Supporting Information

Global Health Impacts of Future Aviation Emissions under Alternative Control Scenarios

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<u>Pages S4-11 includes the following Tables and Figures:</u>

Figure S2: Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2050 ref)

Figure S3: Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2050 Tech & Op)

Figure S4: Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2050 Alt Fuel

Supporting Information

Results from the three sensitivity analyses are presented here.

Impact of different exposure response function models

Results of sensitivity analyses where we used the RR function from the previous American Cancer Society study as opposed to the new curves are shown in Tables S3 and S4, with otherwise the same assumptions as in Table 3. All mortality estimates for 2006 and 2050 in Tables S3-8 were calculated using present day population for both 2006 and 2050. The lower and upper bounds for each estimate were calculated using the lower and upper bounds of each of the three parameters (Table 1) in the health impact calculations. Tables S3 and S4 compare with Tables S5 and S6, which show results using the IER function; the right columns of Table S5 under each scenario are the results presented in Table 2.

In 2006, the estimated excess mortality for adults 25 years and older due to $PM_{2.5}$ emissions attributable to the aviation sector is 395 deaths with the old exposure response function (Table S3) and 393 deaths with the IER function (Table S5), while the mortality estimate for all ages is 396 (Table S4) and 393 deaths (Table S8) using the old and new model respectively. Total excess mortality for adults over 25 years and older from all emission sectors in 2006 is 20.4 million (Table S3) and 1.90 million deaths (Table S7) from the old and new model, respectively. The excess mortality estimates are higher using the old function in 2006. This relationship holds true for total mortality estimates attributable to all emission sectors in the three 2050 scenarios. For example, under the Alt Fuel scenario, total excess mortality for adults 25 years and older 1.59 million (Table S3) and 1.42 million deaths (Table S7) for the old and new function, respectively. However, the new IER function yields higher mortality estimates for the 2050 scenarios for aviation sector attributable $PM_{2.5}$-related mortality. Under the Alt Fuel scenario, excess mortality for adults 25 years and older is 927 deaths (Table S3) and 1562 deaths (Table S5) for the old and new function, respectively. This could be due to the 50 μg/cm^3 high concentration threshold, since we subtract the non-aviation concentration from the total to get the aviation contribution, there will be no contribution from the aviation sector in those very polluted regions (with concentration above 50μg/cm^3) when applying the high concentration threshold.

Impact of different population sources

In Tables S5-8, each scenario (i.e. 2006 Baseline, Reference, Tech Operation and Improvement, and Alternative Fuel) has two columns. The left columns are results based on the CIESIN gridded population of the world in 2010. The right columns (Year_Adj) show results after matching the CIESIN population data to the GBD regional population estimates.

The estimates using the CIESIN population data are slightly smaller than those using the GBD regional population data. This could be due to several factors. First, the CIESIN and GBD regional population data vary slightly such that a small fraction of the global population is lost to bodies of water using the CIESIN data, and the fraction of the population lost varied by the population data resolution. With a population data resolution of 2.5'x2.5' and 1°x1° (not reported), the loss was about 2% and 6%, respectively. This minor population loss could have yielded the smaller mortality estimates using the CIESIN data. Secondly, the total population estimates from the GBD and CIESIN data were adjusted by multiplying the ratio of population difference between the two dataset within the same region. The population ratio variance was greater than 1 in some regions and less than 1 in others; however, we observed an overall greater mortality estimates obtained using the GBD population. We believe this is due to the 2% loss observed in the 2.5'x2.5' resolution population data (data not shown).

Further, the GBD regional population data do not include the countries that are not WHO Member States. However, the total population estimates using the GBD and CIESIN data are 6.9 and 6.8 billion, respectively. We believe that the exclusion of non-Member states did not impact the mortality estimates as they are mostly tourist countries.

Comparing the CIESIN population data to the GBD population data, in 2006, $PM_{2.5}$ emissions from the aviation sector resulted in an estimated 405 excess deaths in adults 25 years or older (Table S5), a difference of 3.2% from the CIESIN data estimate of 392 deaths. All of the mortality estimates obtained using the adjusted population were, on average, 2.8% greater than those using the unadjusted CIESIN data. The adjusted results are more directly comparable to other studies that employ the GBD regional population estimates.

Mortality difference between all ages and adults 25 years and older

Our analysis suggests that including all ages or just adults 25 years and older yields similar excess mortality estimates. Tables S5 and S6 show $PM_{2.5}$-related mortality estimates attributable to the aviation sector for adults 25 years and older and all ages, respectively, and Tables S7 and S8 show mortality estimates attributable to all emission sectors for the two age groups. Corresponding values in each of the two pairs of tables are very similar. In Table S3, mortality estimate for adults 25 years or older under the 2006 Baseline scenario using CIESIN population is 392 deaths, and in Table S6, the corresponding estimate for all ages is 393 deaths. The similar estimates obtained from the two analyses are most probably due to the fact that cardiorespiratory outcomes that we analyzed are health outcomes common among adults. Therefore, the inclusion of those under 25 years old did not alter the mortality estimates significantly.

Table S1. Volpe Aviation Environmental Design Tool (AEDT) global aviation emission inventories.

Emission	2006	2050		
		Ref	Tech & Op	Alt
NO_x (TgN/yr)	0.812	3.95	1.57	1.57
SO_2 ($TgSO_2$/yr)	0.221	1.06	0.604	0.0
Sulfate (Gg/yr)	6.78	32.51	18.52	0.0
BC (Gg/yr)	5.96	29.04	16.56	8.3
OC (Gg/yr)	6.62	27.52	15.75	15.75
CO (Tg/yr)	0.676	2.50	1.42	1.42
Alkenes (Gg/yr)	2.698	5.90	3.35	3.35
Paraffin (Gg/yr)	1.437	3.15	1.78	1.78
CO_2 (Tg/yr)	594	2852	1625	1625
H_2O (Tg/yr)	232	1111	633	633

Shows individual species of global aviation emission inventories under the four scenarios used in this study.

Table S2. Non-aviation anthropogenic sector emission sources in 2005 (and 2050 in brackets)

	NO_x ($TgNO_2$/yr)	CO (TgCO/yr)	SO_2 ($TgSO_2$/yr)	NMVOC (Tg/yr)	BC (Tg/yr)	OC (Tg/yr)	NH_3 ($TgNH_3$/yr)
Residential/ Commercial	10.2 (8.9)	259.3 (215.8)	9.0 (5.1)	39.9 (29.50)	2.23 (1.61)	8.56 (5.68)	0.35 (0.33)
Energy	24.4 (10.4)	24.9 (37.9)	60.4 (14.3)	27.5 (30.0)	0.07 (0.08)	0.47 (0.37)	0.03 (0.02)
Industry	15.0 (10.2)	95.4 (126.9)	27.3 (17.3)	8.8 (7.2)	1.60 (0.89)	2.37 (1.62)	0.16 (0.24)
Shipping	18.7 (20.4)	1.2 (1.4)	11.1 (6.7)	3.2 (4.3)	0.14 (0.20)	0.15 (0.21)	N/A
Surf trans	35.5 (23.2)	231.0 (154.0)	4.6 (5.2)	35.0 (40.4)	1.43 (1.32)	1.60 (1.42)	0.48 (0.30)
Waste	0.3 (0.1)	4.0 (2.3)	0.05 (0.04)	1.6 (1.4)	0.04 (0.04)	0.05 (0.05)	N/A
Agricultural waste burning	0.7 (0.8)	20.6 (21.1)	0.2 (0.2)	2.8 (2.7)	0.15 (0.16)	0.74 (0.76)	0.70 (0.86)
Savannah burning	11.5 (9.7)	221.3 (185.8)	1.5 (1.2)	35.0 (29.3)	1.48 (1.25)	10.82 (9.12)	4.14 (3.37)
Land-use change (deforestation)	6.0 (3.8)	233.1 (127.2)	2.2 (1.1)	42.5 (22.6)	1.11 (0.63)	12.09 (7.59)	6.87 (3.17)
Agriculture Animals/rice	2.2 (2.9)	N/A	N/A	0.9 (1.0)	N/A	N/A	37.91 (48.19)
Solvents	N/A	0.6 (0.4)	N/A	22.4 (22.4)	N/A	N/A	N/A
Total	127.5 (95.6)	1091.6 (872.7)	116.4 (51.4)	219.5 (190.6)	8.26 (6.18)	36.85 (26.81)	50.6 (56.5)

Shows non-aviation anthropogenic sector emission sources of short-lived trace gas and aerosol precursors in 2005 and 2050 in brackets from IPCC Fifth Assessment Report RCP4.5.

Total Excess Mortality		2006 Baseline		2050 Reference		2050 Tech & Operation		2050 Alt Fuel	
		Total	Aviation	Total	Aviation	Total	Aviation	Total	Aviation
Ischemic Heart Disease (IHD)	Upper bound	1535989.73	339.14	1206254.13	2901.80	1204601.72	1249.39	1204133.65	781.32
	Central	1315399.82	268.96	1042720.40	2281.60	1041428.52	989.73	1041032.83	594.03
	Lower bound	998853.13	188.32	798769.04	1590.36	797874.38	695.70	797576.90	398.22
Stroke	Upper bound	474064.05	107.83	345878.37	1141.66	345220.22	483.51	345052.07	315.36
	Central	305564.43	62.21	225139.96	664.75	224758.69	283.49	224653.21	178.01
	Lower bound	33496.82	5.94	24938.74	64.97	24901.73	27.96	24890.46	16.69
Chronic Obstructive Pulmonary Disease (COPD)	Upper bound	600134.87	49.37	511482.45	474.64	511231.45	223.63	511075.06	67.24
	Central	238686.59	16.15	203401.31	164.24	203316.96	79.89	203253.30	16.23
	Lower bound	-319364.84	-17.20	-272185.00	-190.80	-272090.54	-96.34	-272003.19	-8.99
Lung Cancer (LC)	Upper bound	241392.08	71.22	163060.81	726.13	162638.77	304.09	162540.53	205.86
	Central	177314.95	47.58	119735.66	496.53	119447.87	208.75	119377.41	138.28
	Lower bound	91548.19	22.06	61808.31	238.05	61670.78	100.52	61635.21	64.95
Total	Upper bound	2851580.73	567.56	2226675.76	5244.23	2223692.16	2260.62	2222801.31	1369.78
	Central	2036965.79	394.9	1590997.33	3607.12	1588952.04	1561.86	1588316.75	926.55
	Lower bound	804533.3	199.12	613331.09	1702.58	612356.35	727.84	612099.38	470.87

Table S3. Excess mortality using the old RR function (ages $\geq$ 25 years, CIESIN population)

Shows excess mortality in adults 25 and older due to $PM_{2.5}$ from the all emission sectors (left column labeled “total” under each scenario) and the aviation sector for four outcomes under the four scenarios using the old function and CIESIN population data.

Table S4. Excess mortality using the old RR function (all ages, CIESIN population)

Total Excess Mortality		2006 Baseline		2050 Ref		2050 Tech & Operation		2050 Alt Fuel	
		Total	Aviation	Total	Aviation	Total	Aviation	Total	Aviation
Ischemic Heart Disease (IHD)	Upper bound	1553231.28	339.96	1222680.27	2906.86	1221025.64	1252.23	1220554.41	781.00
	Central	1330459.08	269.64	1057087.09	2285.60	1055793.55	992.06	1055395.02	593.54
	Lower bound	1010501.62	188.82	809896.09	1593.16	809000.35	697.42	808700.61	397.69
Stroke	Upper bound	476598.01	107.97	348295.17	1142.59	347636.59	484.01	347467.95	315.37
	Central	307246.90	62.30	226747.57	665.30	226366.06	283.79	226260.25	177.99
	Lower bound	33687.12	5.95	25120.93	65.03	25083.89	27.99	25072.59	16.69
Chronic Obstructive Pulmonary Disease (COPD)	Upper bound	609699.72	49.60	520891.47	474.84	520640.79	224.16	520482.80	66.16
	Central	242549.59	16.24	207201.53	164.29	207117.34	80.10	207052.99	15.75
	Lower bound	-324612.54	-17.34	-277347.65	-190.84	-277253.45	-96.64	-277165.09	-8.28
Lung Cancer (LC)	Upper bound	241934.60	71.26	163513.93	726.63	163091.62	304.33	162993.23	205.94
	Central	177718.82	47.61	120072.97	496.88	119785.00	208.91	119714.42	138.33
	Lower bound	91759.53	22.07	61984.86	238.22	61847.24	100.60	61811.61	64.97
Total	Upper bound	2881463.61	568.79	2255380.84	5250.92	2252394.64	2264.73	2251498.39	1368.47
	Central	2057974.39	395.79	1611109.16	3612.07	1609061.95	1564.86	1608422.68	925.61
	Lower bound	811335.73	199.5	619654.23	1705.57	618678.03	729.37	618419.72	471.07

Shows excess mortality for all ages due to $PM_{2.5}$ from the all emission sectors (left column labeled “total” under each scenario) and the aviation sector for four outcomes under the four scenarios using the old function and CIESIN population data.

Over 25 Excess Mortality	2006 Baseline	Ref	Tech & Op	Alt Fuel

Table S5. Excess mortality due to emissions from aviation sector (ages ≥ 25 years, CIESIN and GBD adjusted population)

		2006	2006_Adj	2050	2050_Adj	2050	2050_Adj	2050	2050_Adj
Ischemic Heart Disease (IHD)	Upper bound	316.63	328.24	3294.06	3406.07	1398.45	1444.88	956.74	990.50
	Central	186.43	191.62	2851.24	2934.68	1182.55	1208.05	814.96	829.38
	Lower bound	119.93	123.18	1879.72	1928.76	771.01	781.77	518.94	522.17
Stroke	Upper bound	187.28	193.83	1939.89	1998.20	807.63	831.68	569.92	587.79
	Central	131.92	136.13	1674.13	1724.54	700.54	721.28	501.64	517.01
	Lower bound	37.60	38.67	572.97	589.30	239.25	245.29	169.03	173.13
Chronic Obstructive Pulmonary Disease (COPD)	Upper bound	56.29	58.38	572.01	590.31	252.20	259.99	132.30	136.86
	Central	34.57	35.92	335.77	346.41	150.53	155.16	70.61	73.11
	Lower bound	12.53	13.07	108.45	111.74	51.18	52.70	15.38	15.95
Lung Cancer (LC)	Upper bound	64.40	67.13	817.91	846.14	340.48	351.98	246.23	254.99
	Central	39.09	40.85	467.81	483.90	195.39	202.01	137.82	142.82
	Lower bound	7.09	7.47	77.76	80.34	33.16	34.24	20.43	21.18
Total	Upper bound	624.6	647.58	6623.87	6840.72	2798.76	2888.53	1905.19	1970.14
	Central	392.01	404.52	5328.95	5489.53	2229.01	2286.5	1525.03	1562.32
	Lower bound	177.15	182.39	2638.9	2710.14	1094.6	1114	723.78	732.43

Shows excess mortality for adults 25 years and older due to $PM_{2.5}$ from the aviation sector for four outcomes under the four scenarios. The left column under each scenario are mortality estimates obtained using the CIESIN population. The right column (_Adj) are mortality estimates obtained using the GBD adjusted population.

Total Excess Mortality	2006 Baseline	Ref	Tech & Op	Alt Fuel

116 Table S6. Excess mortality due to emissions from aviation sector (all ages, CIESIN and GBD adjusted population)

		2006	2006_Adj	2050	2050_Adj	2050	2050_Adj	2050	2050_Adj
Ischemic Heart Disease (IHD)	Upper bound	317.53	329.13	3300.14	3412.17	1401.49	1447.94	957.27	990.99
	Central	187.01	192.18	2855.63	2938.99	1184.36	1209.77	815.16	829.45
	Lower bound	120.31	123.55	1882.47	1931.43	772.05	782.71	518.87	521.96
Stroke	Upper bound	187.52	194.07	1941.48	1999.78	808.40	832.46	570.12	587.98
	Central	132.12	136.32	1675.45	1725.86	701.17	721.91	501.82	517.18
	Lower bound	37.67	38.73	573.42	589.74	239.45	245.49	169.07	173.16
Chronic Obstructive Pulmonary Disease (COPD)	Upper bound	56.59	58.69	573.04	591.34	252.90	260.69	131.90	136.44
	Central	34.79	36.15	336.46	347.09	151.01	155.65	70.29	72.77
	Lower bound	12.65	13.20	108.78	112.08	51.43	52.96	15.19	15.76
Lung Cancer (LC)	Upper bound	64.44	67.18	818.45	846.69	340.72	352.22	246.34	255.10
	Central	39.12	40.88	468.14	484.23	195.54	202.16	137.88	142.88
	Lower bound	7.10	7.47	77.83	80.41	33.19	34.27	20.44	21.19
Total	Upper bound	626.08	649.07	6633.11	6849.98	2803.51	2893.31	1905.63	1970.51
	Central	393.04	405.53	5335.68	5496.17	2232.08	2289.49	1525.15	1562.28
	Lower bound	177.73	182.95	2642.5	2713.66	1096.12	1115.43	723.57	732.07

Shows excess mortality for all ages due to $PM_{2.5}$ from the aviation sector for four outcomes under the four scenarios. The left column under each scenario are mortality estimates obtained using the CIESIN population. The right column (_Adj) are mortality estimates obtained using the GBD adjusted population.

Table S7. Total excess mortality (ages ≥ 25 years, CIESIN and GBD adjusted population)

Over 25 Excess Mortality Adjusted		2006 Baseline		Red		Tech & Op		Alt Fuel	
		2006	2006_Adj	2050	2050_Adj	2010	2010_Adj	2050	2050A_Adj
Ischemic Heart Disease (IHD)	Upper bound	1307246.03	1339669.05	998798.77	1023530.38	996903.15	1021569.19	996461.44	1021114.81
	Central	994539.77	1019806.16	734477.81	753213.14	732809.10	751486.50	731626.56	751107.84
	Lower bound	686833.88	704306.98	508140.58	521137.06	507031.87	519990.06	506779.80	519730.46
Stroke	Upper bound	603822.71	618437.57	428163.03	438730.91	427030.76	437564.40	426793.05	437320.51
	Central	481174.48	492940.79	341222.77	349758.67	340249.18	348755.41	339548.64	348551.14
	Lower bound	172068.41	176324.58	123258.24	126392.05	122924.51	126048.05	122854.30	125975.88
Chronic Obstructive Pulmonary Disease (COPD)	Upper bound	449311.80	461040.33	389576.86	400067.47	389257.05	399737.15	389137.15	399614.02
	Central	296923.17	304694.55	257949.93	264942.54	257764.68	264751.29	257614.15	264669.24
	Lower bound	129509.66	132932.02	113323.79	116447.33	113266.53	116388.30	113230.72	116351.55
Lung Cancer (LC)	Upper bound	198910.03	203668.24	138789.94	142090.86	138312.51	141596.70	138218.26	141499.70
	Central	128799.98	131810.69	89874.13	91977.38	89601.70	91695.49	89406.31	91636.30
	Lower bound	33326.19	34068.36	23698.12	24240.01	23653.52	24193.91	23640.79	24180.85
Total	Upper bound	2559290.57	2622815.19	1955328.6	2004419.62	1951503.47	2000467.44	1950609.9	1999549.04
	Central	1901437.4	1949252.19	1423524.64	1459891.73	1420424.66	1456688.69	1418195.66	1455964.52
	Lower bound	1021738.14	1047631.94	768420.73	788216.45	766876.43	786620.32	766505.61	786238.74

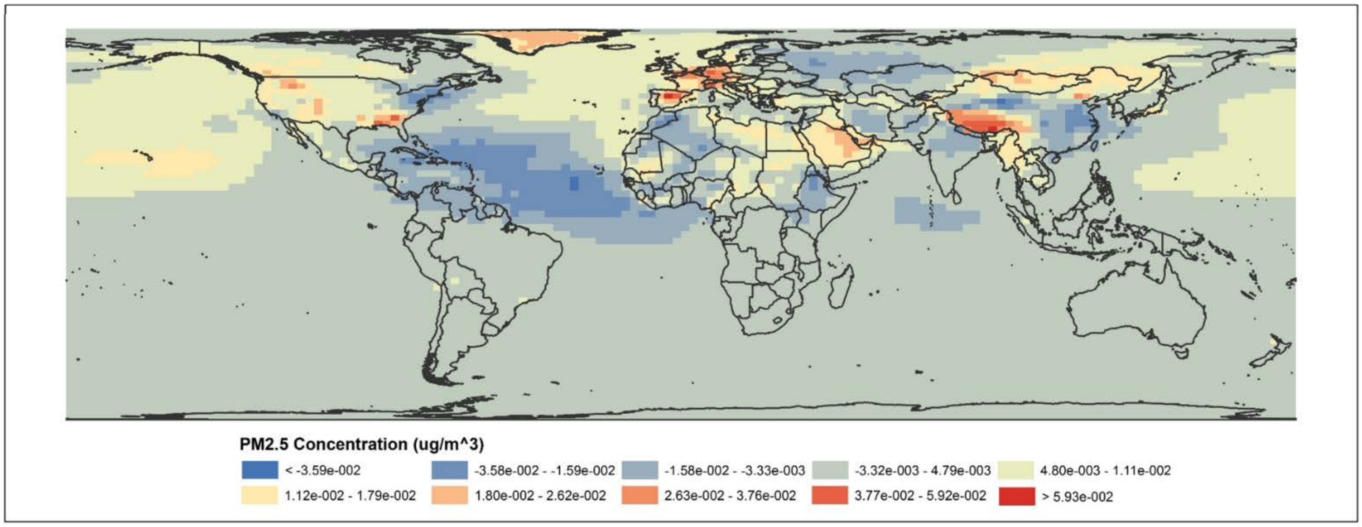
Shows excess mortality for adults 25 years and older due to $PM_{2.5}$ from all emission sectors for four outcomes under the four scenarios. The left column under each scenario are mortality estimates obtained using the CIESIN population. The right column (_Adj) are mortality estimates obtained using the GBD adjusted population.

Total Excess Mortality Adjusted		2006 Baseline		Ref		Tech & Op		Alt Fuel	
		2006	2006_Adj	2050	2050_Adj	2010	2010_Adj	2050	2050_Adj
Ischemic Heart Disease (IHD)	Upper bound	1320951.85	1353769.11	1011818.47	1036930.62	1009919.81	1034966.38	1009475.59	1034509.44
	Central	1004009.61	1029543.98	743419.61	762412.11	741748.34	760682.88	740563.97	760302.56
	Lower bound	693368.99	711027.15	514313.28	527487.42	513202.86	526338.69	512949.68	526077.95
Stroke	Upper bound	606789.11	621484.41	430978.21	441623.88	429845.12	440456.55	429606.84	440212.08
	Central	483495.05	495323.83	343424.94	352021.36	342450.66	351017.41	341749.49	350812.67
	Lower bound	172896.59	177175.01	124045.31	127200.74	123711.34	126856.50	123640.96	126784.17
Chronic Obstructive Pulmonary Disease (COPD)	Upper bound	456337.87	468298.60	396489.70	407211.01	396169.56	406880.36	396048.56	406756.11
	Central	301677.97	309607.83	262632.49	269782.65	262447.05	269591.21	262296.04	269508.33
	Lower bound	131698.62	135195.11	115483.41	118680.74	115426.06	118621.62	115389.82	118584.42
Lung Cancer (LC)	Upper bound	199341.15	204108.75	139158.17	142467.18	138680.44	141972.71	138586.06	141875.59
	Central	129091.37	132108.45	90123.16	92231.92	89850.55	91949.85	89655.01	91890.57
	Lower bound	33411.36	34155.43	23771.79	24315.35	23727.15	24269.22	23714.40	24256.14
Total	Upper bound	2583419.98	2647660.87	1978444.55	2028232.69	1974614.93	2024276	1973717.05	2023353.22
	Central	1918274	1966584.09	1439600.2	1476448.04	1436496.6	1473241.35	1434264.51	1472514.13
	Lower bound	1031375.56	1057552.7	777613.79	797684.25	776067.41	796086.03	775694.86	795702.68

Table S8. Total excess mortality (all ages, CIESIN and GBD adjusted population)

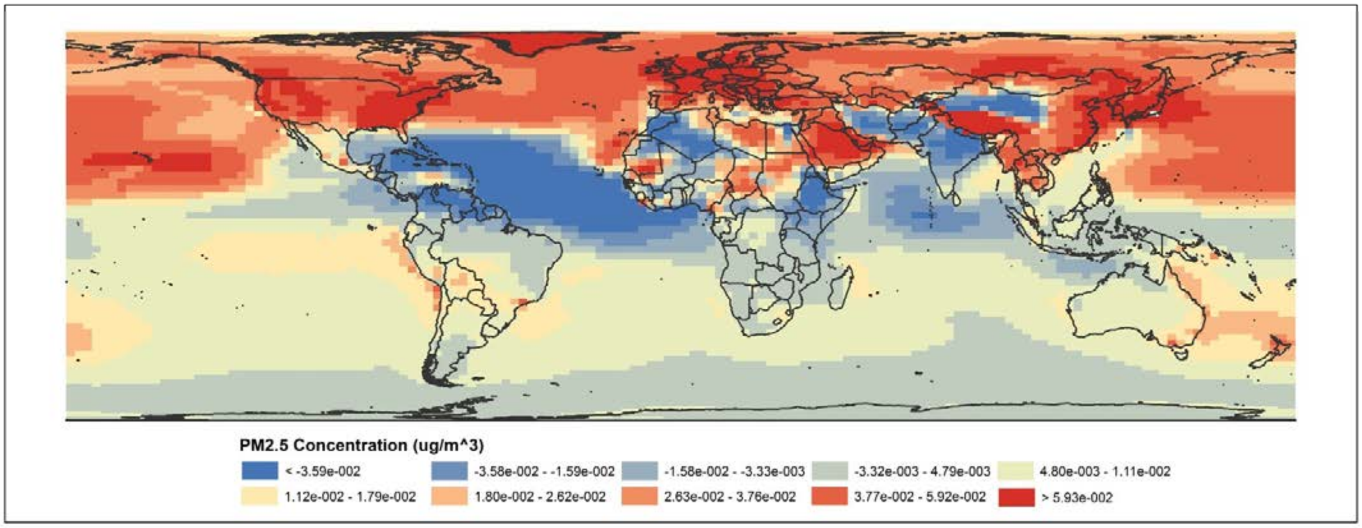
Shows excess mortality for all ages due to $PM_{2.5}$ from all emission sectors for four outcomes under the four scenarios. The left column under each scenario are mortality estimates obtained using the CIESIN population. The right column (_Adj) are mortality estimates obtained using the GBD adjusted population.

Figure S1. Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2006 Baseline)



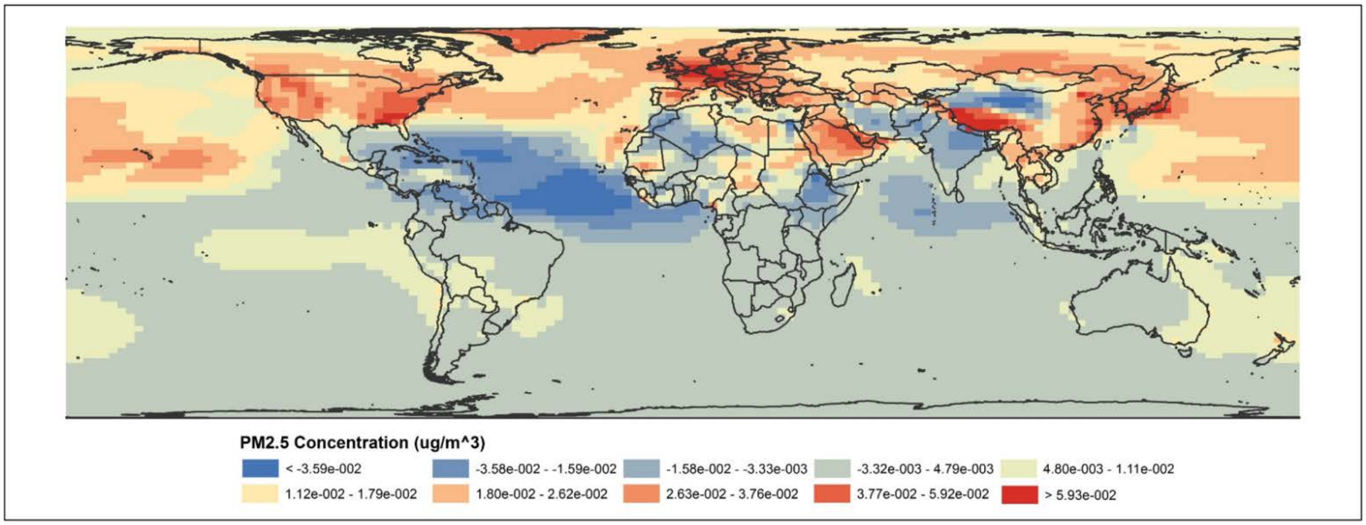
Shows global distribution of $PM_{2.5}$ concentrations due to aviation sector emissions. Much of the Atlantic Ocean, northwestern Africa, eastern China, Middle Eastern regions, and western Russia have negative $PM_{2.5}$ concentration values. The Pacific and Arctic Ocean, northeastern Africa, North America, western China, western European regions, and eastern Russia have higher $PM_{2.5}$ concentrations in 2006. Australia and South America have low $PM_{2.5}$ concentration levels.

Figure S2. Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2050 Ref)



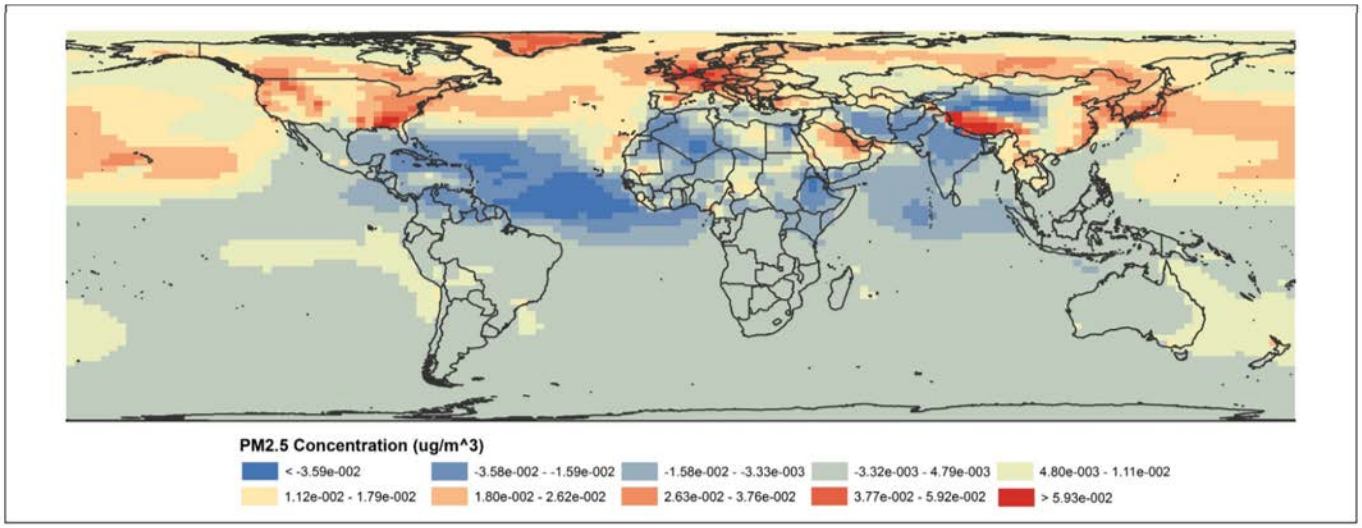
Shows global distribution of $PM_{2.5}$ concentrations due to aviation sector emissions. Much of the Atlantic and Indian Ocean, India, southern and parts of northwestern Africa, northwestern China, and parts of the Middle Eastern regions have negative $PM_{2.5}$ concentration values. The Pacific and Arctic Ocean, northeastern Africa, North America, eastern and southwestern China, and all of Europe have extremely high $PM_{2.5}$ concentrations under the 2050 ref scenario. Australia and South America have low $PM_{2.5}$ concentration levels.

Figure S3. Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2050 Tech & Op)



Shows global distribution of $PM_{2.5}$ concentrations due to aviation sector emissions. Much of the Atlantic and Indian Ocean, India, parts of northwestern Africa, northwestern China, and parts of the Middle Eastern regions have negative $PM_{2.5}$ concentration values. The Pacific and Arctic Ocean, North America, eastern and southwestern China, and all of Europe have high $PM_{2.5}$ concentrations under the 2050 Tech & Op scenario; however, lower concentration levels overall in these regions compared to the 2050 ref scenario. Australia, southern Africa, and South America have low $PM_{2.5}$ concentration levels.

Figure S4. Global Distribution of $PM_{2.5}$ Concentration Attributable to Aviation Sector (2050 Alt Fuel)



Shows global distribution of $PM_{2.5}$ concentrations due to aviation sector emissions. Much of the Atlantic and Indian Ocean, India, most of northern Africa, northwestern China, and parts of the Middle Eastern regions have negative $PM_{2.5}$ concentration values. The Pacific and Arctic Ocean, North America, eastern and southwestern China, western Europe, and parts of Russia have high $PM_{2.5}$ concentrations under the 2050 Tech & Op scenario; however, concentration levels are even lower overall in these regions compared to the 2050 Tech & Op scenario. Australia, southern Africa, and South America have low $PM_{2.5}$ concentration levels.