Potential Public Health Costs from Air Quality Degradation during Grid Disruption Events – The Urgent Need to Adopt Zero Emissions Backup Power Systems

Introduction

Grid reliability is a foremost issue in California and effectively managing grid disruptions caused by natural disasters (e.g., wildfires) or other factors through the provision of back-up power has become an integral part of achieving a safe, reliable, and resilient electrical supply. Perhaps most notably, these disruptions include actions taken by California utilities to de-energize transmission and distribution systems to safely manage grid infrastructure and protect the environment, which are referred to as Public Safety Power Shutoffs or PSPS events. PSPS events have become increasingly more frequent in recent years in response to challenges brought about by the risk of devastating wildfires, a risk that will only continue to grow in coming years due to climate change and the increasing need to transmit renewable energy from remote areas to urban and suburban centers. While PSPS events reduce the risk of wildfire, they also prevent electricity from reaching residential populations and other vital entities including medical and emergency service providers, water agencies, gas stations, grocery stores, and others. To keep essential services in operation and to mitigate economic and comfort damage from PSPS events the use of fossil fuel backup generation is being widely used and the operation of gasoline- and diesel-powered gensets has significantly increased[1].

In response to the expected increases in PSPS events, the expanded use of fossil fuel back-up generators leads to substantial increases in criteria air pollutant emissions which contribute to degradations in regional air quality (AQ) including nitrogen oxides (NO_x) and particulate matter (PM). A deep breadth of scientific literature demonstrates a positive association between increased exposure to air pollution and increased incidence of harmful health effects within exposed populations.[2–4] Additionally, health consequences occur more frequently in socially disadvantaged communities (DAC) that experience increased vulnerability to air pollution.[5] However, translating emission increases into AQ impacts requires the use of an advanced air quality model to simulate atmospheric chemistry and transport to quantify and spatially resolve impacts on both primary (i.e., emitted) and secondary (i.e., formed in the atmosphere) pollutants including ozone and fine particulate matter ($PM_{2.5}$). Therefore, to quantify and value the public health costs that will result from the expanded use of fossil fuel backup generation in California, AQ simulations must be conducted.

Therefore, strategies to provide grid reliability while avoiding emission increases including microgrids that use a combination of solar power, battery energy storage systems, and stationary fuel cell systems that do not produce criteria pollutant emissions are needed. Stationary fuel cell systems operating on any fuel (e.g., renewable biogas, hydrogen, natural gas) do not produce criteria air pollutants, which makes these systems highly desirable compared to gasoline- and diesel-powered combustion generators. Both back-up power and primary power stationary fuel cell systems can displace these backup combustion generators because switchgear and controls can enable primary power fuel cell systems to seamlessly transition from grid-connected to islanded operation. The use of such systems can then prevent degraded AQ and the associated public health costs, which can provide significant economic value to California.

In this study an aggressive scenario of fossil back-up power deployment in response to grid disruption in the South Coast Air Basin in 2035 is evaluated for air quality and public health impacts. First, emissions are projected and spatially and temporally resolved accounting for major drivers from all end-use sectors including changes in demand, expected regulations, technology improvements, etc. Next, atmospheric chemistry and transport are simulated using an advanced air quality model to quantify and resolve increases in air pollution, including $PM_{2.5}$ and ozone, which result from backup generator emissions. Finally, a health impact assessment tool is used to quantify and value the public health costs that result from increased pollutant concentrations, including specifically within DAC. The results demonstrate the significant AQ degradation that could result from the increased use of gasoline and diesel generators, and the subsequent damage to public health that could result. **Conversely, the use of zero or low emission technologies, such as stationary fuel cells and battery systems, to provide backup power are urgently needed to avoid these consequences.** It should be noted that the results presented here were obtained using the information available at the time and required many assumptions be made. More refined estimates should be considered as additional information becomes available.

Methods

The assessment methods used in this this study are summarized in Figure 1. Emission projections are spatially and temporally resolved to the locations and times associated with technology activity based on a California Air Resources Board (CARB) emissions inventory. Next, emission changes are pre-processed using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling framework[6], and translated into impacts on atmospheric pollution levels, including ground level ozone and $PM_{2.5}$, via the Community Multi-scale Air Quality Model (CMAQ) version 5.2[7] which conducts simulations of atmospheric chemistry and transport. Differences in ozone and $PM_{2.5}$ from the Reference Case are then used to conduct a health impact assessment via the environmental Benefits Mapping and Analysis Program (BenMAP)[8] which provides a quantitative estimate of the incidence and monetary value of avoided deleterious health outcomes attributable to the modeled air quality changes including premature mortality and various morbidity endpoints.

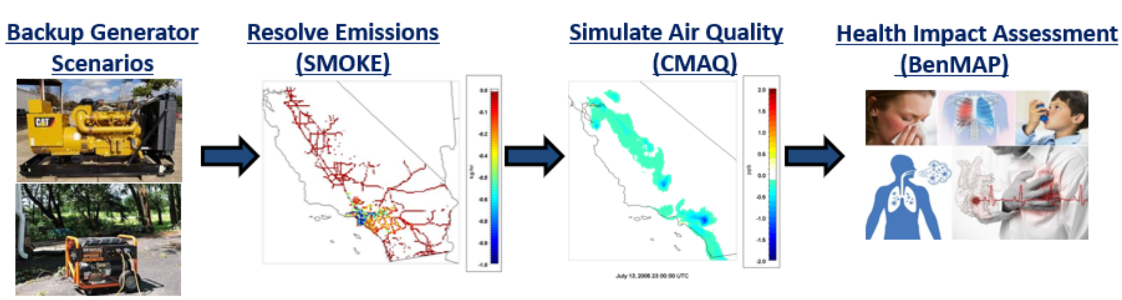

Figure 1. Overview of study methodology

Scenario Design

The goal of this work was to provide an initial estimate of the upper bound of the potential AQ degradation associated with fossil fuel backup generation deployment in response to PSPS events. Therefore, it is assumed that 75% of utility customers (residential, commercial, and industrial) in the South Coast Air Basin (SoCAB) experience a PSPS event in the same month. The events are assumed to be progressive (i.e., not necessarily simultaneous) and to last for 50 hours in total[1]. The scenario is herein referred to as the Grid Disruption (GD) scenario.

For the GD scenario, electricity consumption by customer type (residential, commercial, industrial) for each county in SoCAB is projected using utility data for current consumption[9,10] and demand forecasts[11]. It is assumed that 10% of residential customers who experience a PSPS event deploy a small (<25 hp) gasoline powered generator during PSPS events. In addition, it is assumed that 80% of residential customers live in applicable dwellings, e.g., not in apartments. Population weighted emission factors for gasoline generators are estimated using data from the California Air Resources Board[1]. For portable commercial diesel generators, it is assumed that the ratio of the statewide generator population scales with the actual population in SoCAB by county. Similarly, stationary permitted diesel generators are assumed to be impacted in proportion to population. Generator population, activity, and emissions for diesel generators serving both categories are estimated from CARB data[1]. In the Reference Scenario it is assumed that no additional back-up generator operation occurs other than what is already contained within the baseline inventory[12].

Emissions and Air Quality Modeling

To evaluate the potential worsening of AQ from the widespread use of back-up generators, a comprehensive air quality modeling methodology is used. First, the changes in pollutant emissions including NO_x, SO_x, NH_3, CO, Volatile Organic Compounds (VOC) and Particulate Matter (PM) are projected to 2035 using SMOKE for both the Reference (no increase in back-up generation) and GD scenarios. Next, fully resolved distributions of changes in atmospheric pollutant concentrations are developed using CMAQ.[7] CMAQ was developed by the US EPA and is used extensively for air quality modeling needs including regulatory compliance and atmospheric research associated with tropospheric ozone, PM, acid deposition, and visibility.[13,14] The SAPRC-07 chemical mechanism[15] is selected for gas-phase chemistry, and AERO6 module[16] is used to calculate aerosol dynamics. The Advanced Research Weather Research and Forecasting Model (WRF-ARW) is used to downscale meteorological conditions from the (Final) Operational Global Analysis data.[17] The boundary conditions are obtained via the Model for Ozone and Related Chemical Tracers (Mozart v4.0).[18]

The environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) from the US EPA [8] is then used to quantify the health damages from increases in ozone and $PM_{2.5}$ that result from the increased use of back-up generators. The methods used follow those in the South Coast Air Quality Management District's (SCAQMD) Socioeconomic Report for the 2016 Air Quality Management Plan (AQMP).[19] Population projections are obtained from demographic data[20] at the census tract level. Baseline incidence rates for mortality and morbidity are estimated from public administrative records where feasible and projected from US Census Bureau data.[21] Concentration-response functions are selected based on suggested criteria from a systematic review of the epidemiological literature.[22] It is important to note that only health effects from short-term exposure to ozone and $PM_{2.5}$ are included as appropriate for the modeled episode. Conversely, the quantification of impacts from long-term exposure to $PM_{2.5}$, such as those for annual simulations, would result in significantly higher health impacts (generally an order of magnitude higher than episodic modeling).[23–25] Therefore, the health costs presented here should be considered conservative.

Results

Pollutant Emissions

The operation of fossil backup generation in the considered scenario results in sizeable increases in pollutant emissions, including 8 tons per day of NO_x (shown in Figure 2). This is equivalent to an increase of approximately 3.5% in SoCAB. Similarly, direct emissions of $PM_{2.5}$ increase substantially with particular concern arising from diesel $PM_{2.5}$, which carries notable health effects. Also shown in Figure, the largest increase in emissions occurs in Los Angeles County as a result of large, dense residential populations and presence of commercial and industrial entities.

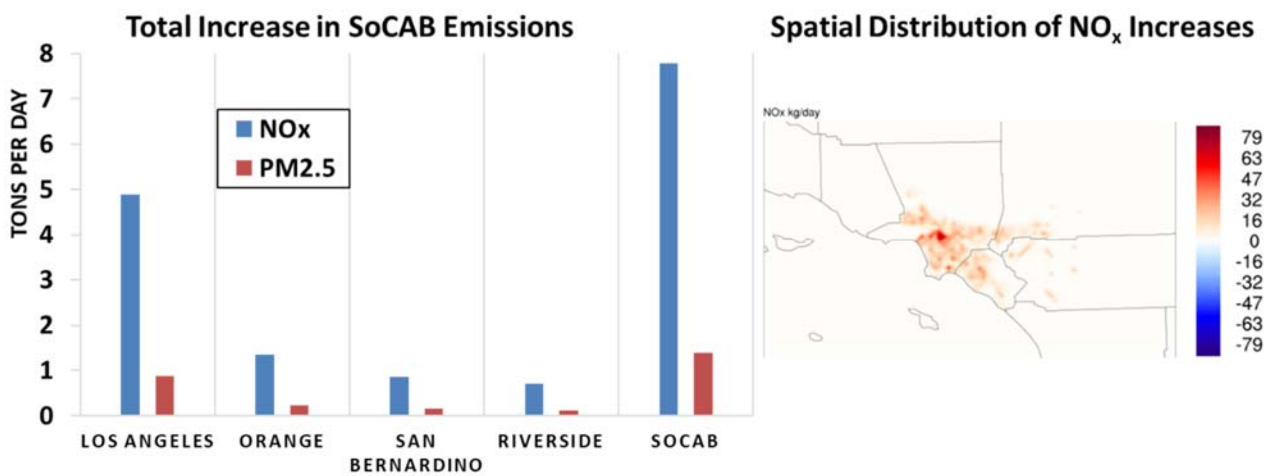

Figure 2. Total increases of NO_x and $PM_{2.5}$ and spatial location of NO_x emissions increases of the GD Scenario

Air Quality

The increased emissions from the widespread use of fossil backup generators leads to significant degradation of regional AQ in SoCAB during conditions conducive to pollutant formation. This is evident in the results shown below, which demonstrate substantial increases in atmospheric concentrations of ozone in summer (Figure *3*) and $PM_{2.5}$ in both summer and winter (Figure *4*). These increases are concerning given the current status of SoCAB as being in non-attainment of Federal health-based standards for both pollutants and the large, dense population within the area which amplifies the potential health consequences. In particular due to the well-known health consequences of exposure[26–28], increases in maximum daily 24-h average (MD24H) $PM_{2.5}$ could exceed 3.7 μg/m^3 in winter and 2.3 μg/m^3 in summer. Considering the current standard is 35 μg/m^3 , increases of those magnitude present a major challenge for successful compliance with AQ regulations in addition to contributing public health burdens. Similarly, maximum daily 8-hr average (MD8H) ozone concentrations are predicted to increase by as much as 1.8 parts per billion (ppb), approximately 2.6% of the current 70 ppb standard. Additionally, the results demonstrate that emissions can degrade AQ both nearby generator locations and also in areas some distance away. For example, increases in ozone are most pronounced in the eastern regions of the SoCAB despite precursor emissions increasing the most near downtown Los Angeles. This is due to the transport that happens due to prevailing meteorology and the temporal period required for chemical reactions in the atmosphere to take place. Contrastingly, $PM_{2.5}$ increases are highest in Los Angeles indicating 1) the importance of direct emissions to overall burdens and 2) differences in chemical mechanisms associated with secondary $PM_{2.5}$ formation from gaseous precursor emissions. The spatial characteristics of pollutant impacts directly determine the resulting population exposure, particularly with regards to health consequences within DAC.

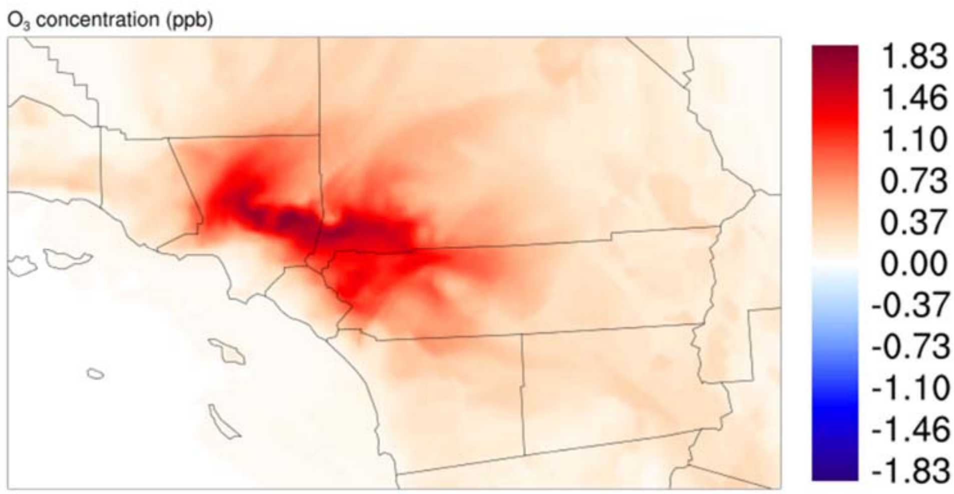

Figure 3. Increases in ground level MD8H summer ozone from the widespread use of fossil backup generators during a grid disruption

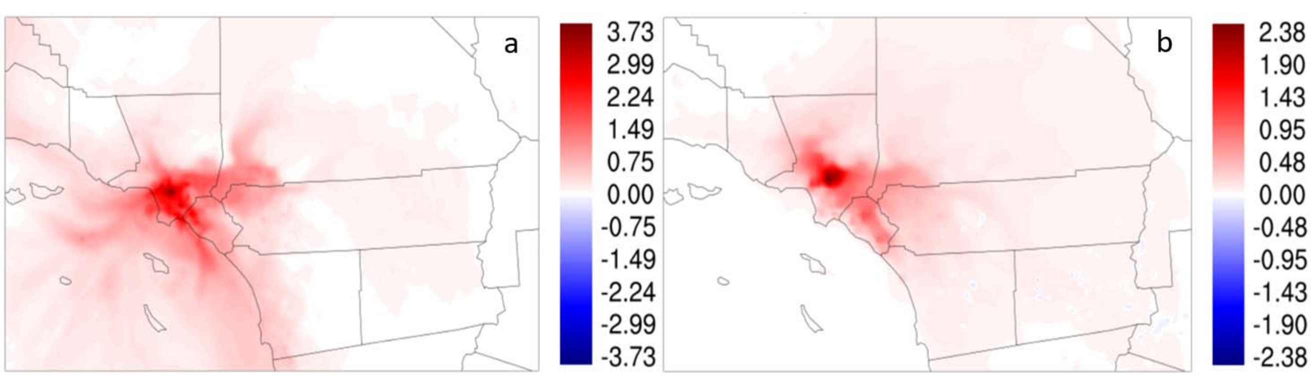

Figure 4. Increases in ground level MD24H $PM_{2.5}$ from the widespread use of fossil backup generators during a grid disruption for winter (a) and summer (b) with units in μg/m^3

The worsened AQ results in increases in the incidence of deleterious health effects in the SoCAB populations that are exposed, including premature mortality and various morbidity endpoints (e.g., respiratory disease, hospital admissions, lost school, and workdays). The economic costs of the increased public health burdens estimated using BenMAP are shown in *Figure 5*. For a 10 day period of poor air quality in summer, the detrimental health cost is estimated to exceed $4 million. Similarly, the cost of detrimental health effects of additional $PM_{2.5}$ burdens in the winter also exceeds $4 million (ozone is not included in winter because it generally does not exceed standards in the winter). The results demonstrate the importance of backup generator contributions to regional $PM_{2.5}$ burdens, e.g., ~85% of the health burden in summer is from $PM_{2.5}$ relative to ozone.

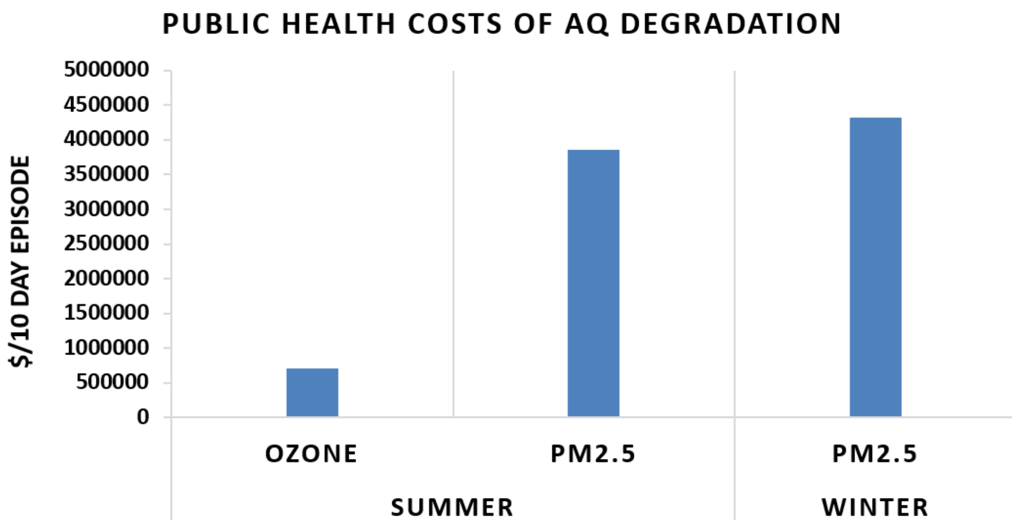

Figure 5. The public health costs estimated from increased short-term exposure to augmented ozone and PM2.5 as a result of fossil back-up generators operating during a grid disruption

Furthermore, the estimated health costs often occur within DAC that already experience higher air pollution burdens and are more vulnerable to the associated health damages (Figure 6). This is particularly true for DAC in Los Angeles during the winter episode, which area experiences significant health costs due to increased $PM_{2.5}$. Additionally, DAC in eastern regions of the SoCAB, including Riverside and San Bernardino Counties, experience detrimental health effects and costs as a result of worsened ozone and $PM_{2.5}$ concentrations during grid disruptions.

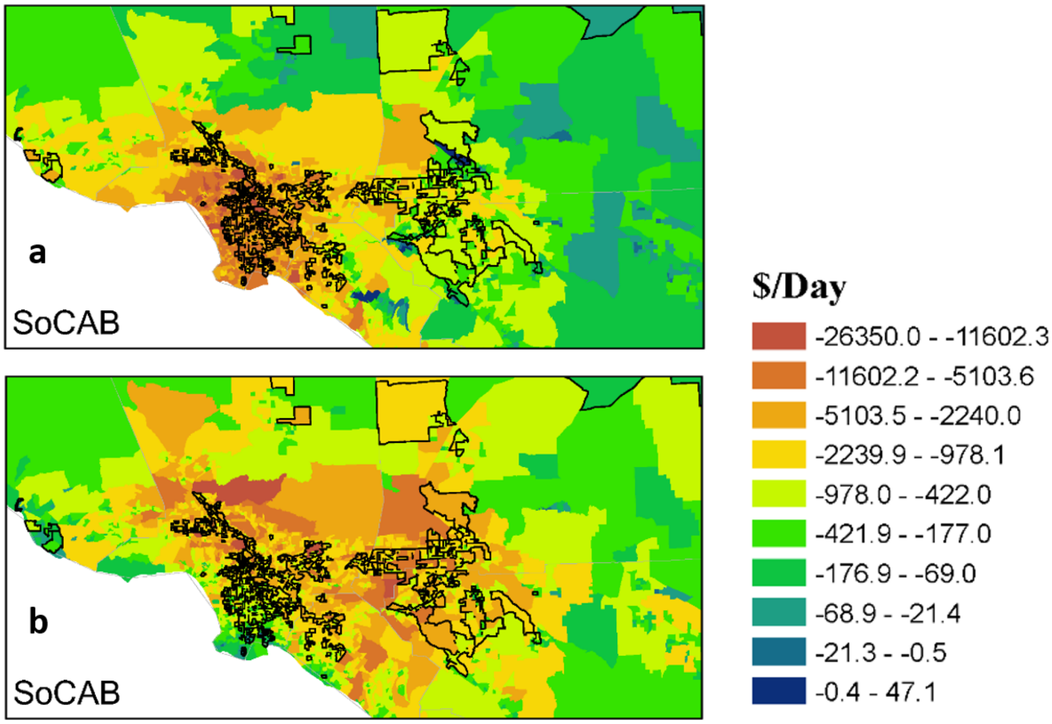

Figure 6. Spatial distribution of public health costs from AQ degradation in (a) winter and (b) summer. Boundaries for socially disadvantaged communities according to CalEnviroScreen are outlined

Summary and Conclusions

The results here clearly demonstrate the degraded AQ and public health costs that could result from expanded use of fossil fuel back-up generators in response to grid disruption events such as PSPS events. While the scenario evaluated is aggressive and represents an upper bound from that perspective, it should also be considered that only health effects from short-term exposure are included which provides a highly conservative estimate of the public health costs. It can be assumed that the public health costs of long-term exposure to increased air pollution from back-up generators would likely be orders of magnitude higher than what is reported here.

Furthermore, the occurrence of increased public health costs within DAC is unacceptable. Current health burdens associated with exposure to air pollution are not uniformly distributed across California populations. Rather, certain regions and population segments bear disproportionate shares of the pollution burden, and many of these same communities also suffer additional socioeconomic burdens that increase their vulnerability to air pollution [29]. It is in these socially disadvantaged communities that improved AQ is badly needed, and this is represented in current California legislative mandates including California laws (e.g., Senate Bills 375, 530, 535, 1000) directing investment towards and protecting socially vulnerable populations. Therefore, it will be essential for grid support strategies to be developed that ensure grid reliability without using fossil fuel combustion-based generation that worsens AQ in DAC.

Therefore, strategies to provide grid reliability that include microgrids that use a combination of solar power, battery energy storage systems, and stationary fuel cell systems that do not produce criteria pollutant emissions must be developed and deployed to avoid the AQ degradation estimated here. Importantly, solar can provide an important fraction of the demand and batteries can provide short-duration energy storage, while both backup fuel cells and continuous power fuel cells with appropriate switchgear for seamlessly transitioning between grid-connected and islanding mode can provide long-duration supply of ultra-low to zero criteria pollutant emissions power during grid disruptions of any kind. Stationary fuel cell systems, together with solar and battery storage systems in microgrids represent a technology class with numerous benefits when deployed to support the electrical grid[30].

As previously mentioned, this work represents an initial attempt at quantifying the AQ impacts of future grid disruption events and there are numerous aspects that could be improved. In particular, more realistic scenarios of grid disruption should be considered, including enhanced geographic specificity with regards to the location and timing of back-up generator usage. Similarly, better-quality data regarding statewide populations and characteristics of fossil fuel back-up generator adoption and use including emission rates would facilitate improved estimates of the direct emissions dynamics. Finally, annual simulations of AQ using CMAQ would allow for estimations of annual pollutant concentration changes, which in turn would allow for a much more comprehensive and realistic accounting of the public health costs.

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