Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Exploring utility organization electricity generation, residential electricity consumption, and energy efficiency: A climatic approach

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HIGHLIGHTS

- Study examined impact of electricity fuel sources and consumption on emissions.
- 97.2% of variability in emissions explained by coal and residential electricity use.
- Increasing cooling degree days significantly related to increased electricity use.
- Effectiveness of state-level energy efficiency programs showed mixed results.

ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form 15 October 2016
Accepted 26 October 2016
Available online xxxx

Keywords:
Electricity
Energy efficiency
Utility
Climate
Generation
Efficiency
Climate change

ABSTRACT

This study examined the impact of electricity generation by fuel source type and electricity consumption on carbon emissions to assess the role of climatic variability and energy efficiency (EE) in the United States. Despite high levels of greenhouse gas emissions, residential electricity consumption continues to increase in the United States and fossil fuels are the primary fuel source of electricity generation. 97.2% of the variability in carbon emissions in the electricity industry was explained by electricity generation from coal and residential electricity consumption. The relationships between residential electricity consumption, short-term climatic variability, long-term climatic trends, short-term reduction in electricity from EE programs, and long-term trends in EE programs was examined. This is the first study of its nature to examine these relationships across the 48 contiguous United States. Inter-year and long-term trends in cooling degree days, or days above a baseline temperature, were the primary climatic drivers of residential electricity consumption. Cooling degree days increased across the majority of the United States during the study period, and shared a positive relationship with residential electricity consumption when findings were significant. The majority of electricity reduction from EE programs was negatively related to residential electricity consumption where findings were significant. However, the trend across the majority of states was a decrease in electricity reduction from EE while residential electricity consumption increased. States that successfully reduced consumption are discussed, in addition to the potential use of communication theory to design interventions aimed at improving EE program success.

1. Introduction

This study examines the impact of electricity generation by fuel source type and electricity consumption on carbon emissions to assess the role of climatic variability and energy efficiency (EE) in 48 contiguous United States (US). The continued reliance on fossil fuels for electricity generation in the face of increased climatic variability has led to electricity consumer demand conditions that are largely met by fossil fuel sources [1]. Since the 1850s, energy producing organizations have emitted the majority of carbon dioxide (CO_2) emissions, with only 90 organizations worldwide emitting over 60% of the of CO_2 [2]. Since 1986, CO_2 emissions have more than doubled globally [2]. There are thousands of utility organizations in the US, where investor-owned utility (IOU) organizations produce and supply the vast majority of electricity, and subsequently produce the vast majority of greenhouse gas (GHG) emissions [1]. The majority of electricity generation is from coal,

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http://dx.doi.org/10.1016/j.apenergy.2016.10.101
0306-2619/

and natural gas is the fastest growing fuel source for electricity since 1990 (Fig. 1; [1]).

Today more than $7 billion is spent on EE programs in the US [3]. Demand-reduction EE programs are used in the residential sector as an alternative to volumetric pricing [4]. That is, utility organizations cannot respond to increased electricity demand by raising prices. The electricity savings values and overall program budgets for IOU EE programs, as well as electricity rates, are governed by state-level regulatory organizations [4,5]. There is a need for both short- and long-term regulatory practices to meet goals in energy markets [6]. However, low perceived value for EE incentives, non-responsive pricing, and underdeveloped program offerings deter residential participation [4,7,8]. Furthermore, a rebound effect (i.e., more electricity is consumed after an EE measure is implemented) is common when residents are not knowledgeable about EE, have negative attitudes towards EE and/or the IOU, or do not receive adequate feedback about EE upgrades [7,9–13]. This is consistent with the theory of planned behavior (TPB; [14]), which states that awareness and positive attitudes about a topic increase the likelihood of a behavior. In the context of this study, the likelihood of energy saving behaviors would increase when preceded by awareness and positive perceptions about EE programs and/or the IOU providers.

Utility organizations primarily rely on a deemed savings model in residential EE programs, where incentive levels are based on a regulatory-assigned kW h savings value rather than observed savings [5]. Overlooked in the deemed savings model is observed climatic interaction. Similar to volumetric pricing charged to residential customers, electricity savings assigned to electricity efficiency programs is unable to completely capture the increase or decrease in electricity demand related to actual weather conditions [9]. As such, EE programs are primarily used as a deterrent to peak electricity demand conditions rather than a real-time response.

The goal of this study was to examine the impact of electricity generation by fuel source type and electricity consumption on carbon emissions to assess the role of climatic variability and energy efficiency (EE) in 48 contiguous United States (US). The study addresses the knowledge gap as to the effectiveness of utility organization efficiency efforts that take into account increased climatic variability. This is the first study to examine these relationships across the entirety of the US. Accordingly, the study will first examine the impact that electricity generation by fuel source and electricity consumption has on the GHG CO_2 for the contiguous US. State-level relationships between climatic variability, EE, and residential electricity consumption will then be explored. Further, the variability in residential electricity consumption will be examined in terms of climatic variability and EE. Procedure, methods, and statistical analysis will then be provided, followed by results, theory application, and discussion of findings.

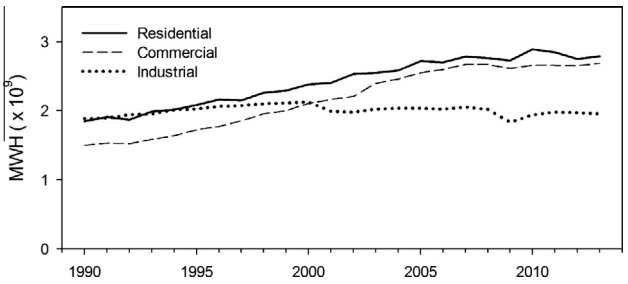

Fig. 2. Megawatt hour electricity consumption by sector between 1990 and 2013.

1.1. Impact of electricity generation and consumption on GHG emissions

Long-term climatic variability and extreme weather events are influenced by GHG emissions, and are projected to intensify [9,15,16]. Consequently, climatic variability and extreme weather events can increase the demand for electricity. In a longitudinal residential study, temperature-related indices were the strongest indicators for electricity consumption [17]. In a review of the impact of climate change on electricity markets, Mideksa and Kallbekken [18] found that electricity demand for cooling is expected to increase and electricity demand for heating is expected to decrease. Increased electricity demand from users, increased population, urbanization, and growing economies have resulted in increased electricity consumption, generation, and GHG emissions [15,19–25].

CO_2 remains the most influential and harmful GHG related to anthropogenic induced climatic variability [15], with 81.5% of GHG emissions from electricity production and use attributable to CO_2 [26]. Overall electricity consumption and generation have traditionally shared a strong relationship ($r = 0.879$, $p < 0.01$; [1,27]) in the US, yet the relative influence on CO_2 emissions that takes into account fuel sources for electricity generation and consumer segments is not widely understood. Electricity generation has historically met consumer demand needs relying primarily on fossil fuels (Fig. 3; [1,27]). Natural gas is the fastest growing fuel source in terms of generation, however, more wind generation capacity was added in 2015 relative to other fuel sources [28]. Despite a shift towards cleaner electricity production, there is still a continued reliance on fossil fuels. With the understanding that long-term climatic variability and extreme weather events are positively related to increased generation, consumption, and GHG emissions, a goal of this study is to gain a clearer understanding of the relationship that electricity generation and electricity con-

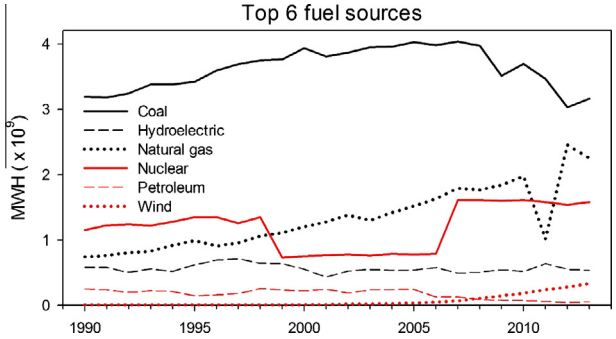

Fig. 1. Megawatt hour electricity generation for top fuel sources between 1990 and 2013.

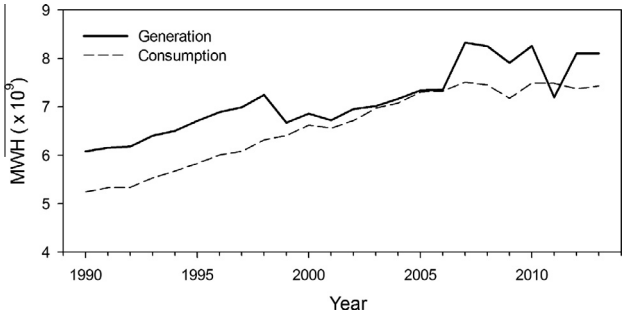

Fig. 3. Overall megawatt hour electricity generation and consumption between 1990 and 2013 for the contiguous US.

Please cite this article in press as: Craig CA, Feng S. Exploring utility organization electricity generation, residential electricity consumption, and energy efficiency: A climatic approach. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.10.101