Air Quality and Health Implications
from Low Carbon CA-TIMES Energy Scenarios

Christina Zapata, Chris Yang, Sonia Yeh, Nathan Parker, James Nelson, Bart Ostro, Joan Ogden, Mike Kleeman

Civil and Environmental Engineering, University of California, Davis - *December 2015*

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I. Introduction

- Climate policy and switching to lower carbon intensity fuel and technology alternatives will not only alter greenhouse gas (GHG) emissions but short-lived conventional criteria pollutant emissions.
- CA-TIMES energy economic model energy scenarios were analyzed for potential criteria pollutant emission changes for CA in 2050.
- Scenarios included the Business-as-Usual (BAU) scenario and the GHGAi or GHG-Step scenario, where the GHG-Step scenario has a GHG target of 80% below 1990 levels.

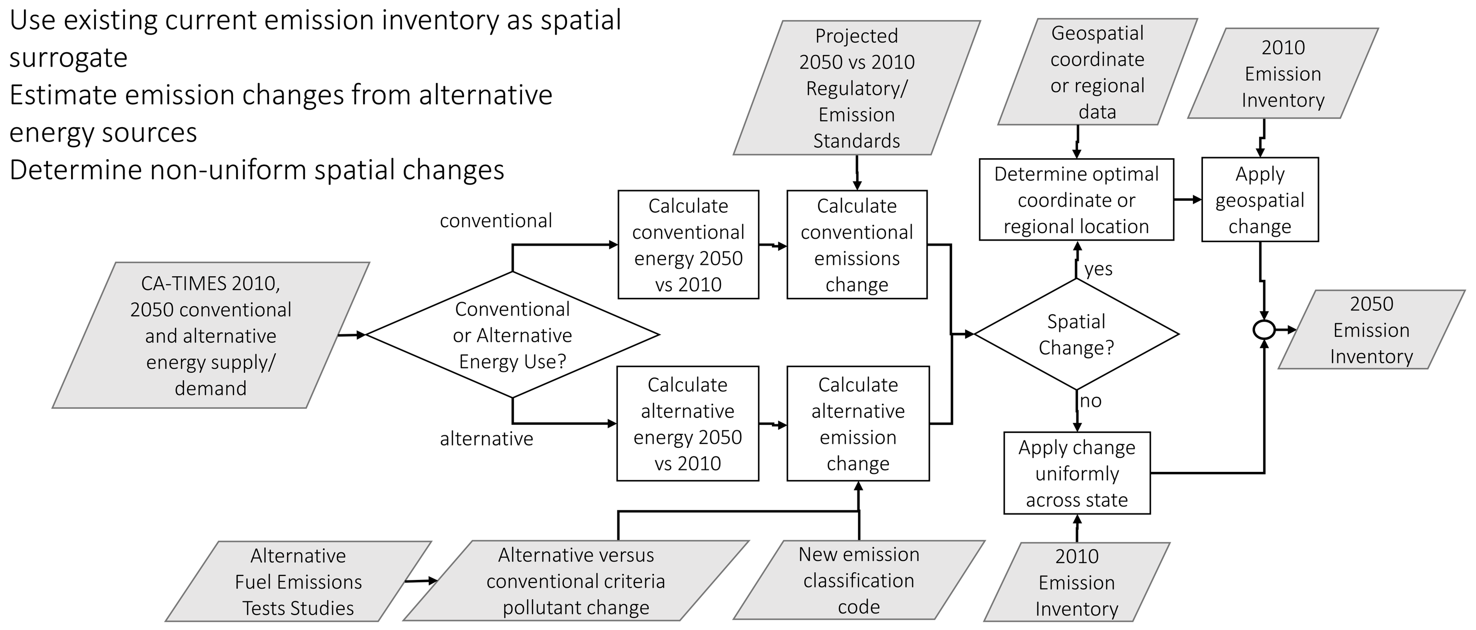
II. Emission Inventory Development

The emission inventory was split into 8 categories, depending on economic sector or transport mode

Index	Sector/Mode	Emission Source Type	Emission Sources
1	Transport – On-road	Vehicle Brake and Tire Wear PM	tire and brake wear particulate matter from vehicles
2	Transport – On-road	Vehicle Exhaust and Evaporative	conventional and alternative vehicles
3	Transport – Off-road	Rail and Other Off-road	construction, recreational off-road, port equipment, locomotives
4	Transport – Sea and Air	Marine and Aviation	harbor craft, boats, ocean going vessels, aviation, military aircraft, commercial aircraft
5	Residential and Commercial	Residential and Commercial	natural gas, wood burning, and other residential/commercial combustion
6	Electricity	Electricity Generation	Renewable and conventional electricity generation
7	Industrial and Agricultural	Petroleum, Agricultural and Other Industries	petroleum activities, biorefining and hydrogen production, agricultural and other industrial
8	Other	Miscellaneous	biogenic, dust, sea salt, and other anthropogenic emissions not listed above

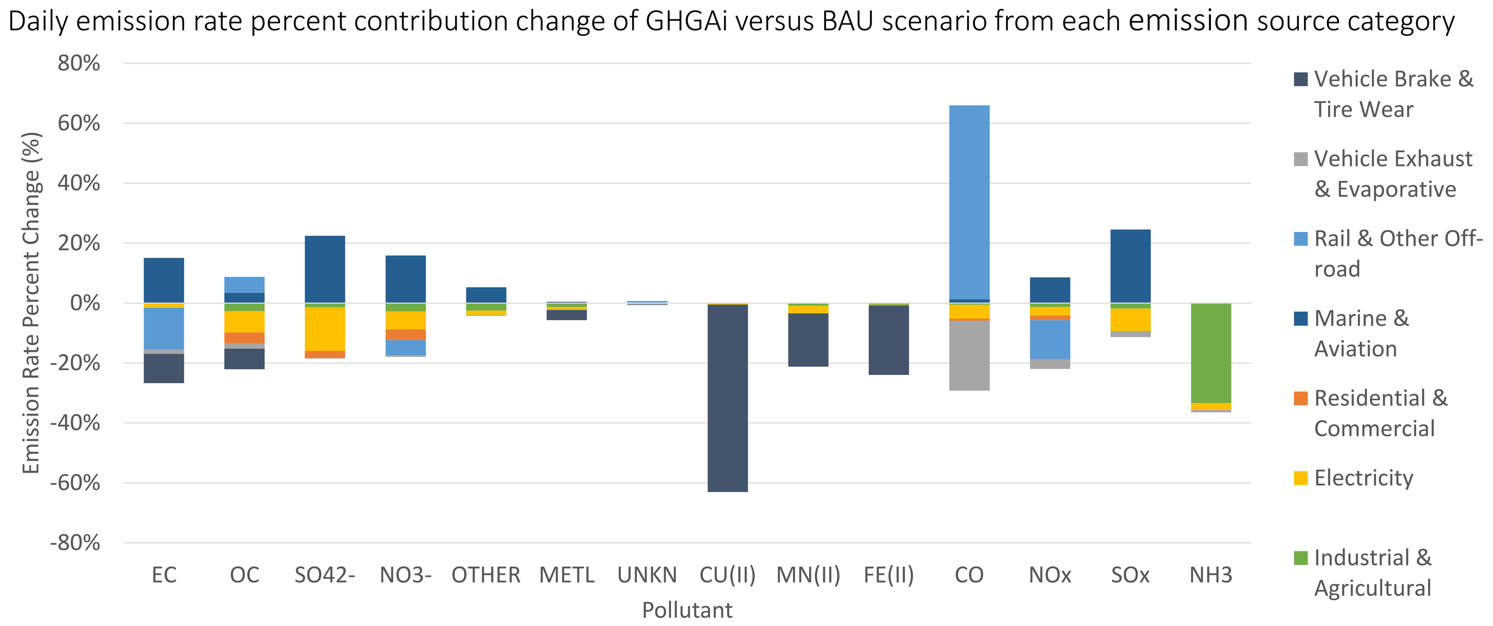
General approach for emission estimation for each sector or mode.

- Use existing current emission inventory as spatial surrogate
- Estimate emission changes from alternative energy sources
- Determine non-uniform spatial changes



III. Energy Scenario Emission Differences

Daily emission rate percent contribution change of GHGAi versus BAU scenario from each emission source category



III. Air Quality Simulation Methodology

Air Quality Model:

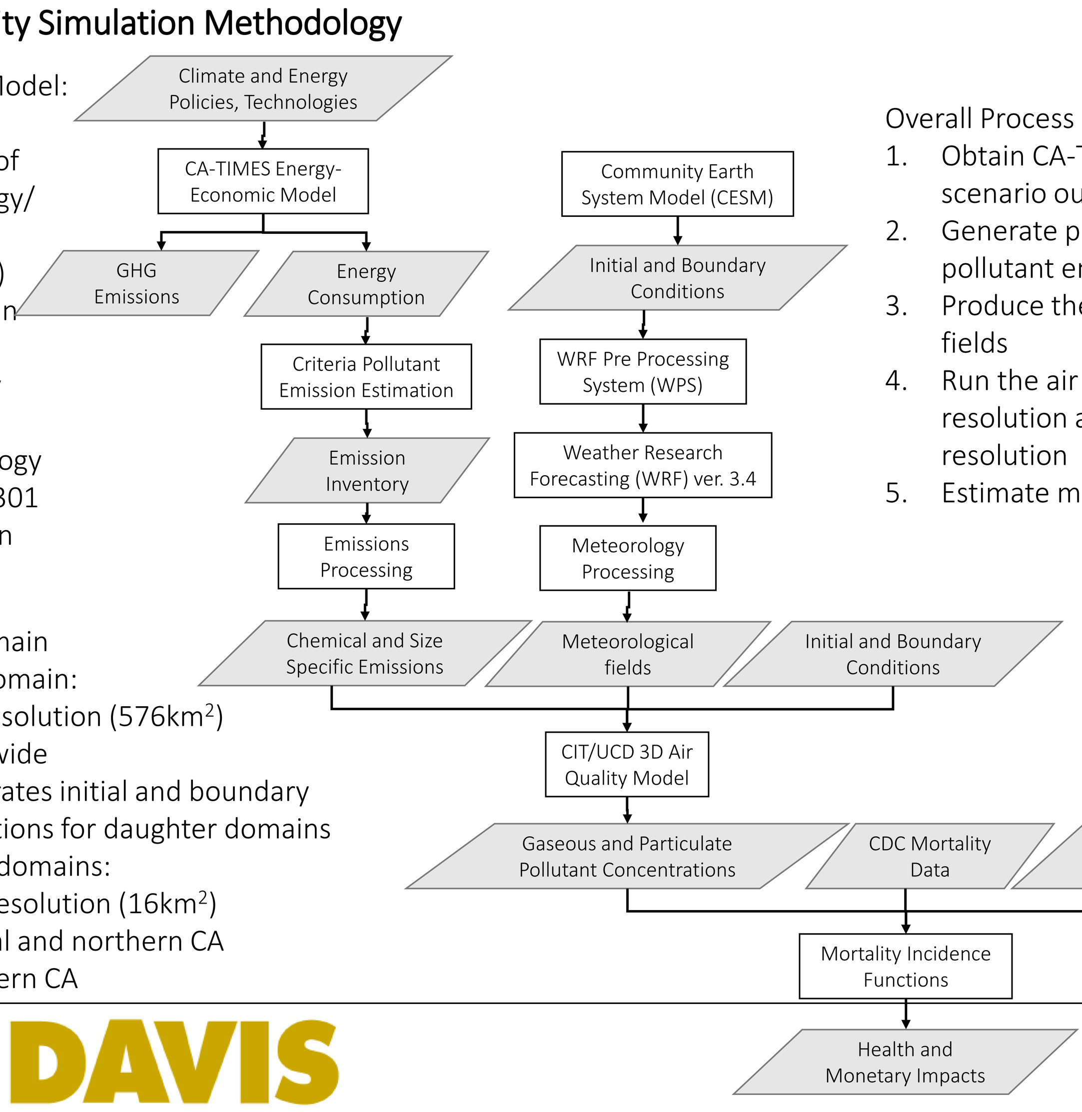
- California Institute of Technology/ UC Davis (CIT/UCD) Lagrangian Model

Meteorology

- 2054 meteorology year of ~301 simulation days

Modeling Domain

- Mother, domain:
  - low resolution (576km^2)
  - Statewide
  - Generates initial and boundary conditions for daughter domains
- Daughter, domains:
  - high resolution (16km^2)
  - central and northern CA
  - southern CA

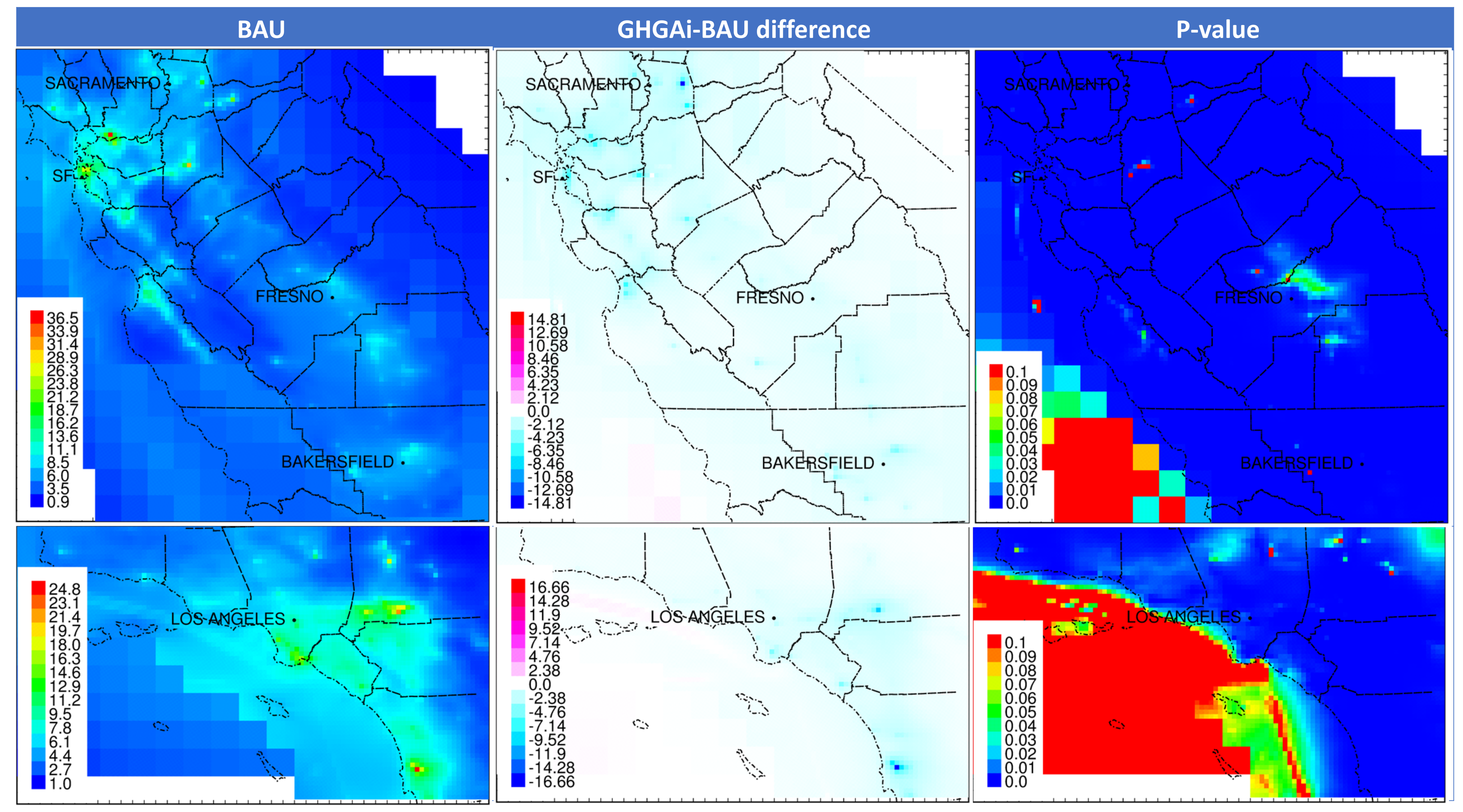


Overall Process Diagram

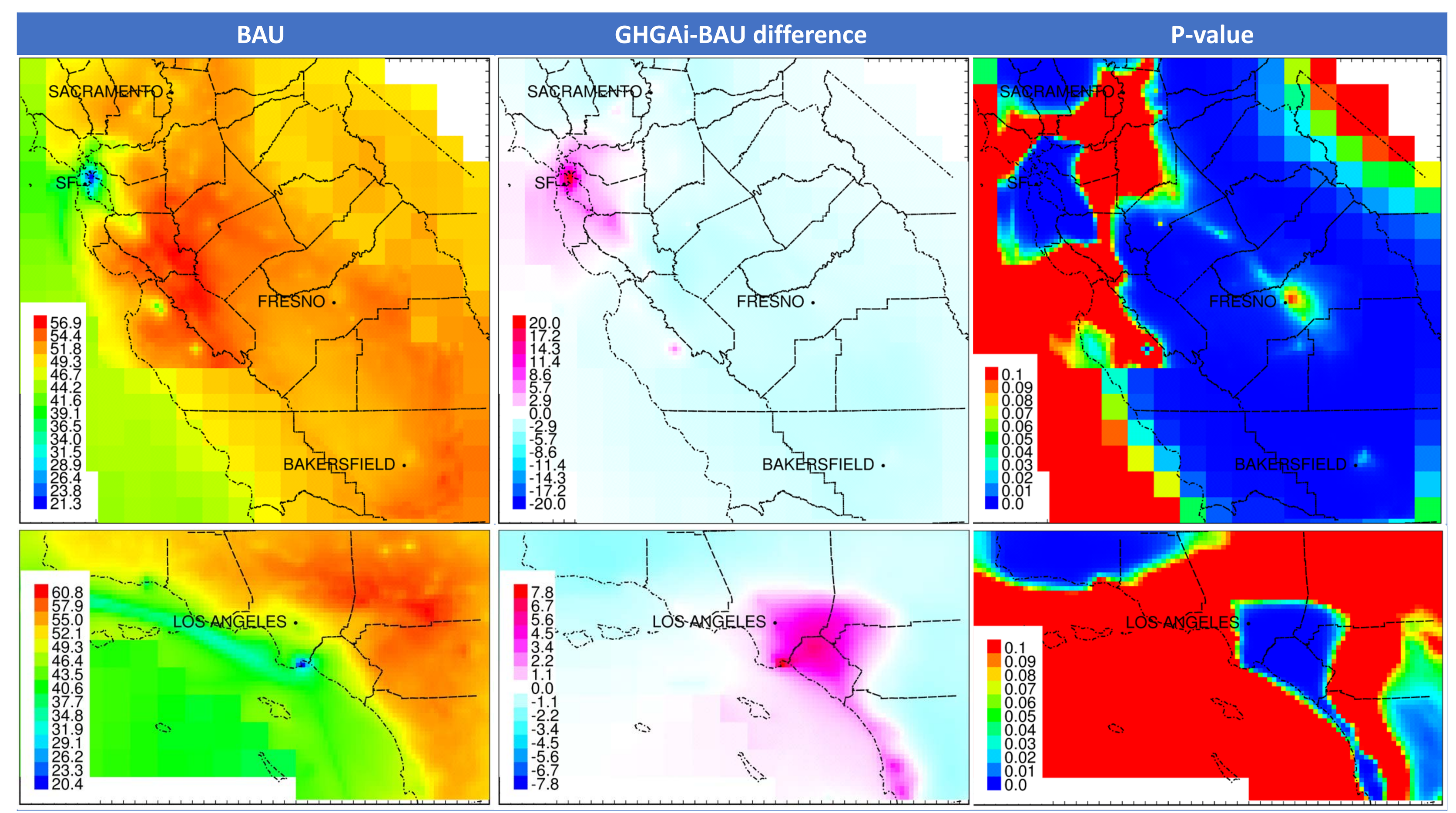
1. Obtain CA-TIMES energy scenario output
2. Generate projected criteria pollutant emissions
3. Produce the future meteorology fields
4. Run the air quality model at low resolution and at high resolution
5. Estimate mortality implications

IV. Air Quality Results

Annual Average PM2.5 Mass Concentration (μg m^{-3})

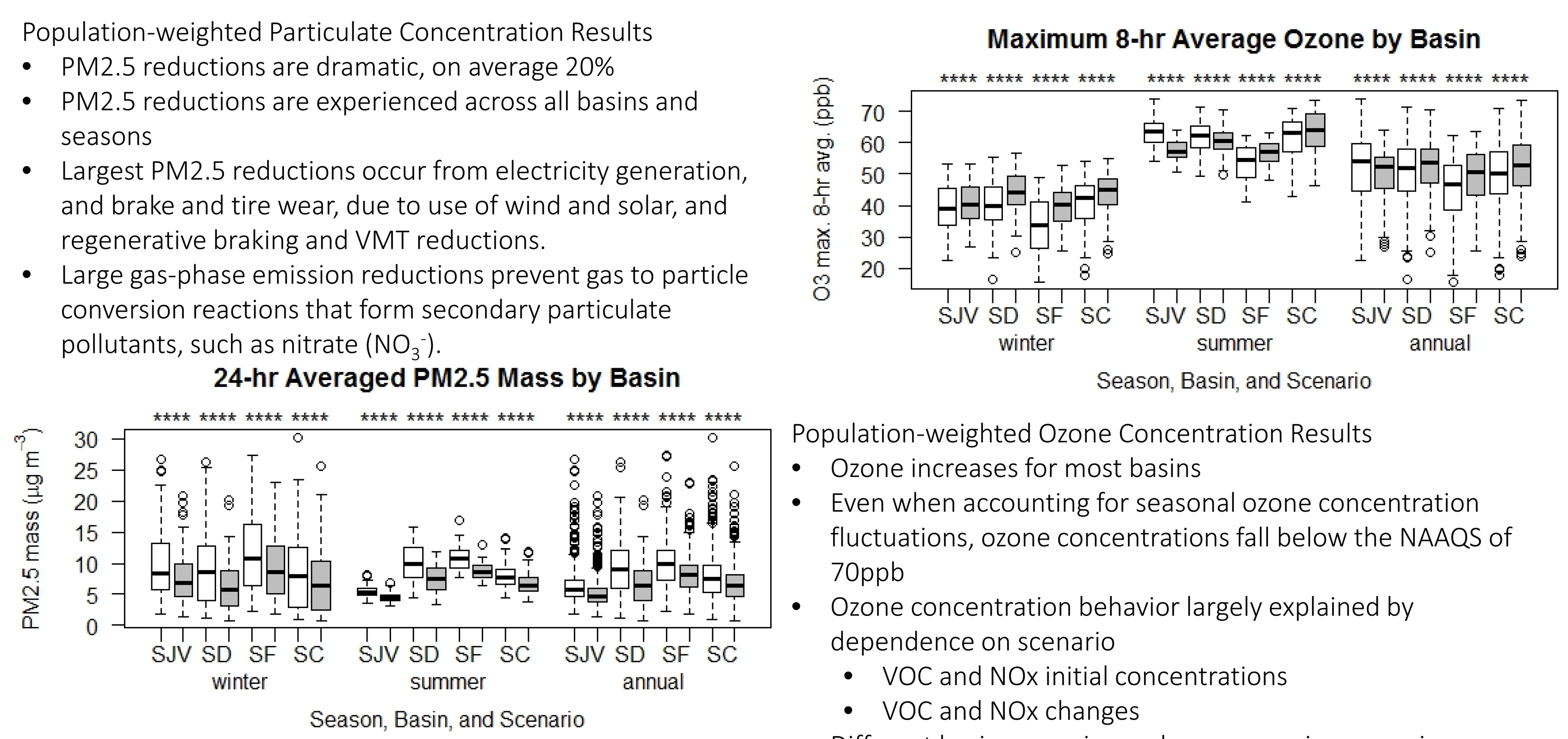


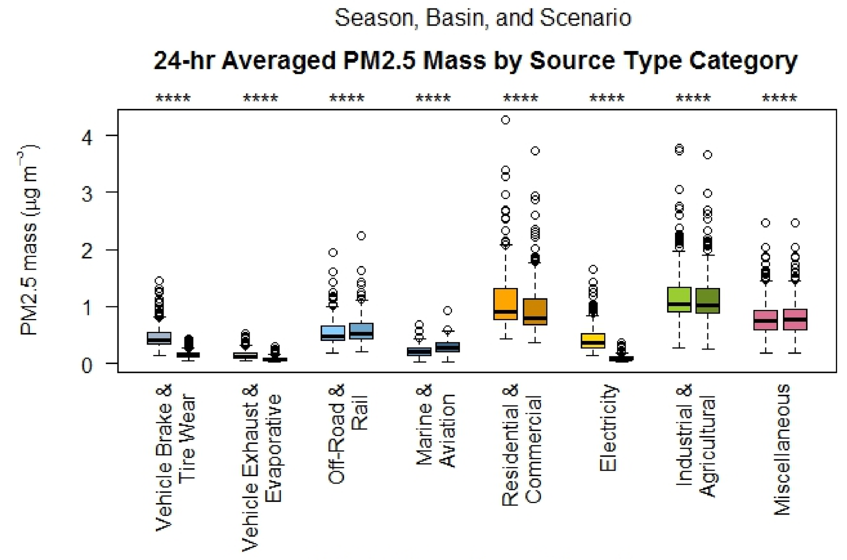
Annual Average 8-hour Ozone Concentration (ppb)



Population-weighted Particulate Concentration Results

- PM2.5 reductions are dramatic, on average 20%
- PM2.5 reductions are experienced across all basins and seasons
- Largest PM2.5 reductions occur from electricity generation, and brake and tire wear, due to use of wind and solar, and regenerative braking and VMT reductions.
- Large gas-phase emission reductions prevent gas to particle conversion reactions that form secondary particulate pollutants, such as nitrate (NO_3^-).





Population-weighted Ozone Concentration Results

- Ozone increases for most basins
- Even when accounting for seasonal ozone concentration fluctuations, ozone concentrations fall below the NAAQS of 70ppb
- Ozone concentration behavior largely explained by dependence on scenario
  - VOC and NOx initial concentrations
  - VOC and NOx changes
- Different basins experience decreases or increases in ozone.
  - Large Nox reductions and minimal VOC changes
  - The SJV basin, a Nox limited region, experiences ozone reductions, mainly in summer
  - SF and SC, would observe a slight increase throughout the year
  - SD would observe a small decrease in summer but larger increases in winter

Scenario
BAU
GHGAi
p-value
p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Air Basin Acronym	
SJV	San Joaquin Valley
SD	San Diego
SF	San Francisco
SC	South Coast

IV. Air Quality Results (Continued)

- Organic (primary and secondary) carbon contributes to a large share of the PM2.5 mass
- Nitrate, ammonium, elemental carbon, primary organic carbon, secondary organic carbon exhibit the largest reductions of the population-weighted concentration, of 40%, 35%, 23%, 15%, 3.2% in that order.
- The particle mass concentration in the ultrafine (PM0.1) particle size range have a larger decline of 35% than the total ultrafine and fine particle (PM2.5) sizes which reduce by 19%.
- Primary organic carbon reduces substantially, but secondary organic carbon formation changes are much smaller.

Annual average population-weighted BAU concentration and percent change between BAU and GHGAi scenario

			BAU Concentration					Percent Change				
			Air Basin				State	Air Basin				State
Pollutant	Units	Annual Avg.	SJV	SD	SF	SC	CA	SJV	SD	SF	SC	CA
Ozone (O_3)	ppb	8-hr max.	51.9	50.9	44.9	50.3	49.5	-3.4%	2.8%	9.6%	5.4%	3.9%
		1-hr max.	55.9	56.8	50.1	55.3	54.1	-4.3%	0.5%	6.5%	5.0%	2.7%
Nitrogen Oxide (NO)	ppb	24-hr avg.	0.97	3.30	9.46	2.26	3.63	-50%	-84%	-82%	-55%	-69.8%
Nitrogen Dioxide (NO2)	ppb	24-hr avg.	7.15	14.3	20.8	11.1	12.6	-34%	-57%	-45%	-33%	-39.4%
Nitrogen Oxides (NOx)	ppb	24-hr avg.	8.12	17.6	30.2	13.3	16.2	-36%	-62%	-57%	-36%	-46.2%
PM0.1 mass (PM0.1)	μg m^{-3}	24-hr avg.	2.38	3.39	3.82	3.25	3.17	-37%	-49%	-35%	-33%	-35.7%
PM2.5 mass (PM2.5)	μg m^{-3}	24-hr avg.	6.84	9.21	10.21	8.21	8.27	-20%	-29%	-19%	-17%	-19.3%
PM2.5 elemental carbon (EC)	μg m^{-3}	24-hr avg.	0.41	0.71	0.90	0.60	0.61	-27%	-34%	-38%	-8.8%	-22.5%
PM2.5 primary organic aerosol (POA)	μg m^{-3}	24-hr avg.	1.45	1.54	2.14	1.82	1.72	-19%	-20%	-11%	-14%	-14.8%
PM2.5 secondary organic aerosol (SOA)	μg m^{-3}	24-hr avg.	1.05	1.23	0.86	1.23	1.13	-7.9%	-0.6%	-3.3%	-1.5%	-3.2%
PM2.5 nitrate (NO_3^-)	μg m^{-3}	24-hr avg.	0.93	1.81	1.50	1.47	1.39	-49%	-49%	-45%	-34%	-40.2%
PM2.5 sulfate (SO_4^{2-})	μg m^{-3}	24-hr avg.	0.49	0.55	0.68	0.47	0.50	-12%	-61%	-28%	-25%	-28.1%
PM2.5 ammonium (NH_4^+)	μg m^{-3}	24-hr avg.	0.50	0.76	0.74	0.63	0.63	-33%	-50%	-36%	-30%	-35.0%
PM2.5 other	μg m^{-3}	24-hr avg.	0.95	0.97	1.01	0.64	0.79	-3.0%	-20%	-5.2%	-4.7%	-5.9%
PM2.5 unknown	μg m^{-3}	24-hr avg.	0.53	0.68	1.58	0.61	0.78	-0.2%	2.6%	2.2%	1.4%	1.7%

V. Mortality Implications

Long-term PM2.5 and O3 mortality estimates, by cause of death

Death Cause	Risk Ratio Reference	BAU (thousands)	GHGAi (thousands)	Difference of GHGAi-BAU (thousands)	Percent Change (%)
PM2.5					
All-Cause	Hoek et al. 2013	11.79	8.23	-3.56	-30.18
		(7.88, 15.78)	(5.49, 11.02)	(-2.39, -4.76)	(-30.35, -30.15)
	Krewski et al. 2009	6.92	4.83	-2.09	-30.22
		(3.24, 10.31)	(2.22, 7.19)	(-1.02, -3.12)	(-31.41, -30.23)
Lung Cancer	Krewski et al. 2009	0.81	0.55	-0.26	-32.59
		(0.53, 1.00)	(0.31, 0.67)	(-0.21, -0.33)	(-40.34, -32.87)
	Cui et al. 2015	0.99	0.67	-0.32	-32.76
		(0.29, 1.65)	(0.14, 1.15)	(-0.15, -0.50)	(-51.22, -30.25)
Cardio-pulmonary	Krewski et al. 2009	7.81	5.49	-2.32	-29.73
		(5.81, 9.94)	(4.07, 6.98)	(-1.74, -2.96)	(-30.02, -29.79)
Cardio-vascular	Hoek et al. 2013	6.65	4.67	-1.98	-29.79
		(3.48, 9.72)	(2.40, 6.85)	(-1.08, -2.87)	(-31.09, -29.51)
Ozone					
Respiratory	Jerrett et al. 2009	0.25	0.47	0.22	89.84
		(0.02, 0.46)	(0.09, 0.86)	(0.06, 0.40)	(258.33, 87.53)
PM2.5 and Ozone Total					
All-Cause	Hoek et al. 2013	11.79	8.23	-3.34	-28.33
		(7.88, 15.78)	(5.49, 11.02)	(-2.33, -4.36)	(-29.57, -27.63)
	Krewski et al. 2009	6.92	4.83	-1.87	-27.02
		(3.24, 10.31)	(2.22, 7.19)	(-0.96, -2.72)	(-29.63, -26.38)

Mortality Results

- 2.1-3.6 thousand premature deaths are avoided from GHGAi to BAU energy differences
- This is a drop in all-cause mortality from long-term associated air pollution of about 30%
- This equates to nearly
- PM2.5 all-cause mortality reductions far exceed increase in ozone respiratory death increase between scenarios
- Of all causes of death from pollution, lung cancer exhibits the largest decline from PM2.5 exposure.

Long-term PM2.5 and O3 mortality estimates, by cause of death

Death Cause	Risk Ratio Reference	BAU (Billion USD)	GHGAi (Billion USD)	Difference of GHGAi-BAU (Billion USD)
All-Cause	Hoek et al. 2013	87.22	60.89	-24.68
		(58.30, 116.75)	(40.60, 81.55)	(-17.23, -32.24)
	Krewski et al. 2009	51.19	35.72	-13.83
		(23.98, 76.29)	(16.45, 53.23)	(-7.07, -20.10)

- Based on value of a statistical life methods, this equates to a 13-25 billion USD savings from deaths avoided, versus 51-87 billion in costs.

VI. Conclusions

Energy Scenario Differences

- The transportation modes off-road marine, and aviation deemed by CA-TIMES as the more difficult or costly to decarbonize in the GHGAi scenario such as, tended to have higher criteria pollutant emissions than the sectors or transport modes decarbonized .

Emissions

- Emission reductions occur for the vehicular exhaust, evaporative, brake and tire wear and increase renewable mix of electricity generation, which exceed the increases in off-road and marine and aviation

Pollution Concentrations

- PM2.5 reduces substantially across the state.
- The chemical composition and size distribution of PM2.5 and gaseous pollutants change dramatically due to the reduction of combustion.
- Due to the large NOx reductions in the GHGAi scenario, some NOx-saturated areas such as SF and LA would experience a slight ozone increase.

Mortality and Costs Avoided

- 30% reduction or 2.1-3.6 thousand premature deaths are avoided from GHGAi to BAU energy differences
- Equates to 13-25 billion US dollar reduction

VII. Acknowledgements

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Contacting the Authors:
Christina Zapata (*cbzapata@ucdavis.edu*), Mike Kleeman (*mjkleeman@ucdavis.edu*)