Energy and Buildings 105 (2015) 9–25

Contents lists available at ScienceDirect

Energy and Buildings

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

Statistical analysis of driving factors of residential energy demand in the greater Sydney region, Australia

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ARTICLE INFO

Article history:
Received 26 April 2015
Received in revised form 8 June 2015
Accepted 11 July 2015
Available online 20 July 2015

Keywords:
Energy demand
Residential household characteristics
Driving factors for electricity consumption
Empirical data
Smart grid
Energy modelling

ABSTRACT

The residential sector represents some 30% of global electricity consumption but the underlying composition and drivers are still only poorly understood. The drivers are many, varied, and complex, including local climate, household demographics, household behaviour, building stock and the type and number of appliances. There is considerable variation across households and, until recently, often a lack of good data. This study draws upon a detailed household dataset from the Australian Smart Grid Smart City project to build a household electricity consumption model. A statistical linear regression model for household energy demand was established and tested for both individual households and regional aggregations of households. The model showed only reasonable performance in forecasting the consumption of individual households – highlighting the influence of factors beyond those surveyed – but good performance for aggregated household consumption. Models such as this would seem highly useful for a range of stakeholders including individual households trying to understand the potential implications of different choices, utilities looking to better forecast the impact of different possible residential trends and policy makers seeking to assist households in improving their energy efficiency through targeted policies and programs.

1. Introduction

Residential electricity consumption is responsible for approximately 30% of global electricity consumption [1]. Hence the residential energy sector will play a critical role in the future of the electricity industry, especially given the increasing global demand for affordable, secure household electricity services, as well as the urgent need to reduce climate change emissions from the electricity sector. The characteristics of residential electricity demand are very context specific with complex drivers including climate, demographics, housing stock, building types, household appliances and behavioural aspects. The respective influence of these is not well understood. There has also been considerable change in these elements over recent decades. In particular, more energy efficient technologies for lighting, communications, space heating and cooling, cooking, refrigeration and water heating have advanced rapidly in the last decade. Along with more energy efficient building standards and other energy efficiency oriented policy efforts, these developments seem likely to have contributed to falling residential electricity demand in a number of locations over recent years [2]. Australia provides a notable example with, for the first time in over a century, decreasing electricity demand in the residential sector since 2010 [3]. Beyond energy efficiency advances, this reduction has also been driven by the increasing adoption of rooftop PV systems (now present on around 15% of Australian houses) and considerable increases in electricity prices [3].

A better understanding of how various factors influence residential electricity demand can assist in understanding possible future developments in the sector, as well as assisting in identifying opportunities to improve outcomes through targeted household and broader policy efforts. For example, such information can provide guidance to policy makers on the impact of different housing and household trends on local residential electricity demand and assist in forecasting the potential impacts of planning changes, housing retrofits and use of new energy efficient appliances under different possible government policy measures. Electricity utilities could use such insights to improve their planning and operational processes, while households could also benefit in better managing their electricity costs through an improved understanding of how decisions about what housing and appliances they choose can

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http://dx.doi.org/10.1016/j.enbuild.2015.07.030
0378-7788/

impact on their electricity bills, and what opportunities they might have to reduce consumption.

However, achieving an improved understanding of the nature of household electricity consumption is challenging, due to the heterogeneity of the residential sector, the complexity of the underlying drivers and the lack of comprehensive data. They include household demographics, including occupant numbers, age distributions, and income; household behaviour such as how often occupants use certain appliances and the interest and effort that they devote towards energy conservation; building types, appliances, such as the type of dwelling (free standing or unit), different appliance ownership and access to alternatives to electricity for some services such as gas for hot water, heating and cooking; and the climate zone of the households as well as the daily weather conditions. The wide variation seen across all of these drivers leads to considerable differences in households' electricity consumption. Furthermore, there has generally been only limited electricity consumption data available. For example, it has been common for households to have their electricity consumption recorded with simple accumulation meters that may only be read four times a year. Finally, this consumption has not been matched with detailed information regarding the houses and households. Where detailed data is available including household surveys covering the drivers above, and even appliance level metering, this has generally been for only a small number of households.

These challenges of complex drivers and poor data have posed significant challenges for reliable and useful residential electricity demand modelling. Using aggregated or partial data consisting of either social economic information or appliance ownership to model residential electricity consumption is insufficient for many of the potential applications of such models. Hence a more sophisticated modelling approach combining all aspects of household characteristics can add considerable value.

In this paper we report on a demand modelling study that could be used to forecast average daily electricity demand based on data from Australia's first large-scale smart grid project—the Smart Grid Smart City (SGSC) project. Amongst other activities, the project collected a year of half-hour demand data for more than 9000 households, and where available, solar generation and air temperature data. Around 40% of these households were also surveyed to establish house type and appliances, and household demographics [4]. We use this data to establish a bottom-up statistical model of residential electricity demand for these households.

More than 1.9 billion records from more than 9000 households over a one-year period have been sampled and analysed in our study [4]. This set of data has several novel elements in comparison with existing data sets in Australia. For example, the smart metered half hour electricity consumption readings from households are matched with half-hourly weather data at the same location (weather data from the closest weather station to the household). In addition there is a broad range of survey data for houses involved in the trial such as the dwelling type, number of occupants and their age groups, details of household appliances including those running on, gas, number of refrigerators, presence of air-conditioning and its type, presence of clothes dryers, and some self-identified behavioural indicators such as the household's frequency of clothes dryer usage and their intentions regarding saving electricity. As such, this survey data covers many of the driving factors of demand previously identified, including at least some aspects of household behaviour, demographics, building type, infrastructure and appliances, as well as climate.

The temporal resolution, large sample size and detailed household characteristics of this dataset present a unique opportunity for better understanding Australian household electricity consumption. The study presented in this paper aims to provide new insights into how a range of driving factors impact on residential electricity demand. The rest of this paper is organised as follows. Section 2 delivers a brief literature review on residential electricity modelling in different regions as well as its techniques. Section 3 introduces the data available from the SGSC project, followed with data treatment methods. Section 4 presents some preliminary, high level, analysis of the data, while Section 5 details the development of the detailed statistical model. The results of the aggregated model fitting and validation are illustrated in Section 6. Discussion and suggested future work are given in Section 7 while Section 8 presents the conclusions of this paper.

2. Previous work

To date, there are three major modelling approaches for residential electricity consumption. Notably, they are all critically limited based on the availability of data. These three approaches are, respectively, the top-down approach, which focuses on the interaction between electricity consumption and economic metrics at a high level scale using aggregated socio-economic data; the bottom-up approach, which statistically analyses household survey data and electricity consumption readings; and the physical model approach, which models physically measured data on specific dwellings, appliances and technologies [5]. All three approaches have their strengths and weaknesses, due to the differing nature of their input data and assessment capability. Top down models are mostly high level studies and analyse highly aggregated data at a national scale. The majority of papers focus on analysing the socio-economic impacts of the electricity sector [6,7]. Alternately, bottom up modelling utilises disaggregated data to estimate the impact of various factors on electricity consumption [8]. Some bottom up approaches use samples of houses' building physics to represent larger housing stock [9], combining building electricity calculations with statistical methods.

A considerable number of international studies have focussed on better understanding household electricity demand. As such the review presented here can only select a few sample studies and these are listed by the modelling approach used in the section below.

2.1. Top down

A study in Pakistan [10] used a top down approach to forecast annual residential electricity consumption using a multiple linear regression model. The study utilised a correlation matrix to analyse the sensitivities and relationships between aggregated power demand and a set of demographic variables. It utilised a univariate time series in conjunction with econometric models to estimate the electricity demand of Pakistan for the next 15 years. The analysis of this model found that GDP, income per capita and population have a key impact on electricity demand. Validation was done by comparative analysis with historical real data and projections of other regression models. A study in Italy, [11] tested various regression models based on available data from 1970 to 2007 regarding national electricity consumption. A regression model was proposed based on the elasticity analysis of the different demographics' effect on domestic and non-domestic electricity consumption. Another study, [12] provided evidence of the impact of population aging on electricity consumption in Italy using results obtained from a calibrated overlapping generations' general equilibrium model. The study found that electricity consumption is particularly sensitive to, and increases with, an aging population.

2.2. Bottom up

In Canada, a study used a bottom up approach utilising the Canadian Hybrid Residential End Use Energy and Greenhouse Gas