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# Impact of climate change on U.S. building energy demand: Financial implications for consumers and energy suppliers

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ABSTRACT

Based on the impacts of climate change on U.S. building energy consumption, we quantify the financial implications to consumers and suppliers at finer space (state) and time (monthly) scales than previously reported. For the U.S. as a whole, we find building energy costs decrease by ~7 billion $/year in the residential sector, while costs increase by ~2.2 billion $/year in the commercial sector. For cold-weather states (e.g., Vermont), there are residential energy savings of up to 340 $/year, while warmer states (e.g., Florida) see increased residential energy costs of up to 231 $/year per household. The increased summertime cooling demand poses important questions for the electricity supply system. Electricity reserve margins fall below 10% in all North American Electric Reliability Corporation (NERC) regions by the end of this century. In order to maintain a reliable electricity supply, an additional 80.6 gigawatt (GW) of capacity is needed, which we estimate to cost between 19.2 and 72.1 billion $/year for construction and operation. These estimates are also sensitive to changes in population distribution. Compared to a 2010 population distribution, results based on a 2090 population distribution show reduced savings nationally.



## 1. Introduction

Energy consumption in residential and commercial buildings will be directly impacted by climate change through the need for space cooling and heating. Buildings account for more than 40% of 2010 U.S. primary energy consumption, of which 23% was used for space heating and 15% was used for space cooling [1]. A number of studies have assessed the impacts of climate change on building energy consumption within the U.S. Some of these studies estimated impacts based on historical relationships between climate variables and energy consumption [2–6,35]. Others evaluated the impact with energy simulation models, either at the building scale [7,8,9,10–12] or the regional/international scale [13–17]. In general, these studies found a net energy consumption increase in the warmer regions of the U.S. due to increased cooling demand. In colder regions, they found a net energy consumption decrease due to lower heating demand. When integrated over the whole nation, however, study results varied from a net increase to a net decrease in building energy consumption and were dependent upon the research methods, the future time period examined, the emissions scenario used, and the energy form (on-site or source energy) chosen.

There has been little systematic translation of these energy demand changes into the financial cost to both building energy consumers and suppliers. The few studies that have attempted such an assessment have estimated the financial impacts of climate change to the U.S. energy sector based on national/international economic modeling [18,16,19,20,21,22]. Some studies found increased costs in the energy sector, ranging from a few billion dollars to a few hundred billion dollars [18,16,20,22]. By contrast, other studies found a savings of a few billion dollars in energy expenditures [19,21]. However, as with the underlying energy demand impact analysis, past analysis of the financial impact has overlooked the importance of climate variation and extremes at finer space and time scales where the financial implications are most acute and where action will likely be needed to plan effectively for an altered energy consumption future.

In a recent paper, [23] explored the sensitivity of the relationship between climate change and building energy consumption in the U.S. by testing the impact of three important analytical elements: the spatiotemporal resolution of analysis, the balance point

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temperature method used, and changes in future population distribution. In this earlier study, we used empirically-based balance point temperatures and empirically-based relationships between energy consumption and temperature over the 2008–2012 time period for each state. We then predicted the monthly energy consumption in future time periods (2020–2099) driven by the 20 different climate models used in phase 5 of the Coupled Model Intercomparison Project (CMIP5) [24]. The daily temperature over the 2006–2099 time period under the Representative Concentration Pathways (RCP) 8.5 emission scenario (radiative forcing rises to 8.5 W/m$^2$ in 2100) was used to predict future energy consumption. We selected the RCP 8.5 scenario, because it was simulated by most CMIP5 climate models, and it represents the worst-case scenario (most dramatic temperature change) for which electricity supply and demand must prepare. Finally, we also analyzed the sensitivity of cost differences to the change of population distribution in 2090.

Using this ensemble of 20 climate model outputs, we found that the summer electricity demand increased by more than 50% and the winter non-electric (natural gas, propane, distillate fuel oil, kerosene, and wood) demand decreased by up to 48% in some states by the end of this century. These opposing extremes canceled when examined at the national/annual scale, ending up with energy demand changes approaching zero in all future time periods. In contrast to most past studies, which estimated the impact of climate change on energy consumption at the national/annual scale, we explored the implications of climate change at the state and seasonal scales. Furthermore, instead of using the traditional fixed 18.3 °C (65 °F) balance point temperature, we developed an empirically-based state-specific balance point temperature, which improved model performance in all states and provided more reliable estimates of future energy consumption. Finally, we found that projected population redistribution exacerbates the building energy consumption impacts of climate change, intensifying the state-scale increases and decreases. When we examined the impact of climate change with the current population distribution, we found a net decrease in national energy consumption. Allowing for a changed future population distribution, we found a net increase in national energy consumption.

This study quantifies the financial implications of these changes to energy consumers and suppliers, and examines the sensitivity of these implications to population distribution. To do this, we use current consumer energy prices and electricity capacity reserve requirements and quantify the impact on the residential and commercial sector separately. We quantify the additional electricity capacity required to satisfy the reserve margin requirement for each North American Electric Reliability Corporation (NERC) region, further converted to annual costs based on construction and operating costs. These estimates are compared to the same analysis performed at the U.S.-aggregate scale to further highlight the improved accuracy and relevance of the sub-national analysis. Finally, we compare the financial impacts based on a 2010 versus a projected 2090 population distributions, to highlight the importance of the spatial relationship between people, energy consumption, and climate change.

We do not attempt to comprehensively project all of the variables that are likely to determine future energy supply and demand costs to consumers from the impact of climate change (e.g., energy price, energy mix, energy policy, building technology). We consider many of these variables difficult to predict over long timeframes and attempting to do so would potentially mask the impact of the variables of interest here – the space/time covariation of climate change, energy demand and population distribution. Thus, it is more appropriate to interpret the results of this study as a *ceteris paribus* analysis.

## 2. Methodology

### 2.1. Consumer energy cost

The Department of Energy/Energy Information Administration's State Energy Data System (EIA SEDS) provides state-scale end-use energy consumption (mmBtu) and end-user energy prices ($/mmBtu) by fuel type, state, and sector [31]. The electricity price ($/mmBtu) is calculated as the average of 2008–12 electricity prices weighted by annual end-use electricity consumption (Table 1). Similarly, the non-electric energy price is calculated as the average of 2008–12 non-electric fuel prices weighted by annual end-use consumption of each non-electric fuel. These state-specific per unit energy prices are used to estimate the state residential and commercial building energy expenditures given the altered energy consumption under climate change.

The per household annual energy consumption cost difference between the future and current periods (due to climate change) is calculated for the residential sector in each state as follows:

$$CD = (P_{ele} \times SD_{ele} + P_{nele} \times SD_{nele})/HH \quad (1)$$

where the cost difference per household, *CD*, is a function of the price, *P*, ($/mmBtu) for electricity, *ele*, and non-electric fuel, *nele*, the on-site energy difference, *SD*, (mmBtu), and the number of households [30], *HH*. The product of $P_{ele}$ and $SD_{ele}$ represents the change in state total electricity consumption costs, while the product of $P_{nele}$ and $SD_{nele}$ represents the change in non-electricity consumption costs. The sum of these two terms, divided by the number of households in a state, represents the change of total energy consumption cost per household.

Because there is a general trend towards electricity demand increases and non-electric demand decreases in the future [13–17], a high price ratio of electricity to non-electric fuel will generally lead to higher future consumer expenditures. The price ratios of electricity to non-electric fuel are calculated for state residential and commercial sectors separately, which are used to explore the cost difference patterns in the two sectors.

### 2.2. Electricity generation capacity and cost

High electricity demand typically occurs during summer months and Huang and Gurney [23] show that summer electricity consumption will increase more than 20% in some states by the end of the century. As a result, additional electricity generation capacity will likely be required to meet the increased electricity demand. The North American Electric Reliability Corporation (NERC) is a nonprofit organization tasked with maintaining reliable electricity supply for the North America. There are eight NERC regions within the contiguous United States: Florida Reliability Coordinating Council (FRCC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), ReliabilityFirst Corporation (RFC), SERC Reliability Corporation (SERC), Southwest Power Pool, RE (SPP), Texas Reliability Entity (TRE), and Western Electricity Coordinating Council (WECC). The electricity generated in one region is primarily supplied to energy consumers in the same region; the inter-region electricity trade is small and limited by the available transmission lines. NERC publishes the estimated summer electricity demand, generation capacity, and reserve margin for each assessment area annually. The reserve margin is defined as the difference between generation capacity and electricity demand, divided by the electricity demand. NERC recommends a 15% reserve margin to maintain electricity system [34]. In the 2008–2010 assessment reports, each assessment area belongs to one NERC region. Starting in 2011, the assessment areas were redistricted, with some assessment areas overlapping multiple NERC regions. This makes it impossible to attribute each assessment area