Energy Policy 59 (2013) 459–469

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Residential demand response reduces air pollutant emissions on peak electricity demand days in New York City

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HIGHLIGHTS

- The impact of residential demand response on air emissions was modeled.
- Residential demand response will decrease pollutant emissions in NYC.
- Emissions reductions occur during periods with high potential for poor air quality.
- Shifting demand to nighttime hours was more beneficial than to off-peak daytime hours.

ARTICLE INFO

Article history:
Received 4 July 2012
Accepted 29 March 2013
Available online 15 May 2013

Keywords:
Residential demand response
External costs
Unit commitment and economic dispatch model

ABSTRACT

Many urban areas in the United States have experienced difficulty meeting the National Ambient Air Quality Standards (NAAQS), partially due to pollution from electricity generating units. We evaluated the potential for residential demand response to reduce pollutant emissions on days with above average pollutant emissions and a high potential for poor air quality. The study focused on New York City (NYC) due to non-attainment with NAAQS standards, large exposed populations, and the existing goal of reducing pollutant emissions. The baseline demand response scenario simulated a 1.8% average reduction in NYC peak demand on 49 days throughout the summer. Nitrogen oxide and particulate matter less than 2.5 μm in diameter emission reductions were predicted to occur (−70, −1.1 metric tons (MT) annually), although, these were not likely to be sufficient for NYC to meet the NAAQS. Air pollution mediated damages were predicted to decrease by \$100,000–\$300,000 annually. A sensitivity analysis predicted that substantially larger pollutant emission reductions would occur if electricity demand was shifted from daytime hours to nighttime hours, or the total consumption decreased. Policies which incentivize shifting electricity consumption away from periods of high human and environmental impacts should be implemented, including policies directed toward residential consumers.

1. Introduction

Air quality is impairments have been recognized and regulated through the Clean Air Act and National Ambient Air Quality Standards (NAAQS) (EPA, 2011a). Research has correlated elevated levels of some pollutants (i.e. particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and ozone (O_3)) with health endpoints such as premature mortality and morbidity (Laden et al., 2006; Dockery, 2001; Ito et al., 2005). To limit the known deleterious effects of exposure to these pollutants, the maximum permissible concentrations of criteria pollutants are regulated, resulting in greatly improved air quality, public health and almost \$1.2 trillion in net benefits by 2010 (EPA, 2011b).

Unfortunately, some urban regions have experienced difficultly in meeting air quality standards and the concentrations of criteria pollutants have periodically exceeded NAAQS limits. For example, New York City (NYC) has been considered a non-attainment area for $PM_{2.5}$ and the 8-h ozone standards since 2005 and 2004, respectively (EPA, 2011c). NYC's exceedance of the NAAQS has been driven by individual pollution events, primarily during the summer months, when NO_x pollution and volatile organic compounds react with sunlight to form ozone. According to the New York State Department of Environmental Conservation (NYS DEC), since 2006, 98% of the three highest daily ozone concentrations reported annually, and 47% of the four highest daily $PM_{2.5}$ concentrations reported annually, have occurred from May to September (NYS DEC, 2012). The non-attainment problem in NYC

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0301-4215/\$ - see front matter
http://dx.doi.org/10.1016/j.enpol.2013.03.056

is an especially important concern given that 2.6% of the total United States' population lives within the city and 6.1% of the total U.S. population lives within the greater metropolitan area as of 2009 (U.S. Census Bureau, 2011).

The existing organization of the NYC electricity system is structured such that demand is viewed as inelastic and significant energy storage does not exist. This likely contributes to air quality excursions on high electricity demand days. Days designated as "high ozone" in NYC have been positively correlated with nitrogen oxide (NO_x) emissions from local electricity production (NESCAUM, 2006), which increase substantially on days when electricity demand has neared the annual peak electricity demand (NESCAUM, 2006). Additional research has shown the electricity generators used to meet peak demand in NYC have significantly higher emission rates than generators used to meet off-peak demand (EEPS, 2009).

Historically, for most days of the year, demand in NYC has been met with imported electricity, natural gas combined cycle (NGCC) generating units (used to meet baseload demand) and natural gas and petroleum fired steam turbines (ST) generating units (used to follow daily changes in demand). But during periods of peak electricity demand in the summer, NGCC and ST generators are fully utilized. Combustion turbines (natural gas fired, NGCT, and petroleum fired, PCT) are the only source of additional generating capacity. Further, since the small amount of energy produced annually from these peak power generators was historically exempt from certain environmental regulations, only the most recently installed small combustion turbines have been subject to emissions regulations, (AKRF, 2010). Thus, when electricity demand peaks and older combustion turbines with higher emission rates are utilized, pollutant emissions increase substantially.

In addition to non-attainment concerns, the utilization of small combustion turbines to meet peak electricity demand has raised questions related to the local impact of pollutant emissions. First, these small combustion turbines often have lower stack heights than larger generators (EEPS, 2009); which increases the public health damage caused by pollutants (Muller and Mendelsohn, 2009). Second, many of the small combustion turbines emit pollutants at much higher rates than other in-city generators (EEPS, 2009). Third, many small combustion turbines are located in close proximity to residential neighborhoods, potentially exposing residents to pollutants (EEPS, 2009). The cohort of small combustion turbines in NYC that are accurately described by the above characteristics have been identified by the NYS Energy Efficiency Portfolio Standard Working Group VIII Technical Study Group (EEPS) (2009) and are referred to here as 'generators of concern'.[1] Fig. 1 shows the approximate location of 'generators of concern' in New York City.

Regulations designed to help NYC reach air quality attainment have not captured important temporal and spatial aspects of pollution. This may explain why improvements in air quality have begun to plateau (NESCAUM, 2006). Current regulations both restrict the rate a pollutant can be emitted (e.g. NO_x Reasonably Achievable Control Technology) and limit the total mass of a pollutant legally emitted for certain period of time and space (e.g. Clean Air Interstate Rule). Neither approach addresses the issue of increased pollutant emissions on peak electricity demand days: on peak demand days, there are many more sources of pollution, including small combustion turbines, and seasonal limits on pollutant emissions do not limit pollutant emissions on individual days. Further, modifying

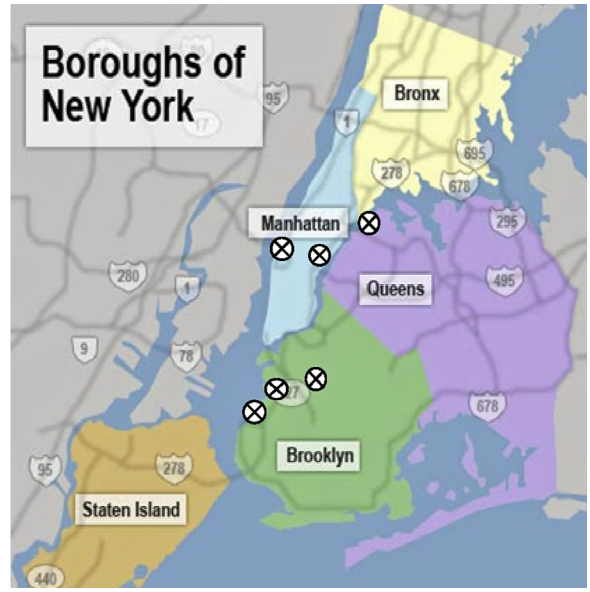

Fig. 1. Approximate location of 'generators of concern' within NYC. Boroughs are differentiated by color (see the online version of this article).

existing regulations to capture the peak day emissions problem may be inefficient. The cost of mandating reductions in pollutant emission rates from infrequently used generators would result in large costs per unit of generation and, there would be technical issues with modifying the seasonal cap to include daily emission caps (Ozone Transport Commission (OTC), 2007). Ozone Transport Commission (2007) recognized that existing regulations may not adequately address the problem of peak day emissions and recommended that additional mechanisms be implemented as appropriate (Ozone Transport Commission (OTC), 2007).

Dynamic electricity tariffs for residential consumers may be one mechanism to reduce peak day pollutant emissions. These tariffs tie the price a consumer pays for electricity to some metric. In pilot programs, higher retail prices have been triggered by high wholesale electricity prices or high system demand levels (Newsham and Bowker, 2010) and have been shown to reduce residential electricity consumption during peak demand periods. The change in demand caused by dynamic tariffs is referred to as demand response. Residential consumers have provided demand response under multiple tariff structures and other experimental conditions (Newsham and Bowker, 2010; Faruqui and Sergici, 2010). Finally, residential consumer account for approximately 48% of peak demand in the Northeastern U.S. and may represent an untapped source of peak demand reductions (EPRI, 2009).

We hypothesize if residential consumers provided demand response during peak demand hours throughout New York State then the small combustion turbines used to meet peak demand would generate less electricity and pollutant emissions within NYC would fall.

2. Methods

This research answers two specific questions: (1) Could residential demand response decrease generation from small combustion turbines? (2) Will the change in generation reduce total pollutant emissions and the impacts of that pollution?

The generation and pollutant emissions analysis was limited to Zone J—New York City (NYC), as defined by the New York Independent System Operator (NYISO). This focus was prompted by NYC's non-attainment issues (EPA, 2011c), the large populations exposed to air pollution (U.S. Census Bureau, 2011), and the

[1] Energy Efficiency Portfolio Standard Working Group VIII Technical Study Group (EEPS) (2009) also raised the question of whether pollution from these generators could result in an environmental justice designation for locally impacted neighborhoods. Environmental justice designations indicate that communities have not been adequately protected from environmental and health hazards or given equal access to decision making processes when decisions may impact their community (EPA, 2012b).