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Does climate influence energy demand? A regional analysis

Saleem Shaik*, Osei-Agyeman Yeboah

400F Richard H. Barry Hall, NDSU Fargo, ND, United States
A-25 C.H. Moore, NCATSU Greensboro, NC, United States

HIGHLIGHTS

- Impact of distribution of climate on regional sectoral energy demand.
- SUR with commercial, industry, residential and transportation energy demand functions.
- Upside and downside first and second moments of temperature and precipitation.
- Empirical application involved panel data, 48 states from 1970 to 2014.
- Energy demand cross-price elasticities (CPE) and Allen elasticities of substitution (AES).

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ABSTRACT

The duality of cost minimization is used to examine the effects of climate change on US sectoral climatic regional energy demands from 1970 to 2014. The first order conditions of transcendental logarithm cost function provide sectorial compensated demands for energy. A system of demand share equations or sectorial compensated demand for energy is explained by exogenous prices, technology and distribution of climatic variables i.e. temperature and precipitation is estimated. The distribution includes the downside and upside first moment, i.e., mean and downside and upside second moment, i.e., variance. The estimated parameters are used to construct energy demand cross-price elasticities (CPE) and Allen elasticities of substitution (AES) for nine climatic regions. The Southwest, Northeast, and South are sensitive to rainfall distributions especially the transportation and industrial sectors while the Northeast, Central, and South are affected by temperature variations affecting residential and industrial sector energy use. The commercial sector uses the least energy because of improved technological changes. Consequently, there are high substitutions of commercial energy for both residential and industrial. The transportation sector has the least price and technical substitutions.

1. Introduction

Researchers [1–3] have looked at the impacts of increasing temperature. An increase in the average temperature led to climatic drought risks [4], coastal flood risks [5] and human health risks [6,7]. Parry et al. [8]; and Warren [9] warned of the impacts of increasing average temperature on the ecosystem. Cline [10,11] conducted a cost-benefit analysis of climate change, considering environmental loss, human life, disaster, water supply and so forth. Climate models predict a range of changes to temperature, precipitation and other climate measures. Most models predict a significant increase in global average temperatures by the end of the current century for scenarios close to a business as usual emission path or a slightly more optimistic path. Auffhammer et al. [12] presented a detailed discussion of climate models and their use in social science. Other empirical estimates of climate sensitivity analyses involve estimating economic impacts on a specific sector, like agriculture [13]. Using micro-level and region-specific data, the importance of climate on energy demand by the commercial, industrial, residential and transportation sector is well established [14–21]. Energy use in commercial, industrial, or residential buildings for example, is one of the largest contributors to global and local energy consumption. Many studies have looked at the impact of building variables on energy use [22–27]. Zhu et al. [28] proposed a time-for-space substitutional model, which evaluates the variations of residential buildings' energy consumption in China driven by seasonality, climate, and socioeconomic factors.

The energy demand by sector has been the focus of the Office of Energy Information Administration in the United States' Department of Energy. The pressing issue in the current energy policy debate is keeping up with the increasing demand from commercial sector (CS),

* Corresponding author.
E-mail addresses: Saleem.Shaik@ndsu.edu (S. Shaik), oyeboah@ncat.edu (O.-A. Yeboah).

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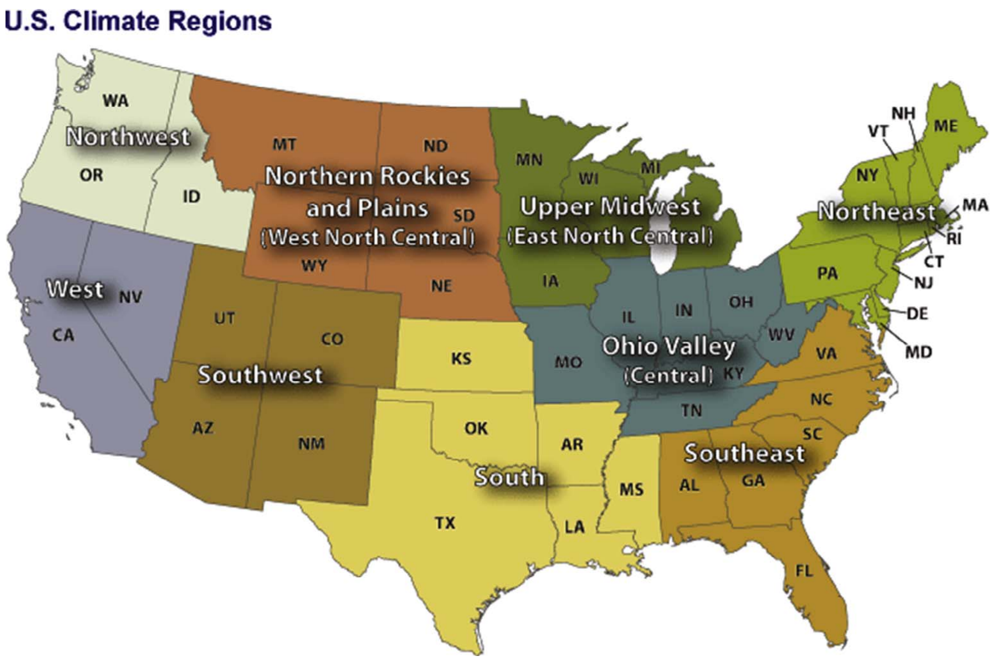

Fig. 1. U.S. climate regions used in the analysis.

industrial sector (IS), residential sector (RS) and transportation sector (TS). Energy demanded by each of the four sectors is unique and influenced by economic activity, climatic conditions, and decisions of individual states within nine climatic regions (see Fig. 1) across the U.S. Due to the difference in climate patterns between states across climatic regions (National Oceanic and Atmospheric Administration define the climatic regions), there is a need to conduct climatic regional analysis. The effect of each sector's energy demand is typically used to predict the cost of climate change adaptation. Analysis of sectoral energy demand is based on the first order conditions derived from non-Hicks neutral technology assumption of cost function. Theoretically, the first order conditions or system of sectoral energy demand equation include prices paid by a sector and technological changes using seemingly unrelated regression (SUR) statistical technique. The cost function is extended to include climatic variables that are outside the control of sectors using energy. The novelty of this extension is to evaluate the importance of climate on sectoral energy demand. Output from SUR are used to validate the substitution or complementarity between the sectors demanding energy using price elasticities. Most of the earlier studies estimated the energy demand considering price and technology changes (references in the next section).

Extending the climate-energy use and energy demand literature, our research contributes by evaluating the importance of the distribution of temperature and precipitation on energy demand by commercial, industrial, residential and transportation sectors simultaneously using panel SUR model. The distribution includes the first moment, i.e., mean and second moment, i.e., variance. To evaluate the importance of observations above and below the average, the overall mean and variance are further decomposed into downside and upside mean and variance. The downside mean and variance is based on observations below the 30-year average, while the upside mean and variance is based on observations above the 30-year average. These variables capture the effect of negative and positive observations on energy demanded by the four sectors, instead of point estimates or extreme points. For example, does the temperature or precipitation deviation below the average have a similar or opposite effect on energy demand compared to deviations above the average? This will help not only draw inference between climate regions based on the results but will also help develop policies to address the climatic-energy demand.

As part of the second contribution, regional energy demand analysis, cross-price elasticities (CPE) and Allen elasticities of substitution (AES) are estimated for nine climate regions to account for potential differences in climate, i.e., temperature and precipitation. The parameter coefficient estimated from the system of sector energy demand equation are used to develop CPE and AES. The AES stand for purely technical substitution possibilities while the CPE includes income effects and therefore reveals potential economic substitutions. The CPE and AES estimates are the first of its kind that take into account the downside and upside first and second moments of temperature and precipitation.

The final contribution of this paper addresses potential differences in regional climate impacts on the energy demand equations. The results from nine climatic regions of the U.S. includes the non-climate change energy demand term (intercept); the effects of technological change on energy demand (trend variable); the effects of all eight climate change variables; and both economic and technical substitution potential by-sector and by-region.

To summarize, the primary goal of this study is to find the influence of climate, i.e., average and variance of temperature and precipitation associated with negative deviations (downside) and positive deviations (upside) on energy demand at the U.S. climate regions using state level data in the U.S. from 1970 to 2014. Employing the transcendental logarithm cost function, a system of residential, commercial, transportation and industrial sector energy demand functions explained by prices, technology and climate as exogenous variables are estimated. Second, the estimated parameters from the system of demand equations are used to construct price elasticities and Hick-Allen elasticity of substitution for energy demand by U.S. climate regions. The findings of this study will be relevant in the development of a comprehensive energy policy across nine U.S. climatic regions based on the changes in the energy demand by residential, commercial, transportation and industrial sectors accounting for technology, price, and climate change. Hence, the use of panel SUR statistical technique is new in the estimation of sectoral energy demand that includes theory based variables (price and technology) and distribution of climatic variables.

The paper is organized into five sections. Section 2 is a brief review of empirical studies on the role of climate on the energy demand, price, and technical substitution. Section 3 presents the theory and methods employed in the analysis. The results of the analysis and its discussions are presented in Section 4 while Section 5 presents the conclusion.