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Residential energy demand in the United States: Analysis using static and dynamic approaches

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HIGHLIGHTS

- Estimating residential electricity and gas demand at the state level.
- Using static panel estimation models and dynamic estimation models.
- Determining own price and income elasticities for electricity and gas demand.
- Measuring residential electricity demand reduction using electricity price increases.
- Quantifying residential gas demand reduction by decreasing building ages.

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ABSTRACT

The residential sector is the main consumer of energy in the United States, and reducing energy consumption is an important goal for policymakers in each state. To know how reducing residential energy demand could be achieved, this study develops a set of static and dynamic models to investigate and identify the impact of socio-economic and demographic characteristics, building age, energy prices, and weather conditions on residential energy demand at the state level from 2005 to 2013. Next, this study proposes two alternative scenarios to reduce residential energy demand based on the most precise model. For every 10,000 dollars of per capita income in each state: (1) increasing residential electricity price by 1 cent per kW h and (2) decreasing average building age by 1%. In the first scenario, the findings indicate that annual residential electricity demand would decrease by 7.3% on average, with the highest reductions in Washington (11.9%), North Dakota (10.9%), and Idaho (9.7%). In the second scenario, residential gas demand would decrease by an average of 15.8% annually, with the highest reduction in Connecticut (33.2%) followed by New York (33.0%) and Massachusetts (30.7%). These proposed scenarios assist policymakers in optimizing decisions and investments to reduce residential energy consumption.

1. Introduction

Global energy demand has grown since World War II and is expected to increase by more than one-third by 2035 (Toka et al., 2014). Total energy demand is related to four key sectors: transportation, industrial, commercial, and residential. knowing about energy consumption in each sector is crucial for policymakers trying to develop CO_2 mitigation policies (Javid, 2016). Among these sectors, the residential sector is the main consumer of energy in most countries and the only sector that directly relates to an individual household's decisions (Bin and Dowlatabadi, 2005). Additionally, the energy demand in the residential sector mostly goes towards heating and cooling residential buildings (Isaac and Van Vuuren, 2009) and heating and cooling residential buildings process is a significant source of carbon dioxide (CO_2) emissions (Javid et al., 2014).

Energy demand in the residential sector in most countries varies from 16% to 50% of total energy demand, with the average worldwide energy consumption in the residential sector being about 30% of global energy demand (Swan and Ugursal, 2009; López-Rodríguez et al., 2013). The OECD Americas countries (United States, Canada, Chile, and Mexico) consumed about one-fourth of the world's residential energy in 2010, and the United States is responsible for the largest amount of energy consumption among these countries as shown in Fig. 1.

The U.S. energy consumption differs from state to state because each state has different regulations and characteristics.

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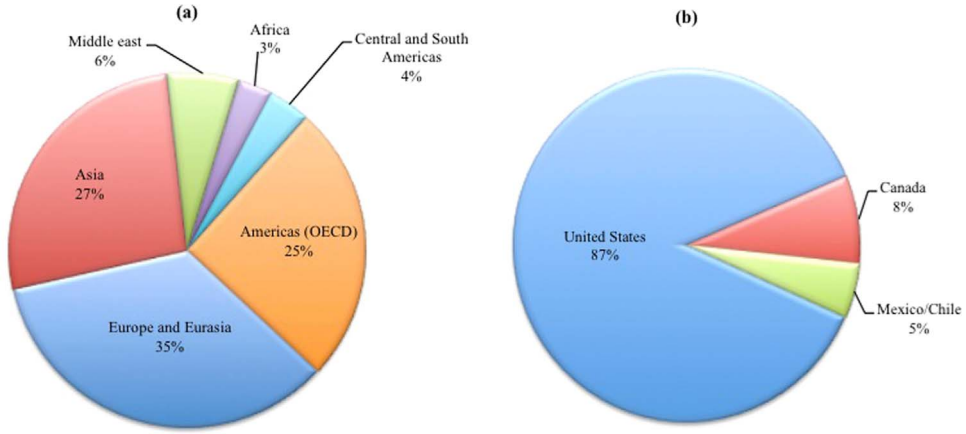

Fig. 1. Percentage of (a) the world energy consumption in the residential sector and (b) the OECD Americas countries energy consumption in the residential sector (2010) EIA (2013).

Additionally, many states have a higher population than some countries, and thus their residential energy consumption is larger in comparison. Each state's opportunities and constraints regarding energy consumption are shaped by unique socio-economic and demographic characteristics and energy prices (Abrahamse and Steg, 2009; Longhi, 2015). It is important to have information about energy prices and income elasticities in each state to identify and determine the residential energy demand. For example, as a household's income increases, the energy consumption may increase due to a rise in the amount of money the household spends on appliances (Tiwari, 2000). Additionally, the states with a higher portion of new buildings expect to have less energy consumption compared to other states because new buildings are more energy efficient (Leth-Petersen and Togeby, 2001; Santin et al., 2009). Moreover, residential energy consumption is particularly affected by climate through differences in heating and cooling demands (Isaac and Van Vuuren, 2009; Kyle et al., 2010; Zhou et al., 2014). The impact of weather on energy consumption has been widely reported in several studies (Sailor, 2001; Pardo and Meneu, 2002; Lindberg et al., 2004). As would be expected, in warmer states, more energy is spent for cooling, while in the cooler states, heating demands more energy. Thus, state-level analyses of residential energy consumption are important due to specific characteristics of each state (Auffhammer and Mansur, 2014). Therefore, understanding the residential energy demand at the state level is essential for economists and policymakers in order to formulate effective policy instruments in each state. Energy Information Agency (EIA) reports that the main energy sources of the residential sector are electricity and gas and they are responsible for 87% of total energy consumption in this sector. Thus, this study focuses on residential electricity and gas demand because these are the important energy sources used by households in the United States. In addition, this study employs the state level of data to design effective policies for lowering residential energy behavior based on empirical evidence of U.S. residential energy consumption at the state level.

The main contribution of this study is to estimate both electricity and gas demand in the residential sector using new aggregated datasets on the U.S. states, while considering socio-economic and demographic variables, building age, energy prices, and weather conditions. Moreover, this study employs more explanatory variables (i.e. educational level and building age) compared to previous studies such as Alberini and Filippini (2011), Blázquez et al. (2013), and Filippini (2011). First, this study uses different estimation techniques step by step to find proper estimation models for both static and dynamic approaches. Meanwhile, this study estimates own price and income elasticities for both electricity and gas demand. Next, this study finds the main variables that have impacts on the residential electricity and gas demand and are feasible to change by policymakers in each state. This study defines two alternative scenarios to quantify the impacts of residential electricity price and building age on reducing residential electricity and gas demand, respectively, at the state level where energy policy decisions are typically made.

This study is organized as follows: Section 2 provides the literature review, including a brief introduction to the main analyses of residential energy demand; Section 3 describes data and the methodology; Section 4 demonstrates the empirical results; Section 5 determines two alternative scenarios to reduce residential energy demand and finally, Section 6 presents the conclusion.

2. Literature review

Energy demand in the residential sector shows the amount of energy consumed by households, excluding transportation uses. Residential energy demand varies significantly across regions. These variations could be attributed to differences in various factors such as socio-economic and demographic characteristics, building characteristics, energy prices, and climate. Socio-economic and demographic characteristics determine a household's behavior regarding energy demand. Energy prices and a household's income are two main important determinants of energy consumption for each household. Household behaviors regarding the energy prices and income are based on the economic theory including utility maximization and consumer rationality (Gyamfi et al., 2013). Energy prices may affect household decisions to reduce gas and electricity expenditures. Thus, policymakers need to know how households will respond to energy price changes and how prices affect decisions about energy consumption. Energy demand changes from a units increase/decrease in price is referred to as price elasticity of demand (Gyamfi et al., 2013). Additionally, socio-economic and demographic attributes, such as level of education and household income, determine household social classes and the ways people live. These classes can influence residential energy consumption behaviors among households.

Improving the energy efficiency of buildings to reduce energy consumption is a priority for policymakers in many countries (Kuckshinrichs et al., 2010; Noailly, 2012; Zolghadri et al., 2014). New buildings most likely have to pass tighter building regulations and have more checks and standards compared to older buildings. Therefore, new buildings are more efficient than old buildings; thus, they are more likely to consume less energy compared to old ones. Moreover, old buildings have production systems with lower