Understanding the spectrum of domestic energy consumption: Empirical evidence from France

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HIGHLIGHTS

- Survey data of 36,000 occupiers from France is analyzed.
- Bottom-up statistical approach is used to analyze domestic energy consumption.
- Occupant characteristics significantly affect domestic energy use.
- The impact of households attributes varies markedly across consumption groups.

ARTICLE INFO

ABSTRACT

This article focuses on residential energy consumption in France. Using a bottom-up statistical approach, this analysis explores determinants of household energy consumption using data from the most recent National Housing Survey. The primary objective is to tease out the impacts of various factors on the domestic energy consumption spectrum across different population groups. The aim of this approach is to neutralize conventional factors affecting energy consumption (age of house, total area, etc.) to finely analyze the impact of other determinants including those relating to household characteristics and other control variables.

First, we define homogeneous consumption groups of households by using multivariate statistical techniques, namely the Multiple Correspondence Analysis and Ascending Hierarchical Classification. Second, we use standard OLS regression to explore the effects of various factors on domestic energy consumption among homogeneous groups of households. This multivariate analysis exercise has led us to identify four main consumption typologies. Results revealed that energy prices were the most important factors determining domestic energy consumption. In addition, this study showed that occupant characteristics significantly affect domestic energy use. Results of this research call for combine all efforts, multiple strategies and smart policies, to incorporate household and consumption behaviors in managing domestic energy consumption.

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1. Introduction

In its most recent World Energy Outlook (2013), the International Energy Agency suggests that energy demand will continue to grow strongly, increasing by one-third over the period to 2035 particularly due to the increased demand from China, India and the Middle East.

The International Energy Agency (*IEO2013* Reference case) projects an increase of 56% in world primary energy demand between 2010 and 2040, mainly as a result of growing residential demand in non-OECD countries. It will rise from 524 quadrillion Btu in 2010 to 630 quadrillion Btu in 2020, and to 820 quadrillion Btu in 2040.

The significant increase in household energy needs at the expense of environmental concerns can be explained by the improved comfort, increased mobility, the need to save time, and improved standards-of-living.

Nonetheless, compared to other three end-use sectors (transportation, industrial and commercial), the residential sector is largely understudied (Swan and Ugursal, 2009; Estiri, 2014). Furthermore, suitable and consistent data sources are not easily accessible (Ewing and Rong, 2008; Estiri, 2014).

This context promoted the interest of researchers and policymakers to advance understanding of the determinants of energy consumption and to identify conservation strategies (Moore, 2010; Musti et al., 2011; Weber and Perrels, 2000). Although the purpose is clear, the task of understanding energy use in residential buildings presents substantial complexities. In fact, energy

consumption characteristics of the residential sector are complex and inter-related. Thus, in order to guide policy-maker's decisions in terms of energy use and CO_2 emissions reduction, it is essential to determine the factors that influence this energy consumption.

Today it is widely accepted that energy consumption in this sector varies according to the physical characteristics of buildings and household behavior. If the determinants of energy consumption relative to buildings have been identified (date of construction, surface of the housing, etc.), those related to household characteristics have been little studied because of their complexity, non-availability and cost of disaggregated data.

Interest in reducing energy consumption and the associated greenhouse gas emissions in the residential sector has grown in the last decade. The residential building sector is identified as the one of the most cost-effective sectors to substantially reduce energy consumption and greenhouse gas (GHG) emission by the French government over the next decade.

Therefore, this study proposes a bottom-up statistical analysis model of household energy consumption in France by using micro-level data. It allows us to determine which factors affect the energy performance of residential housing stock and to what extent.

The purpose of this paper is to provide a better understanding of the main determinants of residential energy consumption in order to guide energy policy making. The proposed model aims to increase knowledge and to gain greater insight into the effect of building and occupant attributes on energy use.

In our knowledge, due to the demanding data requirements, very few studies have focused on socio-economic energy consumption determinants in France. The present paper is one of the first to use micro household-level data to investigate the impact of household characteristics, occupant behavior, climate, physical building characteristics, and energy systems on domestic energy consumption in France using household 'homogeneous' groups.

In addition to the introductory Section 1, the rest of the paper is organized as follows: Section 2 provides a brief overview French building energy consumption. Section 3 presents the state of the art dealing with literature on the subject of residential energy consumption. Section 4 describes the data and the econometric model. We report our empirical findings in Section 5. Based on the results of the model, we draw conclusion and provide some policy implications based on the empirical results in Section 6.

2. Brief overview of french building energy consumption

The residential sector remains one of the most consuming energy sectors in France and offers significant opportunities for energy efficiency. According to the "Energy balance of France" published by the Department of Observation and Statistics (SOeS), the residential sector remains the second final energy consumer with 46 million tons of equivalent oil (Mteo) in 2012, right after transport (49 Mteo), with 30% of final energy consumption, and nearly 20% of greenhouse gas emissions. After a 19% increase between 1985 and 2008, energy consumption in the residential sector decreased slightly due to a decline in heating energy consumption (about 70% of total consumption) due to improvement of the dwellings' energy performance, thanks to the refurbishment of existing buildings and the introduction of strict technical regulations for new buildings.

This performance is mainly attributable to the improvements performed in existing housing supported by tax deductions established by the state in recent years, and to the gradual tightening of thermal regulations over the past three decades. Mainly consumed energies are gas and electricity. At present, 34% of primary residences are equipped with electric heating and 44% are heated

with gas. The penetration of electric heating in new housing has stagnated since 2011.

Furthermore, the development of alternative energies and investments in innovative technologies for energy efficiency remain insufficient to address issues related to the intensity of energy consumption and its harmful impact on the environment. However, understanding the key factors that determine residential energy consumption is crucial in the energy efficiency debate.

Thereby, it helps to inform public policy to achieve the objectives relating to energy and ecological transition. De facto, energy efficiency and the reduction of greenhouse gas emissions in buildings shown in the "environmental Grenelle" framework which aims to reduce dwelling energy consumption by at least 38% by 2020 and four-fold reduction in greenhouse gas emissions by 2050.

This ambitious objective must notably be achieved through the French rehabilitation program which reasserts a target for energy efficiency renovation of 500,000 existing homes each year from 2013, including 120,000 social housing to achieve 800,000 social dwellings renovated by 2020. This plan intends to reduce consumption in social housing by 150 kW h_{pe}/m^2/year. Several incentive schemes are set up by the state to accelerate the energy renovation of the park: income tax deduction, zero rate bank loan, VAT reduction, subsidy, exceptional bonuses ranging from 1350 to 3000 € in 2013, etc.

The recent French Energy Transition for Green Growth bill, reasserts a target for energy efficiency and establishes several environmental and energy goals in the building sector including:

– Accelerating energy renovation in the housing sector (simplification of zero interest loans "Eco-PTZ").
– Improving the energy performance of new buildings (all buildings shall be built to the low-energy building (LEB) standard by 2050).
– Boosting training and skills in the construction industry.

The structure and mix of energy use in the residential sector varies widely around the world, depending on a combination of regional factors, such as the availability of energy resources, climate, living standards, types of equipment use, lifestyles and demographic factors. In summary, domestic energy consumption shows a trend toward saturation in western countries because of national energy efficiency policies, while domestic energy consumption will continue to rise in developing countries. European countries and USA have relatively the largest energy consumption per household.

At the EU level, space heating is the most important end-use in the residential sector (68% in 2009 compared to 74% in 1990). The household energy consumption per dwelling has been decreasing regularly in most countries since 2000 (1.5%/year at EU level) (European Commission, 2015). Final energy consumption of residential buildings decreased in absolute terms from 306 Mtoe in 2005 to 296 Mtoe in 2013 (3%). However, the increasing of household energy consumption due to the rising number of dwellings and growing comfort (increase in the number of appliances and move to the large house) counter balanced by the energy efficiency improvements, especially the efficiency of household space heating system and diffusion of efficient new electrical appliances. Energy efficiency has improved by 1.8%/year at EU level since 2000. In 2008, energy usage per dwelling in France was 25% above Italy and 5% above the EU-27 average (see Fig. 1). Germany was in 22nd position, consuming more energy per dwelling than France and the UK but less than Denmark and Belgium.

Energy consumption in the residential sector accounts for one-fifth of total U.S. energy consumption and energy-related carbon emissions. In 2009, energy consumption in the residential sector