Renewable and Sustainable Energy Reviews 57 (2016) 1210–1226

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Residential energy demand for space heating in the Nordic countries: Accounting for interfuel substitution

Reza Fazeli [a], Brynhildur Davidsdottir [a], Jonas Hlynur Hallgrimsson [b]

[a] *School of Engineering and Natural Sciences, University of Iceland, Iceland*
[b] *Faculty of Economics, University of Iceland, Iceland*

ARTICLE INFO

Article history:
Received 11 February 2015
Received in revised form
9 September 2015
Accepted 17 December 2015
Available online 8 January 2016

Keywords:
Residential energy demand
Space heating
Climate impact
Interfuel substitution
Renewable resources
District heating
Bioenergy

ABSTRACT

Reliable estimation of fuel consumption in residential sector is crucial for the future development of fuel supply system. Three approaches are compared in this study to capture climate impact, as well as and interfuel substitution between fuels, on residential fuel consumption for space heating in the Nordic countries.

The first approach aims at directly estimating the demand for each energy carrier as a function of explanatory variables including heating degree days, fuels price and GDP per capita. The second approach is a two-stage model combing an econometric model for total energy use for space heating, and the market share for energy carriers based on cross/price elasticities, while in the third approach a set of simultaneous equations models were estimated.

Based on the results of the mean average error and root-mean-square error criteria for three approaches across the Nordic countries, it was found that the second and third approaches were able to capture the complementary and substitution effects between fuels. This finding confirms our hypothesis that the interfuel substitution is a key factor for estimating changes in fuel demand and should be accounted for when residential energy demand is projected. The results additionally have important implications for climate change policy, by exploring the impact of fuel price on residential energy demand for space heating.

Contents

E-mail addresses: rfazeli@hi.is (R. Fazeli), bdavids@hi.is (B. Davidsdottir), jhh4@hi.is (J.H. Hallgrimsson).

http://dx.doi.org/10.1016/j.rser.2015.12.184
1364-0321/

1. Introduction

Buildings represent the largest energy-consuming sector in the economy, with over one-third of all final energy and half of global electricity consumed there. They are also responsible for approximately one-third of global carbon emissions [1,2]. Due to cold climates in the Nordic countries space heating accounts for more than 60% of all energy use in buildings. Based on national statistics datasets [3–6], final energy use for space heating in the Nordic residential buildings increased from 614 TJ in 1990 to 682 PJ in 2013, driven mainly by growth in number of households and appliance ownership.

Considering the concerns related to security of energy supply, growing energy demands, limitations of fossil fuels, and threats of disruptive climate changes, diversification and utilization of renewable energy resources are defined as the main strategies in the Nordic countries. In fact, Nordic countries are among the leading countries on successful development of renewable energy and energy efficiency [7]. In 1990, fuel oil, natural gas represented a significant share (43%) of total space heating demand in the residential buildings. However, since the 1990's, rapid development in district and biomass heating systems, resulted in the considerable reduction in the share of fossil fuels to less than 14% in 2010 [8]. One of the key benefits of the district heating system (DHS) is that it offers a considerable opportunity to incorporate different types of energy sources, for example bioenergy, solar energy and industrial waste heat. Nowadays, a well-developed infrastructure for district heating exists in Denmark, Finland and Sweden, while the district heating infrastructure in Norway is limited to large cities. Two explanations account for this different pattern of progress, which are the abundance of hydropower resources and a fairly distributed settlement pattern which slowed the expansion of district heating in Norway [2,9]. Recent studies focused on the developments of using renewable sources for residential energy consumption; progress made by the use of renewable energy in the European Union [10], technological options for large-scale biomass feedstock supply [11], methods to optimize the design and management of biomass-for-bioenergy supply chains [12], development of high solar fraction systems by innovative combination of optimized solar heating, cooling and storage technologies [13] and sustainable management of waste-to-energy facilities [14].

The growing literature on energy demand has offered different dimensions to the evaluation of its dynamics ranging from the choice of specifications to the methodological approaches as well as the underlying factors. Two main purposes of such studies are to identify the main drivers for energy demand and project the energy consumptions, which can be used for energy planning purposes [2,15]. Zhao and Magoules [16] reviewed the methodologies applied for the modeling and prediction of building energy consumption. These methods include engineering, statistical and artificial intelligence methods. The engineering methods use physical principles to analyze thermal dynamics and energy behavior on a building level or for sub-level components. Building energy simulation models such as CAL-PAS3 [17], DOE-2 [18], or FEDS and BEAMS [19,20], have been used to analyze the impact of climate change on the demand for energy in individual commercial buildings by Scott et. al., [21] and in groups of commercial and residential buildings in a variety of locations [22–24]. Statistical regression models are generally micro-econometric studies aiming at estimating energy demand as a function of socio-economic parameters, which are estimated based on the historical data. Several sub-categories have been identified, including cross-sectional analysis [25–31], time-series [32,33], panel database [34,35] and cointegration analysis [36,37]. Artificial Neural Networks (ANN) are the most widely used artificial intelligence models in the application of building energy use predictions. ANN is good at solving non-linear problems and is an effective approach to this complex question. In the past twenty years, researchers have applied ANNs to analyze building energy consumption in a variety of settings, such as heating/cooling load [38,39], electricity consumption [40], optimization and estimation of usage parameters [41].

Undoubtedly, climate change is one of the most pressing concerns facing today society [42]. Most research on climate impact assessments on buildings has evaluated the impacts on total space heating and/or cooling due temperature changes induced by climate change. In general, climate projections are used as exogenous parameters on energy end-use or econometric models. The first studies on this subject date from the late 1980's. In an early study, Barthendu and Cohen [43] estimated the energy demand for heating (winter) and cooling (summer) in 2xCO_2 scenarios[1] in the region of Ontario, Canada, using regression analysis. Based on the effort by Baum, et al. [44], Table 1 provides a brief overview of 30 years of literature focused on climate change impacts on energy consumption in buildings.

This review shows that not many studies tried to capture the climate and fuel substitution effects on fuel demand for space heating at the same time, except [31], where Mansur et al. have used cross-sectional data and a discrete-continuous choice model. They matched detailed climate data to household Energy Information Administration survey data. The climate variables entered into both the fuel choice and conditional consumption equations. The authors found that climate change will result in fuel switching in the United States: warmer summers increase the consumption

[1] Scenarios for doubling of atmospheric CO_2 concentrations.