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A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: Case study on peaker power plant displacement

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HIGHLIGHTS

- We develop a health and environmental framework for siting clean energy resources.
- Metrics include total mass, time, rate and location of displaced marginal emissions.
- Emission displacement is prioritized near dense populations on poor air quality days.
- We apply our framework to the displacement of peaker power plant generation in CA.
- We identify optimal places and times to site and dispatch storage and demand response.

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ABSTRACT

Emerging grid resources such as energy storage and demand response have the potential to provide numerous environmental and societal benefits, but are primarily sited and operated to provide grid-specific services without optimizing these co-benefits. We present a four-metric framework to identify priority regions to deploy and dispatch these technologies to displace marginal grid air emissions with high environmental and health impacts. To the standard metrics of *total mass* and *rate* of air pollutant emissions we add *location* and *time*, to prioritize emission displacement near densely populated areas with poor air quality, especially at times when air pollutant concentrations exceed regulatory standards. We illustrate our framework with a case study using storage, demand response, and other technologies to displace peaker power plants, the highest-rate marginal emitters on the California grid. We combine spatial-temporal data on plant electricity generation, air quality standard exceedance days, and population characteristics available from environmental justice screening tool CalEnviroScreen 2.0 to determine where emissions reductions may have the greatest marginal benefit. This screening approach can inform grid siting decisions, such as storage in lieu of peaker plants in high impact regions, or dispatch protocol, such as triggering demand response instead of peaker plants on poor air quality days.

1. Introduction

The electric power sector is facing a rapid transformation with the influx of new advanced technologies coming onto the electric grid, from distributed resources like demand response and rooftop solar to transmission-level energy storage installations. These emerging technologies have the potential to provide a wide range of societal and environmental benefits, from reducing emissions of greenhouse gases (GHGs) and criteria and hazardous air pollutants, to increasing grid efficiency, energy security and resilience (Manfren et al., 2011; Amor et al., 2014; Anaya and Pollitt; Levy et al., 2003; Novan, 2015). Grid integration approaches for these technologies, however, have typically been focused on immediate monetary value and lacked a larger coherent strategy regarding where these technologies should be added to optimize these co-benefits. Here we develop a framework to optimize the siting and operation of emerging clean energy technologies based on air

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pollution emission, human health, and environmental justice (EJ) metrics, with an emphasis on the dependence of those benefits on *time* and *place*. Application of this framework provides an environmental, health and equity-based screening approach to design and evaluate siting and dispatch protocol, which we demonstrate using a case study wherein technologies like energy storage and demand response are sited or dispatched based on air quality and demographic conditions.

Policy strategies for achieving environmental objectives in the power sector often fall into one of two broad categories: targets may be set to adopt clean energy technologies, such as a target for megawatts (MW) of rooftop solar; or limits may be set on pollutant emission levels in the form of taxes, fees, carbon cap-and-trade schemes, and technology emission standards (Tsao et al., 2011; Liao et al., 2012). While the growth of energy storage, demand response, distributed generation and other emerging grid resources may benefit from pollution limits, their integration on the grid to date has primarily been propelled by incentives and targets aimed at increasing adoption rates. A number of studies have assessed the value of grid services such technologies may provide in specific locations (Anaya and Pollitt; Pearre and Swan, 2015), and regulators are following suit. New York State introduced the Reforming the Energy Vision initiative in 2014 to create market mechanisms for distributed energy resources to compete and provide unique services on the grid, such as deferring distribution upgrades (NYSDPS, 2014). The California legislature set a 1.3 GW energy storage target for 2020 (CA State Assembly, 2010) and regulators are attempting to determine methods for valuing the specific services this storage provides in different places on the grid (Kaun, 2013; Abrams et al., 2013). Like New York, California is also pursuing regulations to assess the locational value of distributed energy resources (CA State Assembly, 2013). While the putative overarching motivation for these policies is to achieve environmental benefits, the proposed valuation schemes that have been introduced tend to focus on directly monetizable grid-specific benefits (Anaya and Pollitt; Pearre and Swan, 2015; Kaun, 2013; Abrams et al., 2013). Although pollution-limiting policy instruments such as cap-and-trade may benefit these technologies, there is limited discussion of how to optimize the integration of energy storage and emerging distributed energy resources to more fully realize their health and environmental co-benefits.

Here we propose the targeted displacement of high-impact marginal emissions, identified using four metrics: total mass, rate, location and time of avoided emissions. These metrics can be used to inform *siting decisions*, such as selecting between storage or a new peaker plant to meet peak demand growth, or *operational decisions*, such as dispatching demand response on poor air quality days, effectively expanding “spare the air” days to the power grid. We prioritize the reduction of emissions of toxic air contaminants and criteria air pollutants from the highest-rate marginal emission sources on the grid, near dense populations and overburdened populations, and on days when air pollution burdens are most elevated, specifically when local air quality conditions exceed state and federal standards. Section 2 provides background on the air quality and health impacts of power generation, environmental justice, and the realization of environmental health co-benefits through grid operation and siting of emerging technologies. Section 3 introduces our set of four metrics to identify target locations to integrate clean technologies and avoid emissions of GHGs and criteria air pollutants. Section 4 applies this approach to the power grid in California and assesses the potential for clean energy technologies to displace emissions from peaker power plants. Finally, Section 5 includes a discussion of the policy implications of our approach, how this framework can be integrated into existing valuation mechanisms for the grid, and its application to different electricity resource mixes in other parts of the country where displacing generators like oil-fired peaker plants may yield even greater benefits.

2. Background

2.1. Power generation and air quality

The traditional power sector contributes to a wide range of environmental and public health burdens. 31% of total 2013 US GHG emissions came from the power sector (EPA, 2015); this sector may have an even higher impact when considering full lifecycle emissions from fossil fuel production (Brandt et al., 2014; Howarth et al., 2011). While GHG emissions have a global impact, fossil fuel power plants also emit criteria and hazardous air pollutants that have direct and indirect local and regional health and environmental impacts, including nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) (De Gouw et al., 2014). NO_x also serves as a precursor for ozone and $PM_{2.5}$ (diameter $<2.5\ \mu m$) formation. Short-term and chronic ozone exposure has been found to increase mortality rates (Thurston and Ito, 2000), particularly respiratory and pulmonary deaths (Gryparis et al., 2004; Bell et al., 2004). High $PM_{2.5}$ concentrations increase the rate of acute coronary events, particularly in those with underlying disease (Pope et al., 2006) and the elderly (Bell et al., 2008). Some populations are more at risk to exposure than other groups: high 1-h NO_x concentrations, 8-h ozone concentrations, and 24-h $PM_{2.5}$ concentrations are associated with increased asthma-related hospital visits in children (Strickland et al., 2011); 8-h ozone concentrations are also strongly correlated with negative health impacts on the elderly and those with low employment status, and weakly correlated with impacts on ethnic or racial minority populations, and populations with high poverty rates or low educational status (Bell et al.).

Mitigation of criteria air pollutant impacts requires a local and regional approach due to the heterogeneity of air quality and local demographics as well as the shorter lifetimes of these pollutants, unlike GHGs which tend to be globally dispersed due to their long atmospheric lifetimes. While GHG mitigation policies tend to focus only on the rate and total mass of emissions, criteria pollutant policies should consider local atmospheric conditions and the size, proximity and demographics of exposed populations. Ozone formation, for example, depends on background concentrations of precursors including NO_x and volatile organic compounds (VOCs), as well as temperature and weather conditions affecting the mixing and dispersion of these pollutants. Higher population density is associated with higher intake fractions of pollutants (Heath and Nazaroff, 2007). Mauzerall et al. (2005) valued the ozone-specific mortality and morbidity benefits of reducing NO_x emissions from power plants at different times and places across the country at \$10,700–\$52,800/ton NO_x (1995USD) depending on local population density and atmospheric conditions like temperature. Fann et al. (2009) estimated the $PM_{2.5}$-specific benefit of power plant NO_x reductions as ranging from \$1,100 per ton of NO_x in Chicago to \$120,000 per ton in Seattle (2006USD). In its 2015 Clean Power Plan, the US Environmental Protection Agency (EPA) estimated the 2020 health benefit of reducing NO_x emissions to be highest in California, at \$22–49,000/ton in $PM_{2.5}$-specific benefits and \$14–59,000/ton in ozone-specific benefits (2011USD) (EPA, 2015).

2.2. Demographics and environmental justice

Local demographics are an important factor when addressing power sector impacts. Power plants have been found to be