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The relative impacts of distributed and centralized generation of electricity on local air quality in the South Coast Air Basin of California

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ABSTRACT

This paper examines the air quality impact of using distributed generation (DG) to satisfy future growth in power demand in the South Coast Air Basin of Los Angeles, relative to the impact when the demand is met by expanding current central generation (CG) capacity. The impact of decreasing boiler emissions by capturing the waste heat from DGs is not examined. The air quality impacts of these two alternate scenarios are quantified in terms of hourly maximum ground-level and annually averaged primary NO_x concentrations, which are estimated using AERMOD. This study focuses on the impact of primary emissions at source–receptor distances of tens of kilometers. We find that the shift to DGs has the potential for decreasing maximum hourly impacts of power generation in the vicinity of the DGs. The maximum hourly concentration is reduced from 25 to 6 ppb if DGs rather than CGs are used to generate power. However, the annually averaged concentrations are likely to be higher than for the scenario in which existing CGs are used to satisfy power demand growth. Future DG penetration will add an annual average of 0.1 ppb to the current basin average, 20 ppb, while expanding existing CGs will add 0.05 ppb.

1. Introduction

Several studies have examined the impact of distributed generation (DG) on air quality at urban and regional scales. Allison and Lents (2002) examined the tradeoff between the increase in emissions associated with urban DG emissions and the decrease in emissions by replacing heating plants with waste heat generated from DG plants. They found that realistic DG scenarios were likely to lead to net increases in emissions in urban areas. Their relatively simple analysis focused on aggregated emissions and did not relate these emission changes to air quality.

Heath et al. (2006) and Heath and Nazaroff (2007) have examined the air quality impact of DGs relative to central generating stations. They found that the air quality impact of DGs, quantified in terms of intake factors, could be several times that of central generating (CG) stations because (a) the ground-level concentrations normalized by emissions from the high stack of a CG plant are much smaller than the corresponding concentrations associated with the near ground emissions from DGs, such as microturbines, and (b) CG plants are likely to be located far from populated urban centers, while DGs are located in urban areas close to energy consumers. These conclusions are based on a simple Gaussian model that assumes an effective emission height of 5 m for DGs. As we will see later, this assumption might exaggerate the relative impact of DGs relative to central generating stations with large effective stack heights. Furthermore, the intake fraction used to estimate the relative impacts of the DG and CG stations normalizes the concentrations by the emission rates, which means that comparison of the relative impacts is effectively a comparison of the dispersive abilities of tall CG stacks with much shorter DG stacks. A more realistic comparison has to account for the fact that CG stations have much higher emission rates than DG stations. Thus, the results from Heath et al. (2003) do not directly address the impact of DG emissions relative to emissions from CG stations.

The region considered in this paper is the South Coast Air Basin (SoCAB) in southern California, covering Ventura, Orange, Los Angeles, San Bernardino, and Riverside counties. The geography, meteorology, and the population of the SoCAB have combined together to give rise to poor air quality, which is among the worst in the country, even though automobile emission controls have led to major improvements in air quality over the last thirty years. NO_x emissions from power plants required to accommodate future growth in electricity demand are of concern in view of the recently promulgated one hour federal standard for NO_2 of 100 ppb (USEPA, 2010). This is the level that cannot be exceeded

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by the monitored three year average of the 98th percentile of the annual distribution of the daily maxima of the one hour averaged NO_2 concentrations. Although current NO_2 levels in the SoCAB are below this standard, Los Angeles and San Bernardino counties record levels close to 80 ppb. NO_2 monitors placed close to roadways, which is required by the new regulation, might indicate much higher levels. NO_x emissions from power plants can also increase ozone and fine particulate levels, which still violate state and federal standards in several regions of the SoCAB.

Distributed generation (DG) using small power plants is one option to reduce the air quality impact of NO_x emissions. In principle, the impact of DG emissions can be minimized using the waste heat from DG for local heating and cooling and thus offsetting emissions associated with these activities. In this paper, we do not consider the effects of these emission offsets.

This paper makes a direct comparison between the relative impacts of DG and CG explicitly accounting for their differences in stack characteristics and emission rates. We estimate the air quality impacts using AERMOD (American Meteorological Society/EPA Regulatory Model, Cimorelli et al., 2005), which is based on current understanding of dispersion and is recommended by the USEPA for regulatory applications. Thus, the focus of this study is the impact of primary emissions at source–receptor distances of tens of kilometers where a straight-line, steady-state dispersion model, such as AERMOD is applicable.

The primary result of this paper is a comparison of the relative impacts of CG and DG on air quality in the Southern California Air Basin (SoCAB) of Los Angeles when CG replaces the projected increase of DG by 2010 (Samuelsen et al., 2005). Because the projection was made in 2005 it might not correspond to the actual increase in DG capacity by 2010.

2. Methods

We use a simple dispersion model to provide preliminary understanding of the relative impacts of CG and DG stations on air quality. We will then refine these calculations using AERMOD (Cimorelli et al., 2005). Assume that a source with an effective stack height of h emits at a rate Q into a boundary layer with a height, z_i, and constant wind speed, U. The maximum ground-level concentration, C_{max}, is given approximately by

$$C_{max} = \alpha \frac{Q}{h^2 U}, \tag{1}$$

where α is a constant. So the relative impact of a DG station versus a CG station in terms of the maximum concentration is given by the ratio

$$\frac{C_{max}^{DG}}{C_{max}^{CG}} = \frac{Q^{DG}}{Q^{CG}} \left(\frac{h^{CG}}{h^{DG}}\right)^2. \tag{2}$$

So if emission rates are not taken into account, the impact of a DG is substantially higher than that of a CG because the effective stack height of a DG station is generally much smaller than that of a CG station. Note that the effective stack height of emissions from a DG can be several times the physical height because of the buoyancy of hot exhaust gases.

Once the emitted plumes are mixed through the depth of the atmospheric boundary layer, the effective height of emission becomes unimportant, and the concentration as a function of distance, r, from the source is roughly

$$C(r) = \frac{Q}{r\theta z_i U}, \tag{3}$$

where θ is the angular spread of the plume. We see immediately from this equation that the relative impact is now proportional only to the ratio of the emission rates of the CG and DG stations. This implies that once the plume is mixed by atmospheric turbulence, the DG has a much smaller impact than a CG with a higher emission rate.

The long-term average concentration, $C_{av}(r)$ at a distance r from the source is approximately

$$C_{av}(r) = \frac{Q}{2\pi r z_i U}. \tag{4}$$

Then, the average concentration that a person is exposed to in moving about in an area that is within a distance R from the source is

$$C_{ex}(R) = \frac{\int_0^R C_{av}(r) 2\pi r dr}{\pi R^2}, \tag{5}$$

which for the simple model works out to be

$$C_{ex}(R) = \frac{Q}{z_i U \pi R}. \tag{6}$$

Thus, total emission rate plays a major role in determining exposure to pollution of a person moving around within a radius R from the source.

Heath et al. (2006) compare the relative impacts of CG and DG using a metric referred to as the inhalation factor, IF. It is defined as the mass of pollutant per unit time inhaled in air by the population living within a specified radius of the power plant normalized by the emission rate from the plant. In terms of the simple model for dispersion, the expression for IF becomes

$$IF = V_b \int_0^R \frac{1}{2\pi r U z_i} \rho(r) 2\pi r dr = \frac{V_b}{U z_i} \int_0^R \rho(r) dr, \tag{7}$$

where V_b is the breathing rate, and R is the distance used to define IF. If the population density $\rho(r)$ is taken to be uniform, we can write

$$\rho = \frac{P}{\pi R^2}, \tag{8}$$

where P is the population within a distance R from the source. With Eq. (7), the inhalation factor becomes

$$IF = \frac{V_b}{z_i U} \frac{P}{\pi R}. \tag{9}$$

This simple model suggests that IF is primarily a function of the meteorology and the region R used to define the factor. If we take $z_i = 500$ m, $U = 5$ m/s, $V_b = 12$ m^3/day, and $R = 100$ km, we obtain

$$IF \approx 2 \times 10^{-7} P, \tag{10}$$

where P is in millions. The magnitude of IF is comparable to that presented in Table 1 of Heath et al. (2006), although it does differ in the details. We see that IF is proportional to the population within 100 km for the source, and is a weak function of source characteristics. Thus, IF is not an appropriate metric for this study, which focuses on effects of the different source characteristics of DGs and CGs on air quality.

We compare the relative impacts of CG and DG using the measures: (1) the maximum hourly ground-level NO_x concentration, which is of regulatory significance, and (2) the annually averaged NO_x concentration averaged over a specified scale, which is a crude estimate of exposure to pollution of a person who travels within the specified distance from the source. Comparing an individual CG to a DG is not meaningful because one does not replace the other. The more relevant comparison is one in which the projected increase in distributed power generation is replaced by central generation. This comparison is performed for the South Coast Air Basin.

The representative generating stations used in the simulations are described next.