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AIR QUALITY IMPACTS OF ELECTRIFICATION IN TANDEM WITH INTERMITTENT RENEWABLE RESOURCES

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1. INTRODUCTION

Renewable resources are a key strategy to reduce environmental impacts of power generation, including emissions of greenhouse gases (GHG) and pollutants towards improving regional air quality (AQ). However, the deep GHG reductions required to meet climate goals will likely require the co-deployment of additional mitigation strategies including the electrification of end-use energy sectors. Indeed, an integrated approach of energy efficiency measures, decarbonizing electricity generation, and electrifying end-use fuels may be the most feasible solution.

The goal of this work is to assess impacts on AQ from electrification in tandem with renewable resources in California. Transitions to electricity (e.g., from gasoline in transportation, natural gas in commercial/residential/industrial) can result in net reductions of GHG emissions, particularly as regional electrical grids integrate more renewable power. Additionally, reductions in pollutant emissions will benefit AQ, including reductions in ozone and fine particulate matter ($PM_{2.5}$). While net impacts are positive, integration of intermittent renewables can result in grid dynamic impacts that increase emissions per unit electricity (e.g., ramping, cycling, part-load operation, start/stop) and may increase generator emissions with potential localized worsening of AQ. Furthermore, assessing AQ impacts is not as simple as quantifying total emissions and requires an understanding of spatial and temporal emissions changes and chemistry and transport yielding changes in atmospheric pollutant concentrations. Thus, there is a need for information regarding how renewable resources in tandem with increased electrification of end-use sectors affects emissions and AQ in California.

In this study, we analyze emission impacts of electrifying end-use sectors while decarbonizing power generation, using detailed modeling of infrastructure and economic dispatch of an electrical grid. Emissions are spatially and temporally resolved and AQ is simulated to quantify and characterize changes in ozone and $PM_{2.5}$.

2. APPROACH

As shown in **Table 1**, a set of scenarios are analyzed in 2030 for augmented electrification in residential and commercial buildings (Buildings Case), light duty vehicles for both uncontrolled and controlled charging scenarios, and the industrial sector. A business-as-usual scenario (Base Case) is developed accounting for targeted renewable resource capacities, load growth, baseline demands, etc. Electrification Cases include projected demands and fuel distributions, electrification potential, and feasibility of available electric technologies. The additional electrification loads are quantified and temporally resolved. Complementary and renewable resource dispatch is resolved via the HiGRID Model [1, 2]. Resolution of utility generators dispatch is accomplished using an electric grid simulation model, PLEXOS [3, 4].

Table 1. Overview of Evaluated Cases

Case	Sector/Sub-sector	Technologies
Buildings	Commercial & Residential	Cooking, space and water heating
Industrial	Industrial	Boilers/HVAC
Transportation – Uncontrolled	Light Duty Vehicles: Uncontrolled charging	Battery Electric Vehicles
Transportation –Controlled	Light Duty Vehicles: Controlled charging	Battery Electric Vehicles
All Sectors	All the above	All the above

2.1 Emissions Assessment

Changes to baseline generator emissions are quantified and spatially and temporally resolved via a detailed representation of the future California electrical grid including centralized utility and distributed generators with temporal generation profiles, emission factors, and spatial information regarding the locations of existing generators. Load profiles are combined with generator emission rates for baseload operation and emission penalties associated with start/stops, ramping, and part-load operation. Generator emissions are spatially resolved via ArcGIS.

End-use sector emissions are manipulated by the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System [5]. Growth and control factors for the Base Case are developed from California Air Resources Board (ARB) projections [6] and applied to the 2005 US Environmental Protection Agency (EPA) National Emissions Inventory via SMOKE, including disaggregation of emissions into constituent chemical species via SCC-specific chemical speciation profiles. Source-specific codes are then used to reduce emissions in end-use sectors corresponding to the off-set of fuel combustion by electricity, e.g., tail-pipe emissions from vehicles (**Table 2**).

Table 2. End-use sector emission reductions for evaluated cases

	Sector Emissions Reduction				
Case	Res.	Com.	Ind.	Trans.	
				LDV	Refine
2030 Build.	-69.7%	-61.5%	----	----	----
2030 Indust.	----	----	-20.8%	----	----
2030 U. Trans	----	----	----	-38.0%	-18.7%
2030 C. Trans	----	----	----	-31.4%	-15.4%
2030 All Sectors	-69.7%	-61.5%	-20.8%	-31.4%	-15.4%

2.2 Air Quality Assessment

Developed emissions fields are utilized as input for simulations of atmospheric chemistry and transport via the Community Multiscale Air Quality (CMAQ, version 4.7.1) model [7] with the CB05CL chemical mechanism [8] for a modeling domain of 4 km X 4 km. Simulations are conducted for a summer period (July 7-13, 2005) and winter period (December 1-7, 2005) to capture high ozone (summer) and high PM (summer and winter) episodes. Results are obtained from the seventh day of simulation and reported as maximum 8-hr average ozone and 24-hr average $PM_{2.5}$. Summer ozone levels in the Base Case are shown in **Figure 1**, with peak maximum 8-hour averages reaching 93 ppb in the South Coast Air Basin (SoCAB). Additional areas of concern include the Central Valley, Bay Area, and Sacramento.

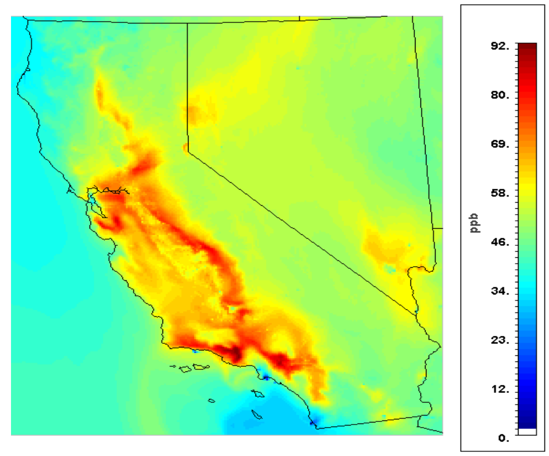

Figure 1. Max 8-hr summer ozone episode for the business-as-usual (Base) case.

5. RESULTS

5.1 Buildings Case

Figure 2 displays the difference in maximum 8-hour average ozone in the Summer 2030 Buildings Case from the Base Case. Quantitatively, peak impacts range from -3.55 to +2.66 ppb. Generally, improvements in ground-level ozone occur in regions downwind of urban populations coinciding with high concentrations of residential and commercial source emissions. Corresponding to sites of large natural gas-fired generators, several areas are associated with increased concentrations of ozone due to increased emissions from growth in total demand and penalties from operational dynamics. Notable areas of worsening occur in and east of Bakersfield with importance due to the human health and regulatory challenges associated with the existing air quality in the region. Impacts on $PM_{2.5}$ range from -0.74 to +12.58 μg/m^3 and -15.22 to +1.42 μg/m^3 in summer and winter, respectively. Impacts on $PM_{2.5}$ are particularly important in winter as a result of high demand for heating, offset of wood burning for heating, and the winter-time chemistry of secondary PM formation.

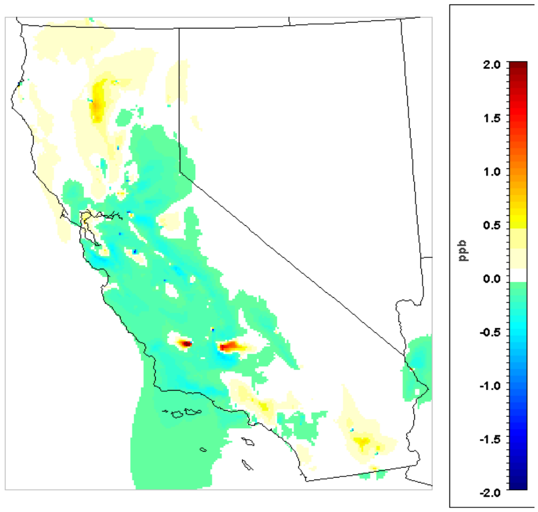

Figure 2: Δ Max 8-hr Ozone in the Summer 2030 Buildings Case from the Base Case

5.2 Transportation

The Transportation Cases assume electrification of light duty vehicles (LDV) only with two separate charging strategies – uncontrolled and controlled. Controlled charging was applied via a method developed in earlier work [9], resulting in significant shift of vehicle charging from the afternoon/evening to mid-day. This has the benefits of increasing the use of solar energy to charge vehicles and reducing peak demand offsetting peaker plant generation. Conversely, constraints on available electricity results in a lower penetration of LDV for Controlled (31%) relative to Uncontrolled (38%). This also translates to a lower turn-down of refinery emissions from reduced gasoline production.

Quantitatively, peak summer ozone impacts range from -1.89 to +0.63 ppb and -1.76 to +2.99 ppb for Controlled and Uncontrolled, respectively. Peak summer $PM_{2.5}$ impacts are -0.96 to +1.02 μg/m^3 (Controlled) and -3.83 to +4.95 μg/m^3 (Uncontrolled). Winter $PM_{2.5}$ impacts range from -0.96 to +1.02 μg/m^3 (Controlled) and -1.24 to +0.63 μg/m^3 (Uncontrolled). Generally, impacts are beneficial and include improvements in populated urban regions with high vehicle numbers such as SoCAB, the SF Bay Area, and some portions of the Central Valley (**Figure 3**). A small but notable area of increase occurs, originating from large natural gas generators in the Central Valley. Refinery emissions play a major role in the AQ impacts of LDV scenarios with more information available in Reference [10].

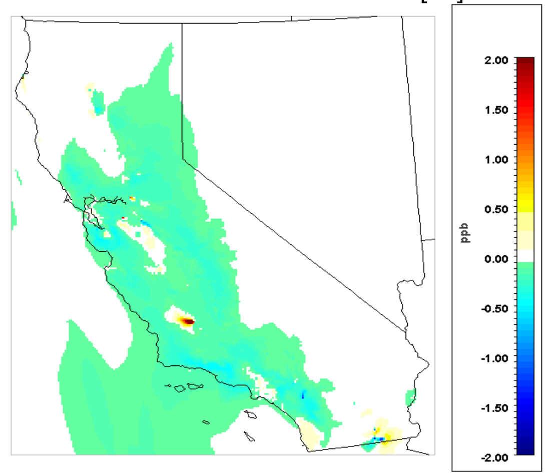

Figure 3. Δ Max 8-hr Ozone for Summer Uncontrolled Transportation Case from Base Case

Despite the larger penetrations of vehicles, the Controlled Case achieves a greater AQ benefit for both summer ozone (**Figure 4**) and winter $PM_{2.5}$ relative to Uncontrolled. On the other hand, a larger refinery reduction translates to increased peak $PM_{2.5}$ impacts for the Uncontrolled Case in Summer highlighting the complex chemistry associated with PM and impact of refinery emissions. Thus, complementary strategies can maximize electrification AQ benefits.

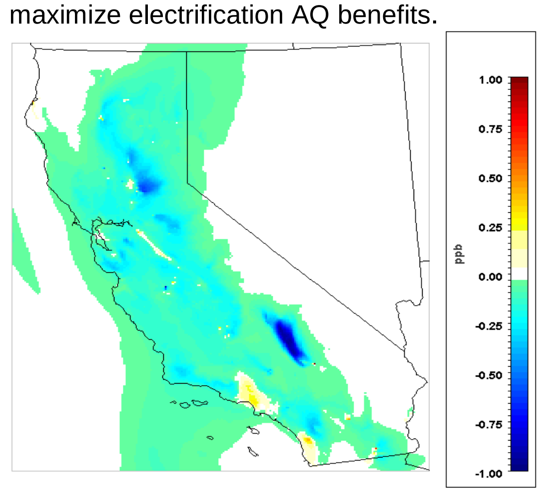

Figure 4. Δ Max 8-hr ozone between Controlled and Uncontrolled Charging Cases in summer.

5.3 Industrial

Figure **5** displays the difference in maximum 8-hour average ozone in the Summer 2030 Industrial Case with peak impacts from -4.13 to +2.87 ppb. $PM_{2.5}$ changes range from -0.24 to +18.31 μg/m^3 in summer to -3.83 to +4.95 μg/m^3 in winer. Despite reaching a higher peak, improvements are moderate with the most important impacts occurring in the Bakersfield region and extending westward. Increases in ozone occur in several other areas, including Northern CA and extreme Southern CA. It should be noted that industrial impacts shown here are associated only with emissions from industrial boilers, resulting in a large new demand for electricity. In CA, industrial boilers are heavily regulated and currently have control technologies limiting emissions. Thus, a more effective strategy could be to target reductions in other industrial source emissions (i.e., process emissions). The complexity of industrial processes prevented the consideration of electrification of specific process emissions in this work.

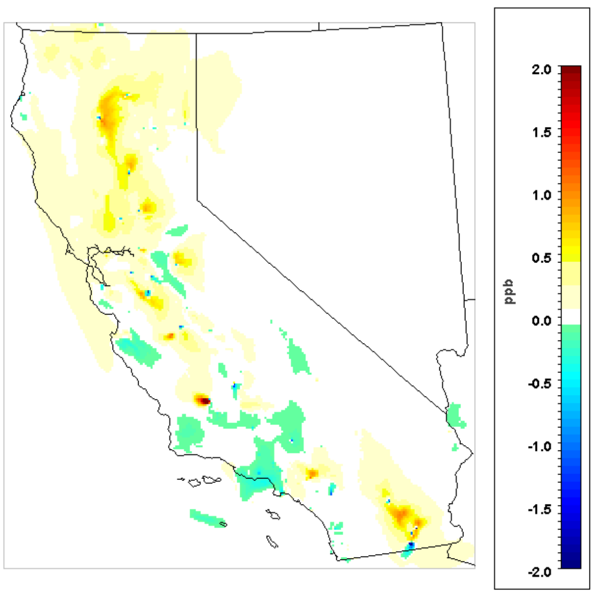

Figure 5. Δ Max 8-hr Ozone for Summer Industrial Case from Base Case

5.4 All Sectors

Figure **6** displays the difference in 24-hour $PM_{2.5}$ in the Winter 2030 All Sectors Case with impacts from -15.95 to +4.10 µg/m^3. Impacts include large improvements visible across the State including many regions currently experiencing poor AQ. Thus, the All Sectors 2030 Case provides a significant benefit to PM levels in winter. Quantitatively, summer impacts range from -1.19 to +27.99 µg/m^3 and are characterized by both improvements and localized worsening.

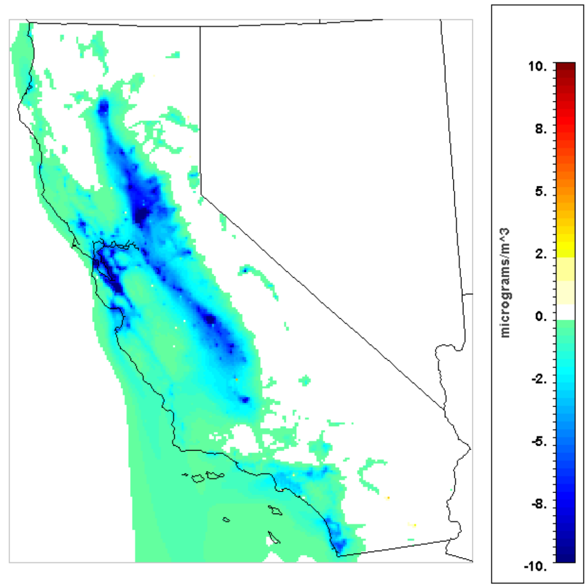

Figure 6. Δ 24-hr $PM_{2.5}$ for Winter All Sectors Case from Base Case

Figure **7** displays the difference in ozone in the Summer 2030 All Sectors Case with peak impacts from -6.49 to +3.05 ppb. Generally, the impacts are similar in spatial impact to the individual cases. Coastal areas of the State experience improvements – including the S.F. Bay Area and SoCAB. Additionally, large areas of the Central Valley experience reductions including extending north into the Sacramento area and beyond. Contrastingly, power generators yield emission increases that worsen ozone levels in localized areas. Two such areas occur in the Central Valley in the Bakersfield area.

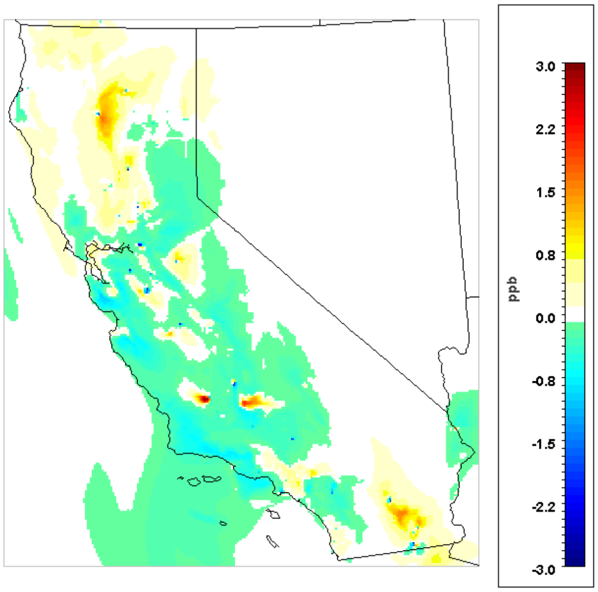

Figure 7. Δ Max 8-hr Ozone for Summer Industrial Case from Base Case

6. SUMMARY

Table 3 displays the peak impacts on 8-hour maximum ozone and 24-hour $PM_{2.5}$ concentrations for the evaluated electrification cases. Significant variation in both magnitude and spatial dimension is predicted for the different cases reflecting the dissimilarities in sector energy use and emissions profiles.

Table 3. Summary of peak AQ impacts

Case		Δ 8-hr Ozone [ppb]	Δ 24-hr $PM_{2.5}$ [μg/m^3]
Buildings	Summer	-3.55 to +2.66	-0.74 to +12.58
	Winter	-0.35 to +2.65	-15.22 to +1.42
Industrial	Summer	-4.13 to +2.87	-0.24 to +18.31
	Winter	-0.45 to +1.28	-1.14 to +4.55
Uncontr. Transport.	Summer	-1.76 to +2.99	-3.83 to +4.95
	Winter	-0.07 to +0.47	-1.24 to +0.63
Controlled Transport.	Summer	-4.38 to +2.04	-0.82 to +9.20
	Winter	-0.11 to +0.39	-1.31 to +1.18
All Sectors	Summer	-6.5 to +3.05	-1.19 to +27.99
	Winter	-0.63 to +2.83	-15.95 to +4.10

The results show that electrification will largely improve AQ, but could yield areas of localized worsening in ozone and $PM_{2.5}$ from generator emission impacts. Furthermore, impacts depend on multiple factors and vary markedly by pollutant, sector, horizon year, season, and location. Electrification of the light-duty vehicles should be targeted as AQ improvements occur in key regions including urban areas and those with existing poor AQ. Electrification of the residential and commercial buildings is particularly important for mitigating PM levels during winter months. Electrification of the industrial sector is complex and further assessment is needed to identify opportunities for process electrification. Advanced complementary strategies should be considered in tandem with electrification to mitigate any potential AQ worsening including advanced energy storage, SMART grid, demand response, and vehicle-to-grid services. The results have implications for both renewable resource deployment and regional AQ improvement planning.

7. References

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