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Understanding electricity consumption: A comparative contribution of building factors, socio-demographics, appliances, behaviours and attitudes

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HIGHLIGHTS

- Multicollinearity is an issue in analysing electricity consumption data.
- Appliance ownership and use are most important in understanding electricity consumption.
- Dwelling and household size are likewise significant predictors.
- Reported attitudes hardly play a role.

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ABSTRACT

This paper tests to what extent different types of variables (building factors, socio-demographics, appliance ownership and use, attitudes and self-reported behaviours) explain annualized electricity consumption in residential buildings with gas-fuelled space and water heating. It then shows which individual variables have the highest explanatory power. In contrast to many other studies, the study recognizes the problem of multicollinearity between predictors in regression analysis and uses Lasso regression to address this issue.

Using data from a sample of 845 English households collected in 2011/12, a comparison of four separate regression models showed that a model with the predictors of appliance ownership and use, including lighting, explained the largest share, 34%, of variability in electricity consumption. Socio-demographic variables on their own explained about 21% of the variability in electricity consumption with household size the most important predictor. Building variables only played a small role, presumably because heating energy consumption is not included, with only building size being a significant predictor. Self-reported energy-related behaviour, opinions about climate change and 'green lifestyle' were negligible. A combined model, encompassing all predictors, explained only 39% of all variability (adjusted R^2 = 34%), i.e. adding little above an appliance and lighting model only. Appliance variables together with household size and dwelling size were consistently significant predictors of energy consumption.

The study highlights that when attempting to explain English household non-heating electricity consumption that variables directly influenced by people in the household have the strongest predictive power when taken together.

1. Introduction

Throughout the OECD (Organisation for Economic Co-operation and Development) countries, residential dwellings are responsible for a large share of national carbon emissions, with the UK being typical at around 25% [1]. Given that heating accounts for the greatest part of residential energy use and the high prevalence of natural gas-fired heating systems in the UK, gas consumption is substantially higher than electricity consumption [2]. Despite energy efficiency improvements in electrical appliances over the last 40 years, electricity consumption of domestic appliances has increased by about 2% per year over this period whereas it has fallen slightly overall [2], making electricity consumption an

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important research area. In 2014, consumer electronics (e.g. TVs mobile phones) were the largest consuming group of domestic appliances with an estimated consumption of 1.8 Mtoe, followed by wet appliances (e.g. electric showers) with 1.3 Mtoe, cooking (1.1 Mtoe), cold appliances (1.1 Mtoe) and lighting (1.0 Mtoe) [2]. Hence, given the need to reduce carbon emissions significantly to mitigate climate change and meet legal targets [3], it is important to understand what factors explain residential electricity consumption and how to minimise or reduce it.

A recent paper has shown that total energy consumption (most of which will end up as heat in the building) in English households is largely explained by dwelling characteristics [4], with a comparatively small contribution of socio-demographics, self-reported behaviours, and attitudes towards environmentally significant behaviour and climate change. However, for electricity consumption without space and water heating it is expected that appliances ownership and use and socio-demographics would have a bigger impact [5].

1.1. Literature review of previous findings on determinants of electricity consumption

We only review empirically based studies, not modelling studies (for those, see e.g. [6,7] for reasons of methodological comparability.

1.1.1. Impact of building characteristics

Regarding the likely impact of dwelling characteristics on electrical energy consumption, one important factor is the composition of the sample. Given the well-documented effect of building characteristics on energy consumption when including heating (e.g. [4,8,9]), the impact of dwelling characteristics can be expected to vary in magnitude depending on whether space heating is included in the electricity consumption.

Homes using electricity for heating (e.g. [10–13]) and hot water are shown to use more electricity compared to those heating water with gas [12,13]. Another rather self-evident effect is that in geographically diverse sample of homes location plays a role (e.g. [14–16]) due to differential demand for heating (if included) and cooling.

Regarding the impact of building variables, a common finding was that detached houses have been reported to have highest electricity consumption, both when controlling for other variables and when not (Wyatt [17], Brounen et al. [5], Yohanis et al. [18]). In one study, the effect of building type only played a role in winter data when heating loads contributed significantly to electricity consumption [15].

Regarding building age, results vary across studies, with some studies finding a non-linear relationship between building age and electricity consumption (e.g. Brounen et al. [5], Wyatt [17]), others finding an effect only in subgroups of homes with electric heating but not gas heating [10], and others reporting no effect [15].

A larger floor area is generally associated with greater electricity use [5,15,16,18], and a higher floor area is more likely to signify a high consumption household [13].

Regarding the impact of additional numbers of rooms, results varied, partly depending on whether floor size was used as an additional predictor: Once controlling for floor area, Brounen et al. [5] found a negative effect of additional numbers of rooms on electricity consumption; not controlling for floor area, Tiwari [19] found a positive effect. Wiesmann et al. [16] found no effect of number of rooms; Bedir et al. [20] found a negative effect of additional bedrooms but a positive effect for additional study and hobbies room, potentially because the latter ones are associated with additional appliances.

Number of storeys, insulation of external walls, insulation of loft, and energy saving windows had no significant effect on annual electricity consumption [10], in that sample, only a subset of homes used electricity for heating, which might explain why these factors played no role.

To summarize, the effect of building variables highly depends on what electricity is used for, i.e. whether it includes space and water heating. General findings are that greater floor area and detached houses use more electricity.

1.1.2. Impact of socio-demographic variables

A larger household size is generally associated with higher electricity use; however, the effect is not necessarily shown to be linear and depends on how the variable is coded. Using household size as continuous predictor showed that a larger household was associated with greater electricity consumption [10,12,20,21]. However, other papers report that whilst larger households use more electricity, the per-capita consumption is lower and hence coded household size as a categorical predictor [15,16,18,22]. Looking at what factors define being a high electricity user; Jones and Lomas [13] found that households with three or more occupants were more likely to be high consumers than homes with one or two occupants. They also found that households with teenagers were more likely to be high consumers of electricity, as did Brounen et al. [5].

Regarding the effect of age of householders, results were ambiguous. with some studies finding a non-linear effect (e.g. [15], others reporting no effect [20]. A higher use with older head of household was reported by Tiwari [19], and similarly, lower consumption if the head of household was younger than 45 years [14]. Regarding the probability of being a high consumer, Jones and Lomas [13] found that dwellings with a head of household over 65 years old were significantly less likely to be high electricity consumers than those between 36 and 50 years old; other age categories did not differ significantly from this reference category.

Income is another much studied variable, with several studies finding that households with higher income were more likely to be in the category of high consumers of electricity [13], or consumed more electricity, respectively [5,16,18,19,21,22], even though Wiesmann [16] stated the effect was relatively small once other variables were controlled for. However, Kavousian et al. [15] found no relationship between income and electricity consumption, and suggest that this might be because the income effect is mediated by appliance ownership which was a separate variable in the analysis. Bedir et al. [20] report that whilst income on its own is related to electricity consumption, it is not a significant predictor once controlling for other variables in an regression analysis, including appliances, lending support to Kavousian's findings.

Hence, both the statistical significance of an income effect and its strength might depend on what other variables are controlled for in the analysis.

1.1.3. Impact of appliances and lighting

Appliance ownership was as an explanatory variable included in several studies, with a general finding that owning more appliances and/or using them for longer is associated with greater electricity consumption [16,20]. This association with greater electricity consumption also holds when taking power consumption of appliances into account [19], and when relating base load to overall electricity consumption [18]. Specific appliances associated with greater electricity consumption were the number of refrigerators and entertainment devices for the daily minimum electricity consumption, and electric water heater, electric clothes dryer, and Spas/Pools for the daily maximum consumption [15]. Bedir et al. [20] reported that general use appliances and hobby appliances use were significant predictors (when controlling for household