.02	1.06	1.07	1.07	1.05	0.93	0.89
A321	1.20	1.23	1.26	1.31	1.24	1.07	0.90
B737	1.02	1.02	1.02	1.04	1.08	0.96	0.88
Others	1.19	1.20	1.08	1.02	0.95	0.83	0.74
Heavy	3.30	3.26	3.24	3.35	3.31	2.89	2.67
A350	2.71	2.70	2.63	2.86	2.85	2.75	2.67
B747	4.79	4.93	5.00	5.19	5.23	4.83	4.18
B767	2.17	2.11	2.17	2.29	2.16	2.17	1.99
B777	3.52	3.62	3.63	3.80	3.75	3.41	3.31
B787	2.39	2.50	2.47	2.42	2.44	2.31	2.24
Other	3.08	3.08	3.00	3.08	2.99	2.54	2.39
A380	5.77	5.88	5.68	5.93	5.87	5.51	5.32
Total	**1.95**	**2.01**	**2.01**	**2.07**	**2.01**	**1.89**	**1.81**

[1] LTO emissions from main engines only (omitting APU and engine testing).

Figure 8 shows the trend in LTO aircraft CO_2 emissions broken down by aircraft type.

Figure 8 Breakdown of LTO aircraft CO_2 emissions[1] by aircraft type: 2015 to 2021



[1] LTO emissions from main engines only (omitting APU and engine testing)

4 Summary and conclusions

The total annual emissions of NO_x, PM_{10}, $PM_{2.5}$ and CO_2 on the airfield have been calculated for the calendar year 2021, based on detailed flight records held by Heathrow Airport. These have been presented along with inventories for 2015 to 2020 that were produced for the Airport Expansion Consultation and developed further for annual "Business as Usual" reporting.

Table 21 shows some summary information about total emissions from the LTO (including APUs, engine testing and brake and tyre wear), while Table 22 presents the same information for ground-level emissions only.

Up until 2019, the number of aircraft movements has remained broadly constant, reflecting the fact that the airport was operating close to the cap of 480,000 ATMs (refer to Figure 1). Despite this, the number of passengers shows a steady increase over the same period, accommodated by a larger number of passengers per movement on average (Figure 2). In 2020 there was a dramatic downturn in both movements and passengers due to the COVID-19 pandemic. This downturn continued into 2021.

Aircraft NO_x emissions in the Landing and Take-Off (LTO) cycle (up to 3,000 feet altitude) increased year-on-year between 2015 and 2018, broadly in line with passenger numbers. However, in 2019 aircraft emissions were 5% lower than their 2018 peak despite continued passenger growth. This is mainly due to the propagating of newer low-NO_x aircraft types in into the fleet.

For PM_{10} and $PM_{2.5}$, emissions in the LTO cycle remained relatively constant between 2015 and 2019.

For CO_2, emissions in the LTO cycle followed a similar pattern to NO_x, increasing year-on-year between 2015 and 2018, with aircraft emissions in 2019 4% lower than their 2018 peak due to the propagating of newer more efficient aircraft types in into the fleet.

For all pollutants, emissions in 2020 and 2021 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

The calculated value of ground-level aircraft NO_x emissions (which are more important than elevated emissions from the perspective of local air quality) also peaked in 2018. The calculated value of ground-level aircraft PM_{10} and $PM_{2.5}$ emissions (including brake and tyre wear, APU and engine testing emissions) remained relatively constant between 2015 and 2019. Ground-level emissions are plotted in Figure 9 and total LTO emissions are plotted in Figure 10. Figure 11 plots total LTO emissions for CO_2.

Figure 12 shows the ground-level NO_x emissions per movement and per passenger. The calculated value of NO_x emissions per movement in 2018 stands clearly above the long-term trend, which is gently increasing. However, the reasons are far from obvious and are likely to be a combination of many factors. The impact of reduced passenger load factors in 2020 and 2021 due to the COVID-19 pandemic can clearly be seen in the calculated values of NO_x emissions per passenger.

Figure 13 and Figure 14 show the ground-level emissions per movement and per passenger, for PM_{10} and $PM_{2.5}$, respectively. Emissions per movement are highest in 2017. As for NO_x, the impact of reduced passenger load factors in 2020 and 2021 can clearly be seen in the calculated values of PM emissions per passenger.

Note that the vertical scales in Figure 12 to Figure 14 are chosen to exaggerate the trends, which are typically only a few percent per year.

Table 21 Summary of total LTO emissions

	2015	2016	2017	2018	2019	2020	2021
NO_x (t/year)	4321.52	4487.28	4634.87	4919.82	4657.52	2017.87	1875.74
NO_x (g/pax[1])	57.66	59.30	59.43	61.42	57.58	91.27	96.70
NO_x (kg/mvt[2])	9.12	9.45	9.74	10.30	9.74	9.86	9.60
PM_{10} (t/year)	48.33	50.57	51.03	50.69	48.71	20.36	18.81
PM_{10} (g/pax[1])	0.64	0.67	0.65	0.63	0.60	0.92	0.97
PM_{10} (kg/mvt[2])	0.10	0.11	0.11	0.11	0.10	0.10	0.10
$PM_{2.5}$ (t/year)	40.64	42.75	43.14	42.75	40.83	16.75	15.29
$PM_{2.5}$ (g/pax[1])	0.54	0.56	0.55	0.53	0.50	0.76	0.79
$PM_{2.5}$ (kg/mvt[2])	0.09	0.09	0.09	0.09	0.09	0.08	0.08
CO_2 (kt/year)	1009.26	1060.57	1077.07	1092.51	1054.21	432.63	395.23
CO_2 (kg/pax[1])	13.47	14.02	13.81	13.64	13.03	19.57	20.38
CO_2 (t/mvt[2])	2.13	2.23	2.26	2.29	2.21	2.11	2.02

[1] Excludes transit passengers
[2] ATMs and non-ATMs

Table 22 Summary of ground-level emissions

	2015	2016	2017	2018	2019	2020	2021
NO_x (t/year)	1679.94	1782.89	1829.73	2013.29	1906.85	826.23	759.63
NO_x (g/pax[1])	22.41	23.56	23.46	25.13	23.57	37.37	39.16
NO_x (kg/mvt[2])	3.54	3.75	3.85	4.22	3.99	4.04	3.89
PM_{10} (t/year)	35.69	37.45	37.94	37.83	36.55	15.39	14.26
PM_{10} (g/pax[1])	0.48	0.49	0.49	0.47	0.45	0.70	0.74
PM_{10} (kg/mvt[2])	0.08	0.08	0.08	0.08	0.08	0.08	0.07
$PM_{2.5}$ (t/year)	28.01	29.64	30.05	29.88	28.68	11.78	10.74
$PM_{2.5}$ (g/pax[1])	0.37	0.39	0.39	0.37	0.35	0.53	0.55
$PM_{2.5}$ (kg/mvt[2])	0.06	0.06	0.06	0.06	0.06	0.06	0.05

[1] Excludes transit passengers
[2] ATMs and non-ATMs

Figure 9 Ground-level emissions of NO_x, PM_{10} and $PM_{2.5}$

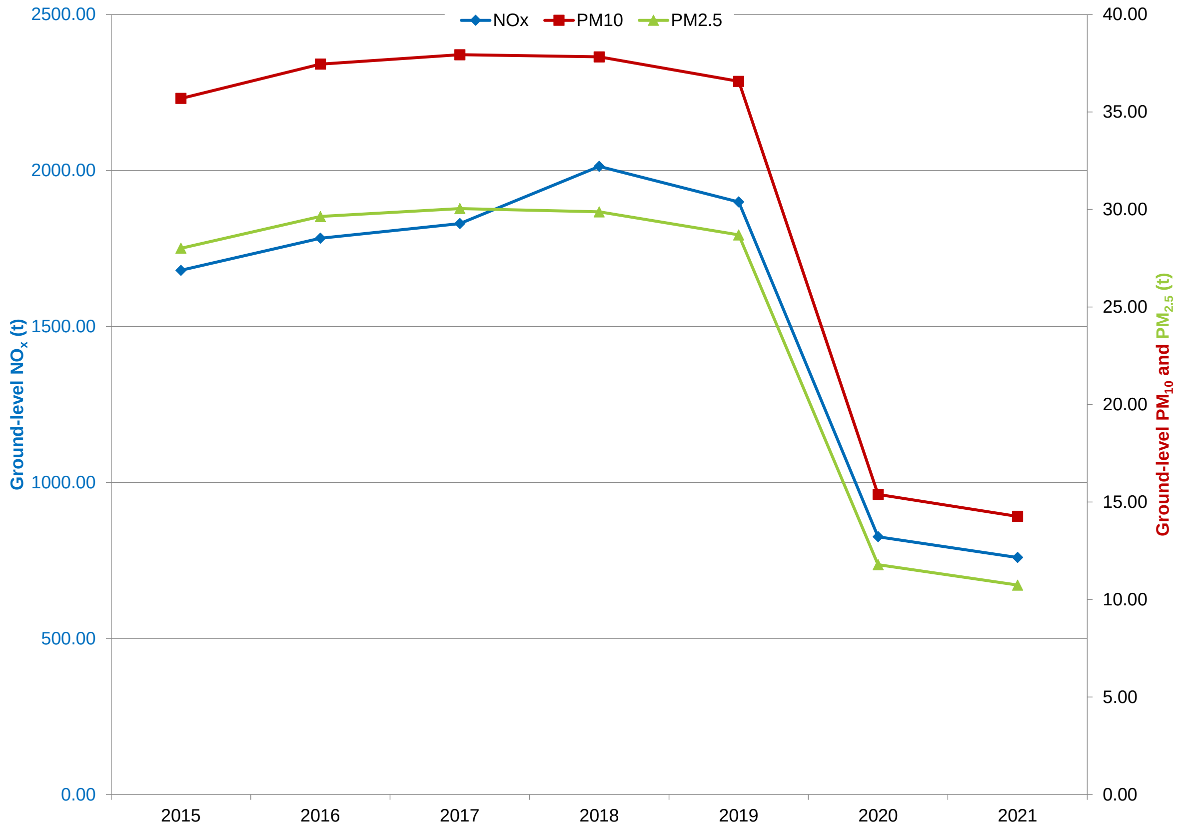


Figure 10 LTO emissions of NO_x, PM_{10} and $PM_{2.5}$

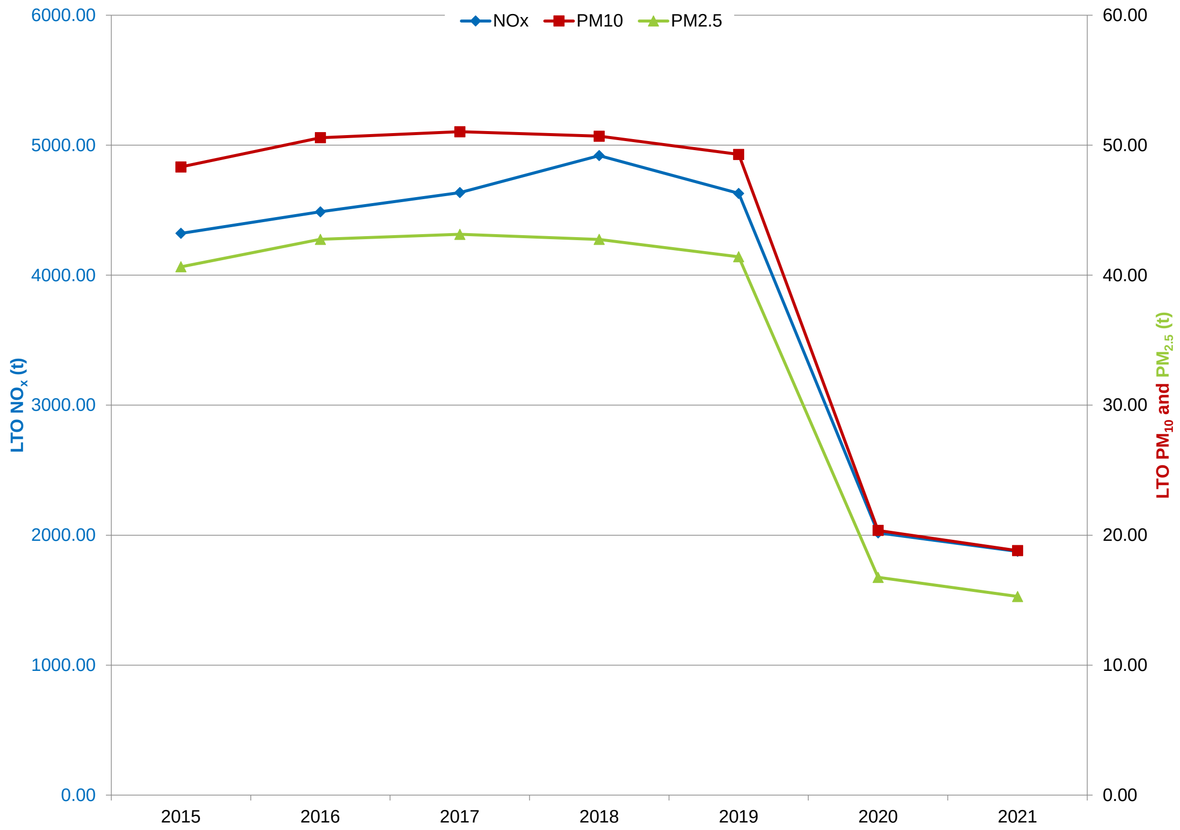


Figure 11 LTO emissions of CO_2

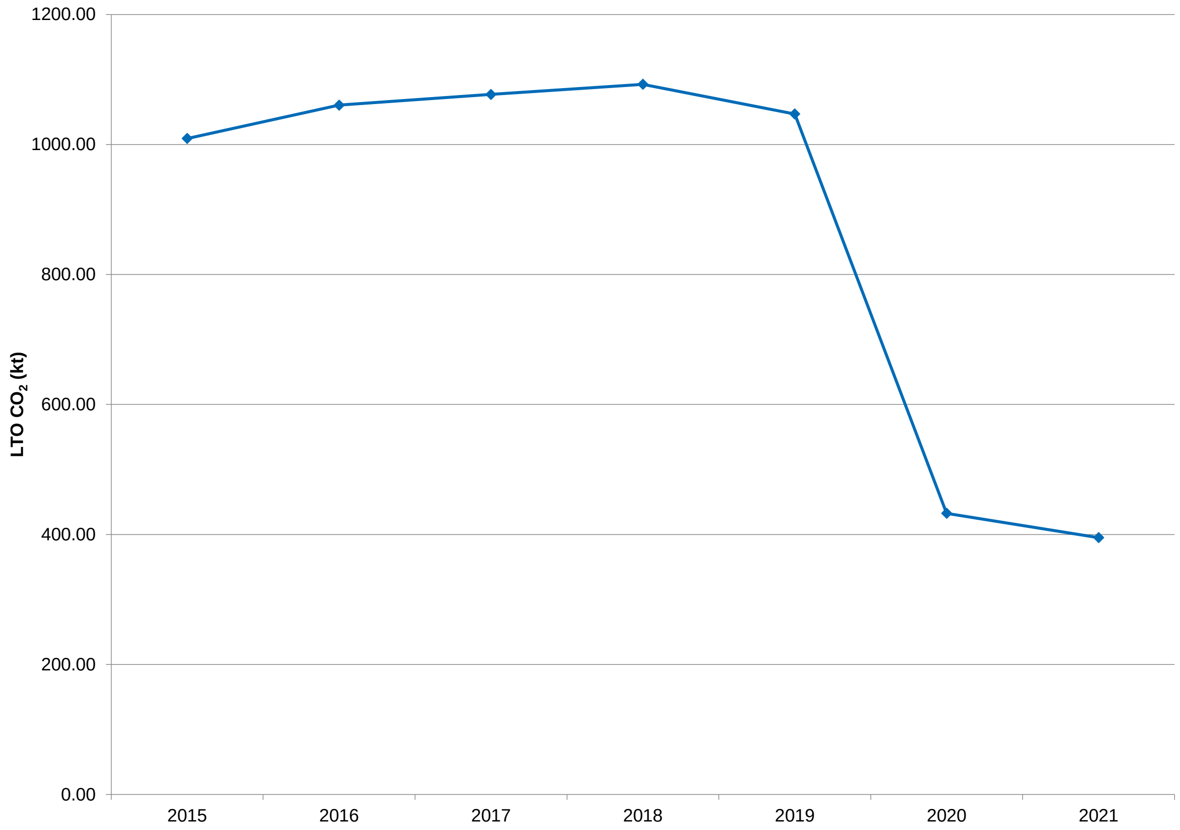


Figure 12 Ground-level NO_x emissions per movement and per passenger

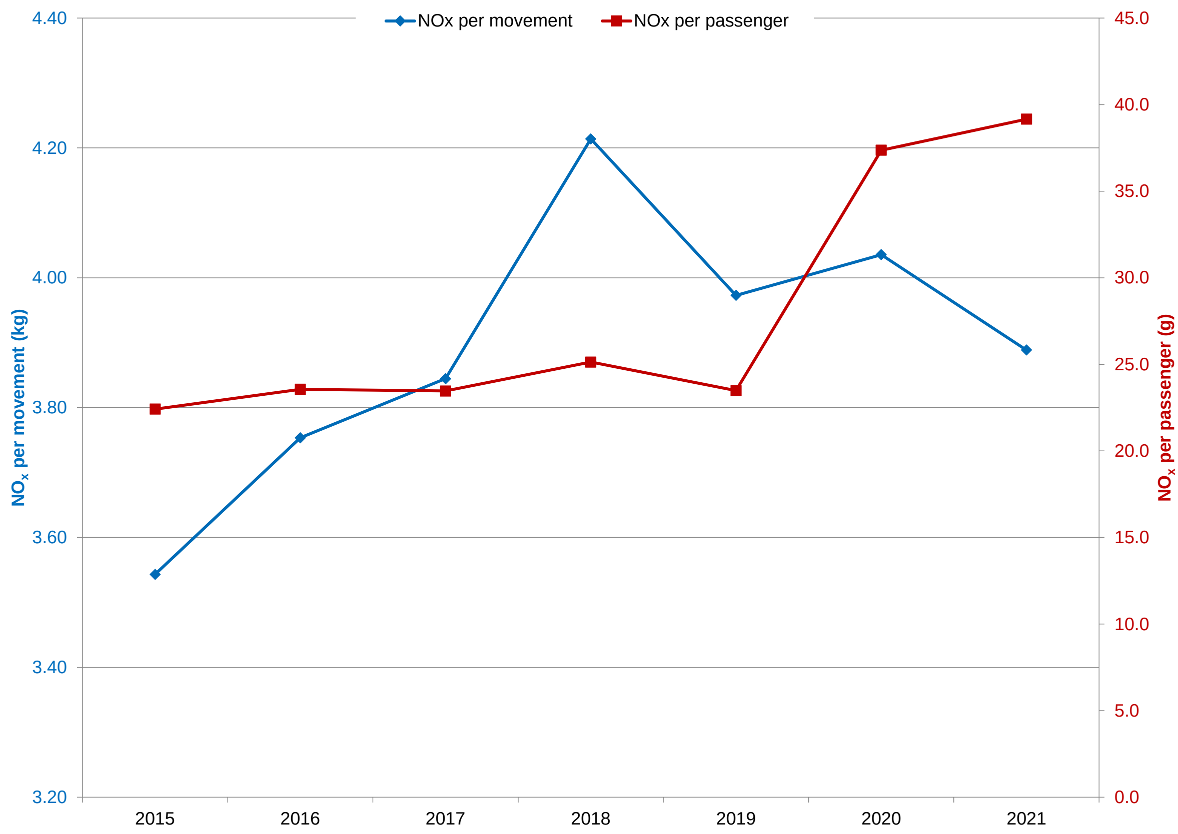


Figure 13 Ground-level PM_{10} emissions per movement and per passenger

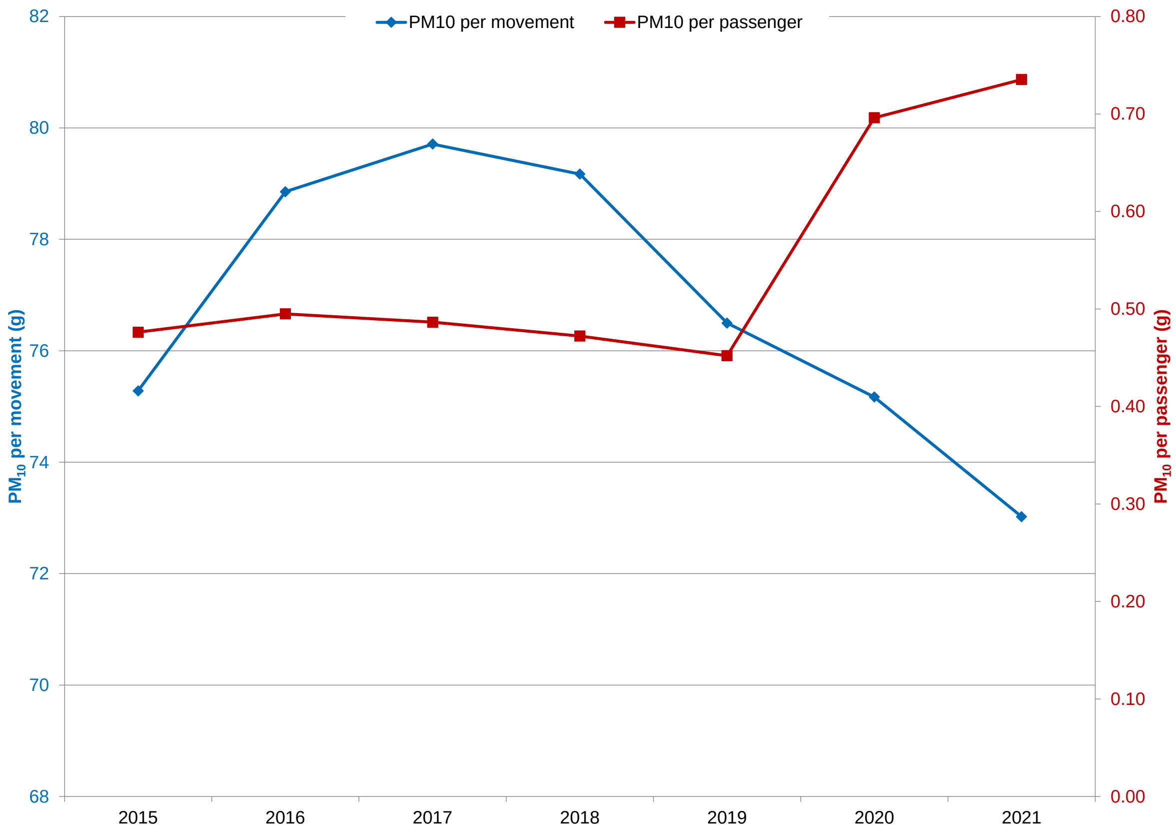
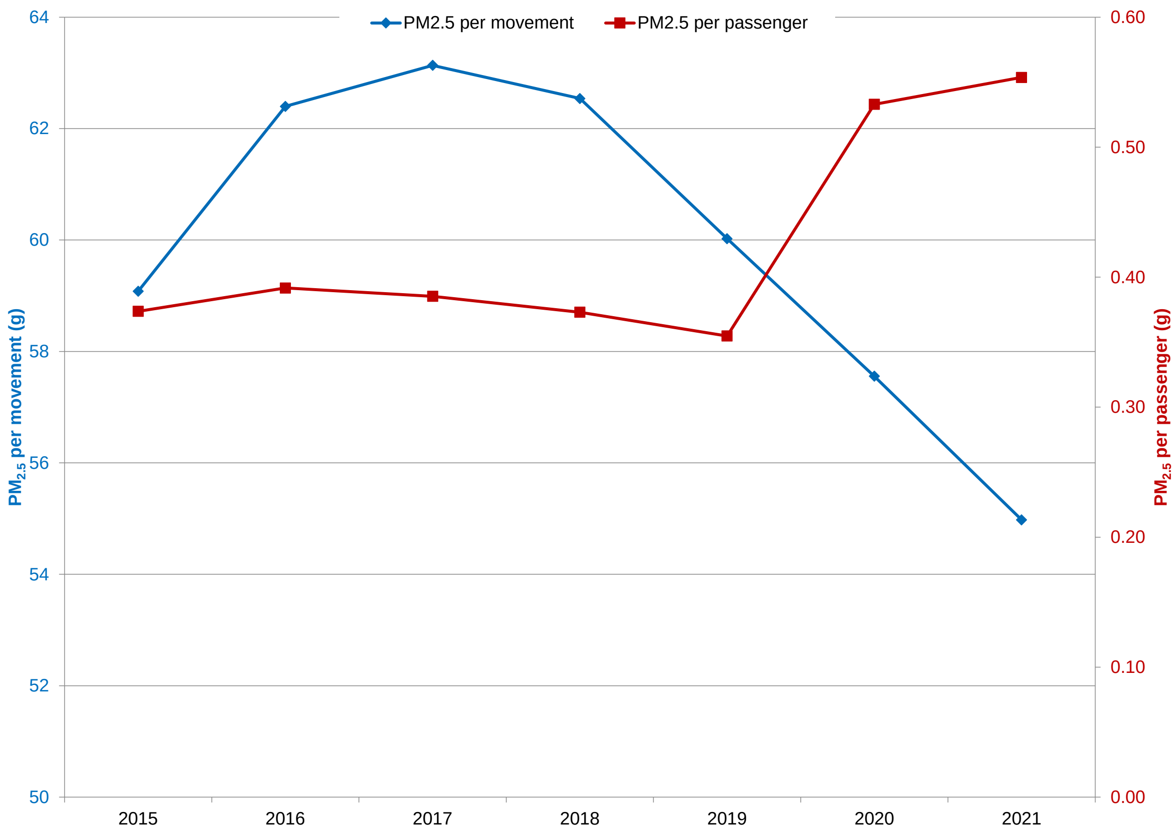


Figure 14 Ground-level $PM_{2.5}$ emissions per movement and per passenger



5 Recommendations

Take-off roll emissions are highly sensitive to the thrust settings selected and, in the absence of specific data, broad assumptions have had to be made. We recommend that Heathrow engage with the airlines to obtain suitable data to estimate take-off thrusts. Accurate fuel flow data should be available from the Flight Data Recorders. Research into this area may provide invaluable data that would improve the accuracy of the inventories. Alternatively, actual take-off weight statistics could be used to provide estimates likely take-off thrusts. Both these routes would require the co-operation of the airlines and non-disclosure agreements may be needed to allay their concerns over the commercial sensitivity of their data.

Considering the apparent reduction in the use of reduced engine taxiing on departure, the survey of its use on arrival should be updated to establish if it is similarly affected.

6 References

[i] Peace H, Walker C T and Peirce M J (2015) Heathrow Airport 2013 Air Quality Assessment. Ricardo-AEA/R/3438.

[ii] https://www.heathrow.com/content/dam/heathrow/web/common/documents/company/about/expansion/Heathrow-Expansion-Consultation-June-2019.pdf

[iii] Walker C T (2022) Heathrow Airport Airfield Emission Inventories 2015 to 2020.

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