Energy 76 (2014) 502–512

Contents lists available at ScienceDirect

Energy

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

The power of efficiency: Optimizing environmental and social benefits through demand-side-management

Ariel Miara [a,*], Craig Tarr [b], Rachel Spellman [b], Charles J. Vörösmarty [a,c], Jordan E. Macknick [d]

[a] CUNY Environmental Crossroads Initiative, City College New York, New York, NY 10031, USA
[b] City College New York, New York, NY 10031, USA
[c] Department of Civil Engineering, City College of New York, New York, NY 10031, USA
[d] National Renewable Energy Lab, 15013 Denver West Parkway, Golden, CO 80401, USA

ARTICLE INFO

Article history:
Received 17 January 2014
Received in revised form
3 July 2014
Accepted 11 August 2014
Available online 6 September 2014

Keywords:
Demand-side-management
Energy planning
Electricity supply and demand
Environmental policy
Carbon dioxide mitigation
External costs

ABSTRACT

Substantial social and environmental benefits can be achieved through regional DSM (demand-side management) strategies. Here, three DSM scenarios that vary in capital investment costs of technology retrofits were tested for the contemporary Northeastern US. These resulted in an 8.3–16.5% decrease in summertime regional electricity consumption. The lower power consumption achieved through DSM was analyzed under an additional five SPR (strategic power reduction) scenarios to explore how the reduced electricity demand could be optimized through different modalities of thermoelectric power production that lower human health risks, thermal water pollution, carbon emissions or system costs (operation and maintenance) of power plants. SPR scenarios show potential to lower health risks to nearly two million people with corresponding avoided external costs of $11 billion per year, lower carbon emissions (31%, maximum) and thermal water pollution (37%, maximum). By internalizing external costs, some unfavorable investments (NPV (net present value) < 0) turned into favorable ones (NPV > 0). Results show that integrating tradeoffs of DSM beyond the building scale unveil considerable social and environmental benefits that are ignored in typical financial valuations. This, in turn, can provide more holistic assessments and identify actionable policy alternatives of value to energy and environmental planners that aim to achieve sustainable development.

1. Introduction

Electricity generation in the US (United States) is largely (>85%) supplied by fossil fuel based thermoelectric power plants that are the source of thermal pollution, carbon dioxide emissions, sulfur dioxide pollution and particulate matter. These externalities can threaten local ecosystems, alter global climate and compromise human health [1–10]. Energy and environmental policy, planning and regulation have aimed to address the adverse impacts of electricity production on local or regional environments via multi-state programs including the RGGI (Regional Greenhouse Gas Initiative), the CAA (Clean Air Act) and CWA (Clean Water Act) [11–13]. In addition to supply-side solution strategies (i.e. converting to renewable electricity generation), DSM (demand-side management) strategies can reduce reliance on thermoelectric generation and thus lower associated, unfavorable impacts [14–16].

DSM is the application of energy efficient equipment, programs or policies aimed at reducing electricity consumption [17]. DSM is encouraged by energy utilities that are motivated to reduce peak demand to avoid financial penalties imposed by states' public utility commission for failing to meet peak demand [17–20]. Consumers also benefit from DSM through utility-funded financial incentives, reducing their electricity bills while simultaneously effecting positive environmental impacts associated with reduced thermoelectric generation [17,18]. Such positive environmental impacts include improved ecosystem services such as cleaner air and water, which in turn benefits society by way of reduced healthcare costs [23]. In this study, we consider such externalities in assessing regional DSM strategies, as well as the costs and benefits of technology retrofits at the building scale. The tradeoff assessment here is executed for the Northeastern US (hereafter NE) (CT, DC, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VA, VT) and provides

* Corresponding author. Tel.: +1 2126507042; fax: +1 2126508097.
E-mail address: amiara00@citymail.cuny.edu (A. Miara).

http://dx.doi.org/10.1016/j.energy.2014.08.047
0360-5442/

useful insight to the potential role DSM can have in sustainable development.

The NE relies heavily on thermoelectric power plants (91% of total capacity) to provide electricity to more than 70 million people, 30 million households, and $4 trillion of GDP (Gross Domestic Product) (26% of national GDP) [3,24–26]. Studies have shown that anticipated climate change will continue to increase air temperature and reduce summertime river flow, limiting operations and hence power production by such power plants [8,10,27–29]. Temperature-related constraints occur when water used for thermoelectric cooling warms, either from upstream thermal pollution or rising ambient temperatures. Higher temperatures lower the efficiencies of power plants and can trigger regulatory limits on thermal loading, further reducing effective power plant operating efficiencies [30,31,35]. Strategic planning to alleviate power production vulnerabilities to climate change may require a set of alternative future conditions beyond business-as-usual not only from the electricity production side, but also the electricity consumption side. We consider these tradeoffs here, but in contrast to demand-based strategies adopted at the individual household level, we explicitly consider their collective impact over the fully regional domain. In so doing we are able to objectively assess the collective impact of these consumer-based energy efficiency strategies. We also assess the regional impact of these strategies in concert with alternative regionally optimized systems of power production. Considering the full continuum from regional electricity production through its consumption, in turn, can help to identify actionable policy alternatives of value to energy sector planners.

In the NE, more than 80% of electricity consumption is dominated by the residential and commercial sectors [32]. Moreover, retail electricity rates are 56% higher in the NE (13.4 c/kWh average) compared to the contiguous US (8.6 c/kWh) and could be considered as an incentive for consumers to lower electricity consumption [36]. Space cooling (i.e. air conditioning) relies exclusively on electricity in the summer and accounts for a large share of this demand [33]. Thus, electricity demand and rates both peak during summertime and DSM strategies can do much to lessen this peak demand [34]. In light of mounting concerns regarding climate change, its mitigation and adaptation strategies, the energy sector thus becomes an important component of the nation's climate response [10].

Fossil fuel combustion is associated with emissions of acidic gases, metals and particulate matter [12,37]. Acidic gases cause respiratory damage and chronic diseases such as bronchitis and asthma and contribute to the formation of acid rain, which damages trees, manmade structures and alters the pH of water bodies, threatening fish and other animals [4,5,7]. Fine particles (2.5 microns in diameter or less) are linked to cardiopulmonary problems and reduced life expectancy [38,39]. In the NE, fossil fuel-fired plants are responsible for 70% of sulfur dioxide, over 30% of mercury and 15% of nitrogen oxide emissions [40]. Coal power plants produce the vast majority of these emissions and the local external costs of these pollutants, mostly attributed to healthcare costs, amounted to an estimated $36 billion in 2010 in the NE [3,23,41], representing 6% of the region's annual expenditure on healthcare [42]. However, estimates of external costs do not capture all aspects of air pollution, such as reduced life expectancy, which is likely to be significant but difficult to monetize [43,44]. Nonetheless, several studies have advanced the level of understanding of external costs, and their findings can be used in more holistic assessments of emission impacts [43–47].

Carbon emissions are the cause of unnatural changes in climatology, which has and may continue to disrupt local, regional and global scale ecosystems, if not curbed in the coming decades [48]. In Fall 2013, the EPA (Environmental Protection Agency) released a revised proposal to limit new coal and natural gas power plants to 500 kg (1100 lb) of CO2 per MWh and 455 kg (1000 lb) of CO2 per MWh, respectively [49]. Currently, 99% of coal capacity and 36% of natural gas capacity in the NE have carbon emission rates higher than the proposed limits, amounting to 39% of the region's thermoelectric capacity [3,50]. Therefore, implementation of carbon policies across the NE would necessarily require a significant reduction of carbon emissions from the current power production portfolio.

Traditional analyses of DSM focus on direct costs and benefits at the building scale, with some studies highlighting that DSM can contribute to lower carbon emissions and air pollution [51–56]. Here, we build on such studies and see it as important to consider a broad range of issues from cost savings at the consumer end to environmental, social and economic tradeoffs of reduced thermoelectric generation over a fully regional domain that takes into account the geospatial context of populations locally affected by air pollution. We consider three DSM scenarios (based on capital costs) of improved efficiency in the most electricity intensive end-use categories. In each of the end-use categories, alternative appliances replace inefficient baseline appliances to reduce power consumption. To enrich the analysis beyond tradeoffs at the building scale, we address the value of reducing electric power demand. The lower power consumption calculated in the three DSM scenarios is analyzed under five SPR (strategic power reduction) scenarios (15 scenarios total), which determine the specific means by which power is reduced across the thermoelectric sector. The SPR scenarios are designed to achieve one of the following (i) reduced carbon emissions, (ii) lower harmful air pollution (two types of scenarios), (iii) limited thermal effluents and (iv) reduced system costs (O&M (operation and maintenance) costs at power plants). Impacts were assessed using traditional economic metrics to calculate costs and benefits, and pollution rates were used to compute emission reductions and associated externality costs. The evaluation takes into account the geospatial distribution of the NE thermoelectric sector; the proximity of populations to airborne pollution from thermoelectric power stations; the sub-regional distribution and seasonal fluctuations of electricity prices; and, the geographical relationships between thermal loading and receiving waters as organized through the topology of river networks. The framework and steps taken for this study are described in the following section.

2. Methodology

2.1. DSM scenario design

The DSM strategies target the most consumptive (MWh/yr) end-use categories, which could be termed as the “low-hanging fruit” of electricity end-uses for technology retrofits. Currently for the NE, these comprise of lighting, refrigeration and space cooling within the most electricity demanding sectors, that is, commercial and residential [32,33]. The most electricity-intensive and inefficient baseline appliances were identified for retrofits within each end-use category, typically one appliance per end-use, using sources including the US Lighting Market Characterization (2010) and the Buildings Energy Data Book (2010) [33,57]. The baseline appliances targeted for retrofits account for a large majority of the combined electricity consumption of lighting, space cooling and refrigeration (65%, 152 TWh/yr) and for 27% of total electricity consumption in the NE. This amount of electricity is therefore the maximum that potentially could be saved through the DSM scenarios here (i.e. if appliances are no longer used).

Next, a range of more efficient alternative appliances of varying capital costs were identified as potential replacements of the