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# The North East Scotland Energy Monitoring Project: Exploring relationships between household occupants and energy usage

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ABSTRACT

The total amount of energy consumed by households over a given period of time is a function of socio-physical factors and occupant behaviour. Findings are presented here from Phase 1 of the three-phase North East Scotland Energy Monitoring Project (NESEMP), a longitudinal study of household energy consumption patterns including baseline, intervention, and post-intervention evaluation phases. Electricity data from 215 households were recorded remotely at 5-min intervals between January 2011 and January 2012 inclusive. The study explored the different electricity consumption profiles associated with particular household types. It is suggested that such empirically-derived profiles have great potential in illuminating group differences and that these merit further research. Households were also asked to fill in a carbon footprint calculator questionnaire as part of the study and estimated carbon footprints derived from the carbon calculation tool were compared against electricity use. A significant association was found between carbon footprint estimates derived from the carbon calculation tool (specifically the component related to appliance use) and the actual electricity consumed by households. This demonstrates that the carbon footprint calculator – a pen-and-paper questionnaire that does not take actual energy consumption into account – can potentially be used as a tool to gauge electricity use where consumption data are not available.



## 1. Introduction

Wiedmann and Minx define the carbon footprint as "a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." [1]. While other uses of the term encompass greenhouse gas emissions besides carbon dioxide, Wiedmann and Minx note that there are difficulties in measuring these accurately (ibid.). This study focusses on household energy consumption and the resulting carbon dioxide emissions. The household carbon footprint is thus a measure of the carbon dioxide emissions caused by all household activities and accumulated over the lives of all household products, including products with functions such as heating, lighting and cooking. Whilst there are several contributors to household carbon dioxide emissions [2], this paper is mainly concerned only with those related to direct domestic energy consumption.

The annual carbon footprint of the average UK household is approximately 10 t of $CO_2$ [3]. Of this, approximately 37% is associated with space heating and the heating of water, 43% is associated with travel, and the remaining 20% is attributable to lighting and electrical appliances. Households account for 32% of the total energy consumption and 36% of the total electricity consumption in the UK [4,5]. The energy consumption of individual houses can be estimated from dwelling characteristics including: property type; the efficiency of the primary fuel source; the total space heating requirement of the household; and the number of people living in the house [3,6]. Although it is possible to calculate the $CO_2$ emissions of individual households from quarterly or annual gas or electricity bill data, it is not always possible to get accurate data for all household fuel sources. Furthermore, any total $CO_2$ estimates derived from annual bill data will not capture the more complex picture of how energy is used within the house over different time periods and in different seasons.

Although in recent years, issues of energy security and climate change have led to an increased level of motivation to find ways of reducing energy use in buildings, a large proportion of any given household's energy use is determined by socio-demographic variables. The socio-demographic factors associated with each

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house's energy use include variables such as income, occupancy, presence of children and house size [7,8]. In addition to these demographic associations, the behaviour of house occupants has an important influence on household energy use. Much research has been conducted in order to assess the effectiveness of intervention techniques designed to encourage environmentally friendly behaviours, including recycling household waste, reducing water use, and reducing energy use [9–11]. In addition, attempts have been made to understand the psychological antecedents of pro-environmental behaviour change more generally [12].

There are several ways that households can reduce energy use. In recent years, there has been a great deal of focus given to encouraging households to consume less (net) energy—by improving the energy efficiency of new housing and improving the thermal properties of existing housing stock, producing renewable electricity on site, purchasing energy-efficient appliances, or by curtailing certain behaviours associated with high levels of energy use [13–16].

This paper begins by briefly discussing energy use and the relationship between measured energy use and household behaviour. The subject of household carbon footprints is then introduced and the link with energy consumption and socio-demographic influence is established. The specific case of electricity consumption and measurement is then discussed before presenting the design and the baseline results from the on-going North East Scotland Energy Monitoring Project (NESEMP). This project will run for three years including baseline, intervention, and post-intervention evaluation phases. Section 4 of the paper focusses on the estimated household carbon footprints for the sample of households, and the relationship between these footprint estimates and the measured electricity consumption.

After the oil crisis in the 1970s, there was a large amount of research carried out into the psychological issues related to energy reduction behaviour. Various studies have shown that simply providing general information about energy saving measures in the format of workshops or mass media campaigns can often increase knowledge and concern about energy issues [17,18]. However, such increases in knowledge and concern often do not translate into observable behaviour changes unless the general information is combined with other behaviour change techniques [12,18–20]. One issue of great importance is that of personal relevance; any program or intervention that is perceived by household occupants to be irrelevant to their everyday life is unlikely to motivate change. This provides and explanation for the greater success of tailored information provision campaigns in reducing energy use, compared with more general styles of information provision [17]. Research has shown that when households are provided with general information about energy savings, this increases environmental concern, but does not reliably influence actual behaviour [17,19]. In order to provide households with sufficient information to understand what opportunities there are for changing household behaviour (the behavioural opportunity set), it is necessary to first know the baseline from which that household is starting. This paper focusses on two methods by which the baseline electricity consumption profile of households can be measured—household carbon footprints, and direct energy monitoring. These methods can be used in combination to gain a better understanding of how these baseline energy use profiles vary between different household types.

## 2. Background

### 2.1. Carbon footprints and socio-demographics

The direct consumption of electricity, gas, oil and biomass in the house is an important component of a household's carbon footprint, and this direct consumption relates to the functional domains of space heating, water heating, lighting, and appliance use. Whilst the household heating source is an important factor in calculating the total energy consumption (and associated emissions), it is important to consider the complex influence of household socio-demographics on energy use. This topic has received some attention in the literature. Abrahamse and Steg used data from a sample of 189 Dutch households to test relationships between socio-demographic variables and estimated household energy use [7]. They found that larger households and those with higher incomes tended to report higher energy usage. Similarly, a study by Druckman and Jackson used data from a sample of approximately 7000 households to investigate relationships between socio-demographic variables and energy use [21]. They also found that energy use related positively to income and household size. Existing research thus suggests that larger households and those earning more are likely to use more energy. However, there is also a considerable variation in energy use within households of the same type and income bracket, which indicates that individual occupant behaviour and psychology are significant drivers of energy use. In some cases there can clearly be strong associations between socio-demographics and occupant behaviours (for example, the presence or absence of children). In most households of a given type, one might think of there being a 'window of likely consumption' in terms of energy use, but that the actual levels of consumption are determined by both occupant behaviour and the psychological antecedents leading to such behaviours. Indeed, the above study by Abrahamse and Steg found that once a baseline of energy consumption was established, psychological antecedents were far more important than additional socio-demographic variables in terms of statistically predicting energy saving behaviour [7].

### 2.2. Household electricity consumption

The study makes use of data collected from the North East Scotland region of the UK. This region is situated in the climate region of Eastern Scotland (including the cities of Aberdeen, Edinburgh and Dundee) which is drier, on average, than Northern or Western Scotland. The UK's Met Office provides a climate profile for Eastern Scotland, and some key details from this are summarised here to allow comparison with other locations [22]. The lowest temperatures in the region (mean daily temperature between 1.5 °C and −2 °C) occur during the winter months (December–February), with high temperatures approaching 20 °C in July. The region has between 95 and 150 days of ground frost per year, and receives an average rainfall of between 700 mm (in coastal areas) and 1500 mm (in mountainous areas). There are between 1100 h and 1500 h of sunshine per year on average, but the occurrence of sea-fog (haar) in places on the east coast (including Aberdeen) can lead to a localised reduction in sunshine hours.

In Scotland, the average yearly electricity consumption per household is around 4150 kW h, which equate to approximately 11.4 kW h/day [23]. To put this in an international context, the average annual household electricity consumption in North America is approximately 12,500 kW h, whereas in developing regions it is considerably lower (e.g., approximately 600 kW h in India and 900 kW h in Africa) [24]. These average figures however do not tell us how much electricity is consumed by any given household, nor how it is used. Clearly, some houses consume very little electricity and some consume a great deal. Previous research has shown that income and, in particular, house size explains a significant amount of the variation in household electricity consumption [25]. This is particularly so when comparing small dwellings (e.g., small apartments) and medium size dwellings (e.g., houses), possibly illustrating the demographic profile differences between