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Air quality impacts of projections of natural gas-fired distributed generation

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HIGHLIGHTS

- 6–24 GW of natural gas-fired DG penetration is estimated for 2030.
- Ozone levels may increase up to 6 ppb due to increased NG-fired DG penetration.
- Largest air quality impacts from NG-fired DG occur in New England and California.
- The greatest projected DG penetration occurs New England, New York, and California.
- Stricter emission limits for NG-fired DG greatly reduce air quality impacts of DG.

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ABSTRACT

This study assesses the potential impacts on emissions and air quality from the increased adoption of natural gas-fired distributed generation of electricity (DG), including displacement of power from central power generation, in the contiguous United States. The study includes four major tasks: (1) modeling of distributed generation market penetration; (2) modeling of central power generation systems; (3) modeling of spatially and temporally resolved emissions; and (4) photochemical grid modeling to evaluate the potential air quality impacts of increased DG penetration, which includes both power-only DG and combined heat and power (CHP) units, for 2030. Low and high DG penetration scenarios estimate the largest penetration of future DG units in three regions – New England, New York, and California. Projections of DG penetration in the contiguous United States estimate 6.3 GW and 24 GW of market adoption in 2030 for the low DG penetration and high DG penetration scenarios, respectively. High DG penetration (all of which is natural gas-fired) serves to offset 8 GW of new natural gas combined cycle (NGCC) units, and 19 GW of solar photovoltaic (PV) installations by 2030. In all scenarios, air quality in the central United States and the northwest remains unaffected as there is little to no DG penetration in those states. California and several states in the northeast are the most impacted by emissions from DG units. Peak increases in maximum daily 8-h average ozone concentrations exceed 5 ppb, which may impede attainment of ambient air quality standards. Overall, air quality impacts from DG vary greatly based on meteorological conditions, proximity to emissions sources, the number and type of DG installations, and the emissions factors used for DG units.

1. Introduction

Distributed electric power generation (DG), as a subset of

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distributed energy resources (DER), entails the use of small capacity power generation technologies, such as gas turbines, internal combustion engines and fuel cells on the order of a few tens of MW or less, to produce electricity, and in some instances thermal energy, for local use. While DG also includes renewable energy technologies such as solar photovoltaic (PV) and wind turbines, the focus of the present study is an environmental analysis of the potential air quality impacts of natural gas-fired DG units. A variety of electricity industry drivers are converging to allow for a resurgence of interest in natural gas fired distributed generation. These drivers include improved DG technologies, low natural gas prices, high electric retail rates, flat load growth, and policy and incentive programs in certain areas of the country. DG technologies can fulfill the energy needs of customers. For instance, DG units can deliver critical customer loads with emergency stand-by power; support available capacity to meet peak power demands; and provide low-cost total energy in combined heat and power (CHP) applications. Typical uses of DG deployments include cogeneration, peak shaving, backup generation, and on-site generation (EPRI, 2014). Typical customers for fossil fuel fired DG systems include commercial and industrial enterprises, which are the focus of this study. Emerging DG technologies have the potential to be an important component of future electricity infrastructure, as the traditional grid is expected to morph into a smart power system capable of supporting the needs of the digital society of the twenty-first century. Therefore, it is crucial to ensure a clear understanding of their potential environmental impacts, including air emissions and any resulting changes to air quality.

There have been a number of studies that analyzed the potential effects of DG on air quality in some areas of the United States. Some studies focused on the potential increase in emissions from natural gas-fired DG compared to central generation (Allison and Lents, 2002; Strachan and Farrell, 2006) and advocated for manufacturer-based regulations that account for total supplied energy output (heat and power) to include all major efficiency advantages of DG technologies. Others have examined the impact of a shift from centralized power plants to fuel-powered (e.g., natural gas or diesel) small-scale distributed electricity generation on population inhalation exposure of primary pollutants in California (Heath et al., 2006; Heath and Nazaroff, 2007). They found that the low stack height of DG sources and their proximity to densely populated areas dramatically increases human exposure to air pollutant emissions compared with central station power plants. Several studies analyzed the effects of natural gas-fired DG in California, using dispersion modeling (Venkatram et al., 2010; Jing and Venkatram, 2011) or photochemical grid models (Rodriguez et al., 2006; Carreras-Sospedra et al., 2010; Vutukuru et al., 2011). Those studies investigated effects of new emissions regulations, duty cycle, and the spatial distribution of DG installations and used air quality modeling to evaluate impacts of DG on ozone and particulate matter (PM) concentrations and pollutant exposure in those regions. The studies concluded that the most important parameters that define the potential air quality impacts are the total installed capacity and emission factors for DG. Various plausible spatial distributions showed little effect on overall air quality impacts. Other studies analyzed potential effects over the Eastern US caused by natural gas-fired DG (Carreras-Sospedra et al., 2008) and back-up diesel generators (Gilmore et al., 2006, 2010). The studies on diesel back-up generators determined changes in ambient concentrations of pollutants and used concentration-response functions and economic parameters to evaluate the monetary cost of health impacts. Results showed that uncontrolled diesel backup generators as peaking DG units would increase PM concentrations but would cause both increases and decreases in ozone concentrations. Increases in PM concentrations up to 5 μg/m^3 were found in all four modeled cities and were due mostly to primary emissions. Increases in NO_X emissions caused modeled ozone concentrations to decrease in urban centers due to titration effects but increase in the surrounding areas where the NOx/VOC ratio is lower.

In general, the modeling studies were limited to simulations that spanned only a few days, although the time periods selected for the modeling were representative of conditions that typically lead to adverse air quality. Most research has focused on California and, to a lesser extent, the northeastern United States. This study estimates the potential implementation of natural gas-fired DG in the contiguous United States, including displacement of power from central power generation, and simulates the potential impacts on emissions and air quality. The study includes four major tasks:

1. Modeling of distributed generation market penetration using the DISPERSE model
2. Modeling of central power generation systems using the US-REGEN model
3. Modeling of spatially and temporally resolved emissions
4. Photochemical grid modeling using the CAMx model

The methodology for each of the tasks is described briefly in the Methodology section, and a more exhaustive description is included in the supplementary material. This article provides an updated picture of the potential impacts of increased implementation of natural gas-fired DG in the contiguous United States by integrating a novel and comprehensive electric power sector model with a DG market study. Impacts on emissions are refined from previous studies by using up-to-date emission factors from recent technology surveys. Additionally, air quality simulations are performed for both summer and winter conditions and over time periods that span several weeks, rather than only a few days, to provide a more complete assessment of potential impacts on air quality. This paper explores a range of plausible scenarios while providing a modeling framework and methodology that can be applied in future studies to assess the potential implementation and impacts of distributed generation of electricity. The results of this analysis are not intended to be definitive predictions of future DG deployment or future air quality but rather provide insights on potential degrees of DG deployment and the resulting impacts on emissions and air pollutant concentrations. Limitations of this study and recommendations for future work are summarized in section 4.

2. Methodology

The potential air quality impacts of increased DG penetration are evaluated for a winter and summer period in 2030 using year 2007 meteorology. DG units include power-only distributed generation (power-only DG) and combined heating and power (CHP) units that are located near the place of use and are used to supply electricity and thermal energy to a specific commercial or industrial load. In this paper, “DG” will be used to refer to both power-only DG and CHP units. Projections of DG penetration throughout the contiguous United States are estimated using the DISPERSE model, which produces hourly-resolved and size-resolved electricity generation for both power-only DG and CHP applications for up to 34 states where DG penetration was projected to be cost effective. DG market penetration estimates are translated into spatially and temporally resolved emissions and combined with emissions from other sources. The US-REGEN model is used to determine the impact of additional distributed generation on the capacity and dispatch mix of the electric sector, and thus, the impact on electric sector emissions. For other source sectors, the 2030 baseline