

Air Quality Impacts of Implementing Emission Reduction Strategies at Southern California Airports

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Supplementary material

1. Aviation Emissions Inventory Code (AEIC)

1.1 Methods

AEIC uses an OAG database to compute the flight schedules. It then computes the time in mode of each phase of the LTO and the emission index for each specie, power setting and engine type. Both results are multiplied to compute the emissions per specie, LTO phase, flight and airport. Then, a temporal allocator resolves the emissions using the flight schedule. At the same time, a spatial allocator resolves the emissions using each individual flight's path, computed from the location of the departure and arrival airport. The methodology for each items is described in detail in Stettler et al. (2011), Simone et al. (2013) and in the user manual (Simone et al., 2013b).

1.2 Results

The total emissions for each airport included in the study and for each case is shown in table 2. Table 2 provides a by pollutant detail of total emission for each of the studied scenarios. Table 3 of the main manuscript shows the percentage differences of each scenario emissions compared to the base case using the data from Table 2. Additionally, fig. 1 provides a vertical distribution of fuel burn.

Table 1. Average daily emissions for the simulated periods for each airport and pollutant (tons/day)

Scenario	Fuel burn	NOX	HC	SOX	PM2.5
Base case	1063.39	12.71	2.34	1.24	0.24
TOT	1011.01	12.53	2.02	1.18	0.24
GSE	1054.77	12.16	2.28	1.24	0.21
BIO	1063.39	11.4	2.31	0.04	0.06
ALL	1002.39	10.67	1.94	0.04	0.03

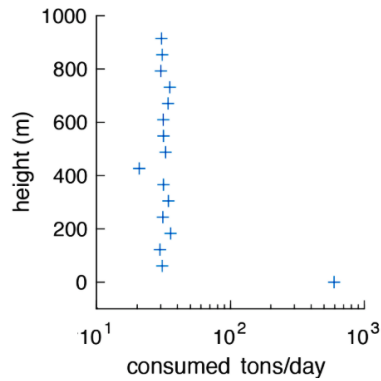


Fig. 1. Vertical distribution of fuel burn in the AEIC domain.

1.3 Results comparison

The results have been compared with two other sets of results from different modes. Additionally, Stetler 2011 provided an estimate of uncertainty of emissions calculated from AEIC with respect to operational variability (e.g., TIM, thrust setting) and measurements of EIs. These are discussed further below, and provide a quantification of the uncertainties of our emission inventory.

1.3.1 AEIC comparison to ARB's 2012 detailed inventory

To develop the inventory presented below, ARB collected aircraft activity data from airports, FAA's databases, and SCAG. Then, the FAA's Emissions and Dispersion Modeling System (EDMS) model for airports was used with detailed aircraft activity data for commercial air carrier operations or the EPA's average emission factors for airports with total aircraft operations data (by major aircraft type) and other aircraft operations with no details on aircraft or engine types.

Table 2. AEIC estimates comparison with ARB's 2012 detailed inventory by airport and pollutant.

Airport	NOx	HC	SOx	PM2.5	Operations
ARB's 2012 emission inventory, from 2016 draft for SCAQMD (tons/year)					
LAX	3,634	510	377	67	605,480
SNA	333	47	35	7	88,290
ONT	345	38	32	6	68,338
BUR	165	23	18	5	65,656
LGB	100	9	11	3	34,574
AEIC estimates (tons/year)					
LAX	3,474	693	329	65	603,922
SNA	391	46	42	7	102,964
ONT	275	33	30	6	81,840
BUR	188	28	23	4	63,913
LGB	99	7	11	2	26,750

Difference (%) (corrected with operations / year)					
LAX	-4	36	-12	-2	0
SNA	1	-17	1	-2	0
ONT	-33	-27	-22	-20	0
BUR	17	27	30	-8	0
LGB	28	4	21	0	0

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43 1.3.2 AEIC comparison to AEDT 2006 data

44 AEDT 2006 data for US Landing and Take-Off (LTO) aviation emissions is provided in
 45 appendix H of Ashok, A. (2011) and data is provided by airport.

46

47 **Table 3.** AEIC estimates comparison with AEDT 2006 data provided in appendix H of Ashok, A.
 48 (2011) by airport and pollutant.

Airport	Fuel burn	NOx	HC	SOx	PM2.5	Operations
AEDT (2006 data) (tons/year)						
LAX	287,332	3,601	500	328	76	599,178
SNA	40,303	447	96	46	13	136,652
ONT	36,231	443	77	41	11	106,369
BUR	23,388	249	44	27	7	93,459
AEIC estimates (tons/year)						
LAX	282,400	3,474	693	329	65	603,922
SNA	36,181	391	46	42	8	102,964
ONT	25,885	275	33	30	6	81,840
BUR	19,354	188	28	23	5	63,913
Difference (%) (corrected with operations / year)						
LAX	-2	-4	38	0	-15	0
SNA	19	16	-36	21	-18	0
ONT	-7	-19	-44	-5	-29	0
BUR	21	10	-7	25	4	0

49

50 Fuel burn and emissions are scaled with the provided number of operations. Fuel burn, NO_x
 51 and SO_x in LAX (the SoCAB airport with 70% of the traffic) differences between the AEDT data are -
 52 2%, -4%, and 0% respectively. However, HC and PM2.5 differences are 38% and -15% respectively.
 53 The PM_{2.5} methodology differs between AEDT and the AEIC: the former used FOA3 and smoke
 54 number while the latter uses FOX. Stettler et al. (2011) recognizes that AEIC has uncertainty in their
 55 emissions estimation methodology and provided ranges for the emissions estimates: [-23 to +29] for

56 NO_x, [-59 to +155] for HC, [-29 to +32] for SO_x and [-36 to +45] for PM_{2.5}. Note that HC values can be
 57 between -59 +155% as EI(HC) (derived from EI(HCHO)) is very uncertain and is represented by a
 58 uniform distribution with bounds at 90%.

59 2. Aviation air quality impact weight in SoCAB

60 2.1 Emissions comparison

61 **Table 4.** Aviation emissions relative weight to total emissions in the SoCAB according to 2012
 62 Estimated Annual Average Emissions in the SoCAB (tons/day) (ARB, 2016)

	TOG	NOX	SOX	PM2.5
Grand total	1333.1	514.3	16.8	65.1
Aviation	3.28	13.64	1.46	0.53
Aviation relative weight	0.25%	2.65%	8.69%	0.81%

63

64 2.2 Pollutant concentration comparison

65 **Table 5.** Aviation attributable pollutant ground concentration differences relative weight to SoCAB
 66 average concentrations. The base and delta concentrations are calculated in this study as part of the
 67 the air quality impacts study of implementing airport emission reduction strategies.

		O ₃ (ppb)		PM _{2.5} (µg/m ³)	
		Winter	Sumer	Winter	Sumer
Domain averaged concentration	Base	47.3	37.2	4	4.6
	Delta	0.00244	-0.0064	-0.00066	-0.00186
	Relative weight	0.01%	-0.02%	-0.02%	-0.04%
Domain maximum concentration	Base	52.7	78.3	25.1	23.8
	Delta	1.32	2.3	-1.19	-1.42
	Relative weight	2.50%	2.94%	-4.74%	-5.97%

68

69 3. Base case concentrations

70 Fig. 2 shows the spatial distribution of base case ground-level of 8-hour average O₃
 71 concentration and 24-hour PM_{2.5} concentration in 2012 from CMAQ (base case). Table 6 shows the
 72 base case maximum and average ground-level 8-hour average O₃ concentration and 24-hour PM_{2.5}
 73 concentration in 2012 from CMAQ.

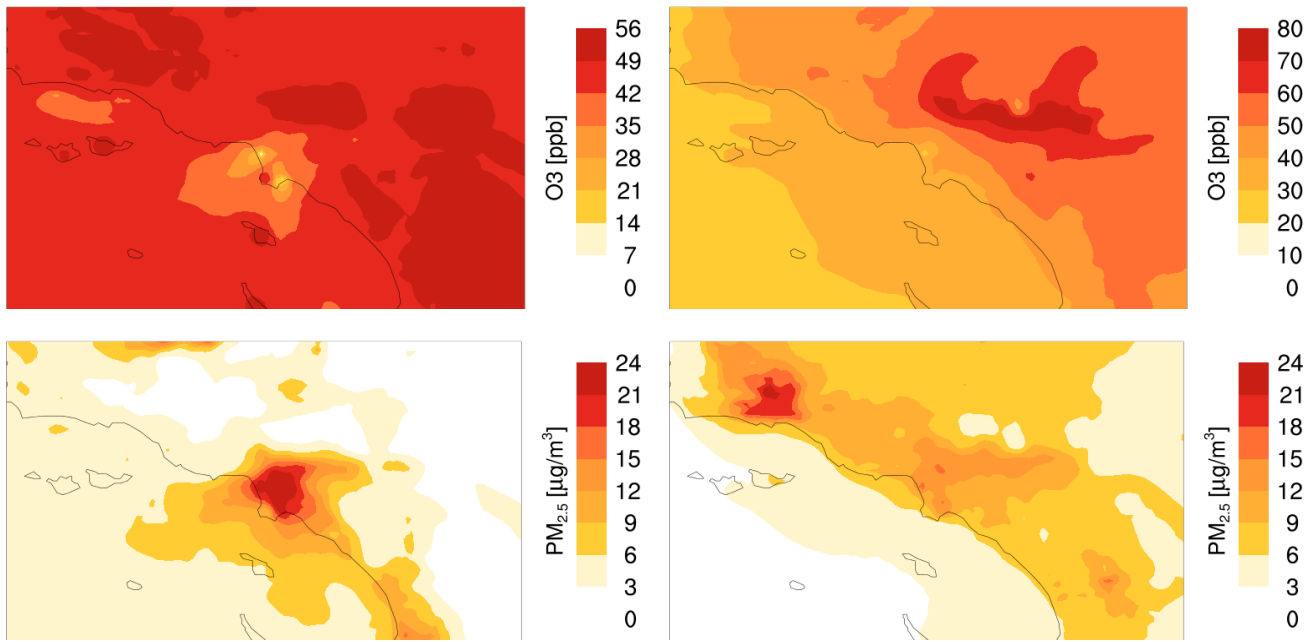


Fig. 2. (top) Base case spatial distribution of the one week summer (left) and winter (right) average daily 8-hour maximum average of O₃. (bottom) Base case spatial distribution of the one week summer (left) and winter (right) average daily 24-hour average of PM_{2.5}.

Table 6. Base case ground-level O₃ and PM_{2.5} concentrations

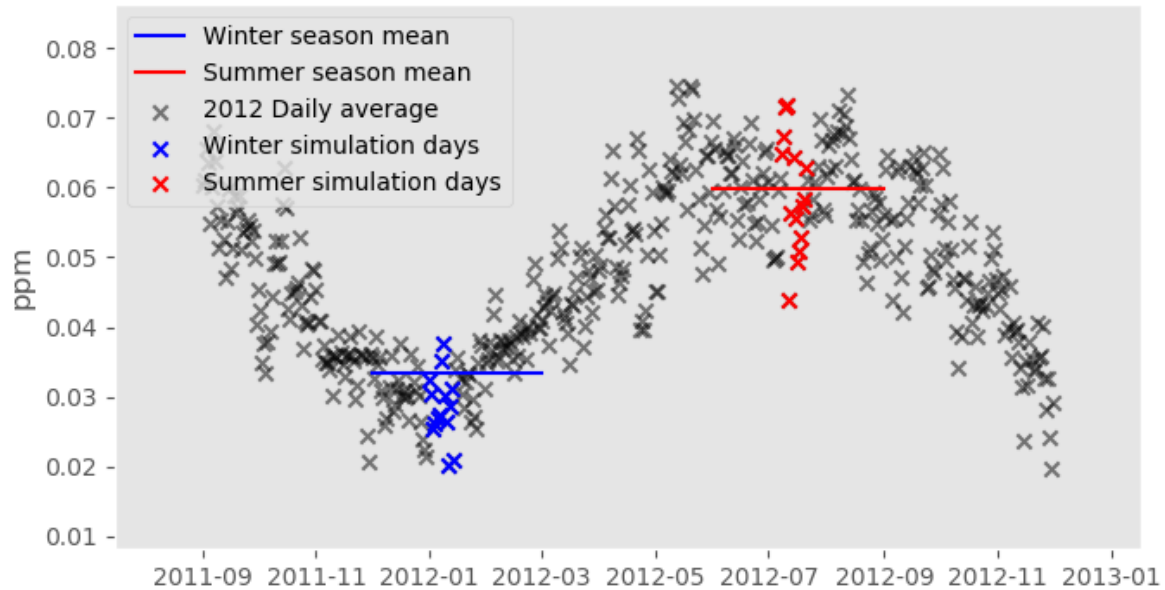
	8h O ₃ [ppb]		24h PM _{2.5} [µg/m ³]	
	max	avg	max	avg
Winter	52.7	47.3	25.1	4.0
Summer	78.3	37.2	23.8	4.6

4. Simulation episode comparison with ground level seasonal SoCAB measured pollutant

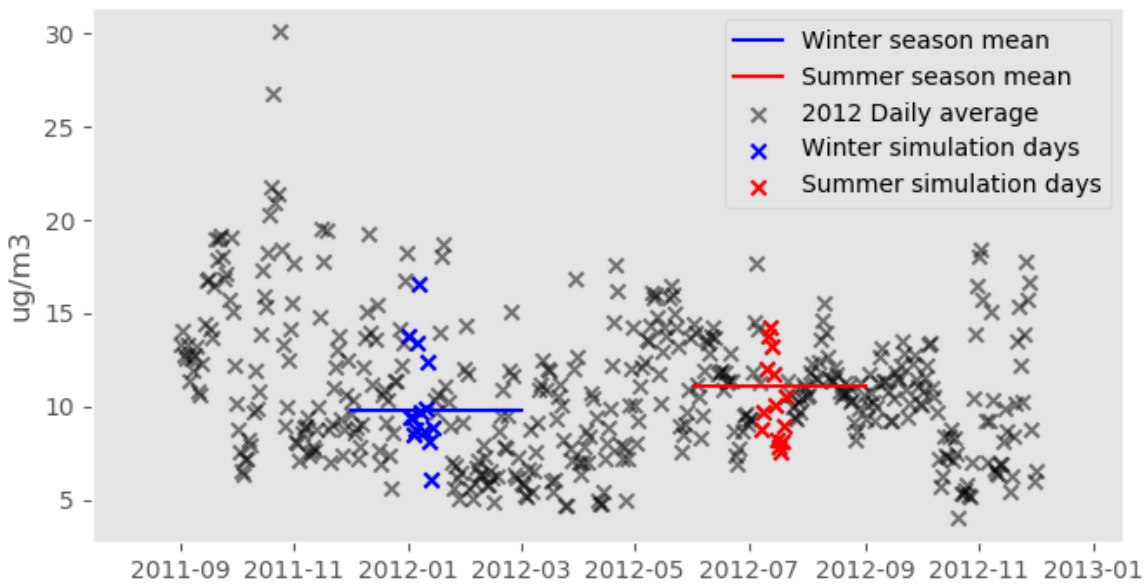
The simulation periods selected are characteristic of each period with sufficient accuracy to satisfy the goals of this study and use the results to identify the relative “delta” in impacts. A daily comparison of O₃ and PM_{2.5} measured ground level concentrations across the SoCAB for the year 2012 is shown in Fig 3 and summarized in table 7. Ground-level measured concentration differences between the simulated episodes mean and seasons mean are -14% and -2% in winter and summer respectively. Future studies should perform longer simulations to improve accuracy.

Table 7. Measured concentrations averages (ppb). Data from the EPA’s Air Quality System (AQS) database. Retrieved from: epa.gov/outdoor-air-quality-data/download-daily-data (February 2018)

	Winter	Summer
Simulated episode mean	28.5	59.1
Season mean	33.3	60
Difference	-14	-2



(a)



(b)

Fig. 3. Daily O₃ (a) and PM_{2.5} (b) ground level measured concentrations at the reporting stations. The scattered data (x) is the domain average of all stations inside the SoCAB for each day. The days on which the simulation was performed are highlighted in colors. Data from the EPA's Air Quality System (AQS) database (AQS, 2018).

5. Alternative fuel implementation scenario of a 100% FT1 blend

97 Following the methodology described in section 2 of the main paper emission indexes have
 98 been extracted from the AAFEX report for the FT1 100% blend. For clarity, in this section the BIO-
 99 50% tag refers to the BIO scenario discusses in the main paper (50/50 blend of FT1 and JP-8 fuels)
 100 while the BIO-100% tag refers to the implementation of a pure blend of FT1 fuel. Results show a
 101 proportional behavior, in Summer and a more non-linear behavior in Winter. Looking at the total
 102 aviation attributable population exposure to criteria pollutants, the BIO-50% scenario raises O₃ in
 103 Winter a 25% less than half the increase of the BIO-100% scenario. Also, the BIO-50% decreases
 104 PM_{2.5} by 10% more than half the decrease of the BIO-100% scenario. Despite the present technical
 105 difficulties of deploying 100% alternative fuels, the FAA has shown its clear intention of achieving so.
 106 The results presented below represent a more feasible reality than the BIO scenario.
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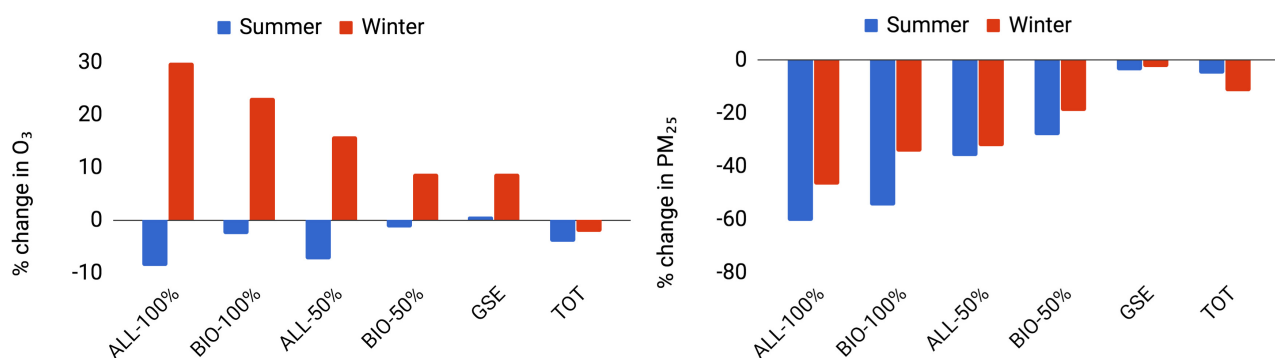


Fig. 4. Percentage change in total aviation attributable population exposure to O₃ (left) and PM_{2.5} (right), computed from the difference in population-weighted average of each case minus no aviation case versus the base case minus no aviation case.

108 6. Health impact assessment

109 6.1 Methods

110 The environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-
 111 CE), is a health impact assessment tool maintained by the U.S. EPA (Davidson et al., 2007) used to
 112 quantify and assess the monetary impacts of predicted air quality changes. For this work, BenMAP-
 113 CE is used to quantify the health impacts of ground concentration differences in O₃ and PM_{2.5}
 114 between the ALL case minus the base case, in order to provide an upper bound for potential impacts
 115 of airport emission control strategies. Impacts are reported for short-term exposure to both pollutants
 116 as appropriate for the modeled episode. The methods used closely follow those in the South Coast Air
 117 Quality Management District's (SCAQMD) Socioeconomic Report for the 2016 Air Quality
 118 Management Plan (AQMP) (Shen et al., 2017). The gridded population density is obtained from
 119 Landscan data (ORNL, 2016). Baseline incidence rates for mortality and morbidity are selected at the
 120 county level by five-year age group based on recommendations from a comprehensive review of the
 121 literature (Marrison et al., 2016). The premature mortality functions for O₃ and PM_{2.5} derived in Bell,
 122 Dominici, and Samet (2005) and Atkinson et al. (2014) were used respectively. The C-R functions are
 123 selected based on suggested criteria from a thorough review of the literature and prioritized for the
 124 SoCAB four-county region (IEc, 2016a; IEc, 2016b). An overview of utilized C-R functions can be
 125 found in Table 3B-1 in Appendix B of Shen et al. (2017). Valuation functions for both morbidity and
 126 mortality incidence are selected from a literature review with recommendations for the SoCAB
 127 (Geggel et al., 2016; Roman et al., 2016).

128 **6.2 Results**

129 Table 1 shows the estimated reductions in incidence of premature mortality and morbidity from
130 improvements in ozone and PM_{2.5} for the ALL scenario minus the base case for a summer and winter
131 day. The health impacts correspond to a mean valuation of \$550,880 per day in Summer and
132 \$344,580 per day in Winter. Avoided premature deaths associated with PM_{2.5} are minor which is
133 expected for short-term exposure. Impacts are higher for the summer modeling period indicating a
134 greater value in reducing short-term exposure to PM_{2.5} relative to winter for impacted populations in
135 the SoCAB. Ozone values are shown as negative (i.e., a cost) due to the modeled increases in
136 ground-level concentrations. Results show that PM_{2.5} benefits are 4.7 and 2.9 times the O₃ costs for
137 the summer and winter episodes respectively. Therefore, the overall air quality impact of the scenario
138 results in a net benefit.

139
140 **Table 8.** Valuation of reduced short-term exposure to ozone and PM_{2.5} in the All Case estimated in
141 BenMAP. Valuation estimates in thousand \$ / day, 95% confidence intervals in parenthesis.

Endpoint	Valuation Estimates thousand \$/day (95% confidence interval)	
	Summer	Winter
<i>Premature Deaths Avoided, All Cause</i>		
Short-Term Ozone Exposure	-145.94 (-324.70, -15.03)	-176.28 (-392.21, -18.16)
Short-Term PM2.5 Exposure	671.28 (338.73, 1062.93)	503.41 (254.03, 797.13)
Mortality Total	525.34 (14.03, 1047.90)	327.14 (-138.18, 778.97)
<i>Reduced Morbidity Incidence</i>		
Short-Term Ozone Exposure	-3.48 (-6.95, -0.03)	-4.42 (-8.83, -0.02)
Short-Term PM2.5 Exposure	29.02 (20.08, 41.79)	21.86 (15.12, 31.35)
Morbidity Total	25.54 (13.13, 41.75)	17.44 (6.29, 31.33)
Scenario Total	550.88 (27.16, 1089.65)	344.58 (-131.89, 810.30)

142
143 Reduced morbidity incidence is shown in table 2 for all endpoints including myocardial
144 infarction, asthma, respiratory symptoms, and others. Conversely, incidence of premature death and
145 morbidity increase for the short-term ozone exposure as a result of the increased concentrations
146 modeled in the summer and winter episodes.

147
148 **Table 9.** Breakdown by endpoint of the reduced morbidity incidences. Valuation estimates in
149 thousand \$ / day. *Pooled from HA, Chronic Lung Disease (less Asthma) (18-64) and HA, All
150 Respiratory (65 or older) ** Days when normal activities are altered due to ailments

Endpoint (Reduced Morbidity Incidence only)	Valuation Estimates	
	Summer	Winter
<i>Short-Term Ozone Exposure</i>		
Emergency Room Visits, Asthma	-0.08	-0.11
Hospital Admissions (HA), All Respiratory	-0.34	-0.39

Hospital Admissions (HA), Asthma	-0.03	-0.03
Minor Restricted Activity Days**	-0.87	-1.05
School Loss Days, All Cause	-2.17	-2.83
<i>Short-Term PM_{2.5} Exposure</i>		
Acute Myocardial Infarction, Nonfatal	16.12	12.19
Asthma Exacerbation (Wheeze, Cough, Shortness of Breath)	0.10	0.08
HA, All Cardiovascular (less Myocardial Infarctions)	1.49	1.12
HA, All Respiratory (less Asthma)*	1.26	0.96
HA, Ischemic Stroke	2.04	1.55
HA and ED Visits, Asthma	0.05	0.04
Lower Respiratory Symptoms	0.06	0.04
Upper Respiratory Symptoms	0.11	0.08
Minor Restricted Activity Days**	2.79	2.08
Work Loss Days	4.99	3.72

References

- AQS, 2018. Air Quality System database. *United States Environmental Protection Agency*. Retrieved from: epa.gov/outdoor-air-quality-data/download-daily-data (February 2018)
- ARB, 2016. CEPAM: 2016 SIP - Standard Emissions Tool. Retrieved from: arb.ca.gov/app/emsmv/fcemssumcat/fcemssumcat2016.php (Accessed June 2017)
- Ashok, A., 2011. The Air Quality Impact of Aviation in Future-Year Emissions Scenarios. Massachusetts Institute of Technology. Retrieved from: hdl.handle.net/1721.1/68168 (Accessed January 2018)
- Davidson, K., Hallberg, A., McCubbin, D., Hubbell, B., 2007. Analysis of PM_{2.5} using the Environmental Benefits Mapping and Analysis Program (BenMAP). *Journal of Toxicology and Environmental Health, Part A* 70, 332–346. doi:10.1080/15287390600884982
- Geggel, A., Ludwig, L., Roman, H., 2016. Review of Mortality Risk Reduction Valuation Estimates for 2016 Socioeconomic Assessment. Retrieved from: aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/iecmemos_november2016/evaluationcriteria_113016.pdf (Accessed January 2018)
- IEc (Industrial Economics), 2016a. Literature Review of Air Pollution-Related Health Endpoints and Concentration-Response Functions for Ozone, Nitrogen Dioxide, and Sulfur Dioxide: Results and Recommendations. Retrieved from: aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/iec_gasplitreview_092916.pdf (Accessed January 2018)
- IEc (Industrial Economics), 2016b. Literature Review of Air Pollution-Related Health Endpoints and Concentration-Response Functions for Particulate Matter: Results and Recommendations. Retrieved from: aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/iec_pmlitreview_092916.pdf (Accessed January 2018)
- Marrison, H., Penn, S., Roman, H., 2016. Review of Baseline Incidence Rate Estimates for Use in 2016 Socioeconomic Assessment. Retrieved from: aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/iecmemos_november2016/scbaselineincidence_112916.pdf (Accessed January 2018)

179 ORNL, 2016. LandScan. Oak Ridge National Laboratory. Retrieved from:
180 web.ornl.gov/sci/landscan (Accessed January 2018)
181 Roman, H., Marrison, H., Robinson, L., 2016. Review of Morbidity Valuation Estimates for Use
182 in 2016 Socioeconomic Assessment. Retrieved from: aqmd.gov/docs/default-source/clean-air-
183 plans/socioeconomic-analysis/iecmemos_november2016/scmorbidityvaluation_112816.pdf (Accessed
184 January 2018)
185 Shen, E., Dabirian, S., Oliver, A., Hamilton, P., 2017. Final Socio-economic Report 2017.
186 South Coast Air Quality Management District. Retrieved from: aqmd.gov/docs/default-source/clean-
187 air-plans/socioeconomic-analysis/final/sociofinal_030817.pdf (Accessed January 2018)
188 Simone, N.W., Stettler, M.E.J., Barrett, S.R.H., 2013a. Rapid estimation of global civil aviation
189 emissions with uncertainty quantification. *Transportation Research Part D: Transport and*
190 *Environment* 25, 33–41.doi:10.1016/j.trd.2013.07.001
191 Simone, N., Stettler, M., Eastham, S., Barrett, S., 2013b. Aviation Emissions Inventory Code
192 (AEIC) User Manual (R1). *Massachusetts Institute of Technology*. Retrieved from:
193 nehalem001.mit.edu/uploads/LAE_report_series/2013/LAE-2013-001-N.pdf (Accessed January 2018)
194 Stettler, M.E.J., Eastham, S., Barrett, S.R.H., 2011. Air quality and public health impacts of UK
195 airports. Part I: Emissions. *Atmospheric Environment* 45, 5415–5424.
196 doi:10.1016/j.atmosenv.2011.07.012
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