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Explaining shifts in UK electricity demand using time use data from 1974 to 2014

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ABSTRACT

Peaks in electricity demand generate significant negative environmental and economic impacts. As a result, recent policy and research attention has focused on the potential for temporal flexibility of demand, especially in the context of intermittent low-carbon generation. Much of this work emphasises the need to understand what makes up the peak and to engineer solutions to meet this 'normal' consumption. However, today's patterns of temporal consumption may only be a snapshot of continuing change. This paper uses UK household time-use survey data to analyse change in temporal patterns of activities over the last 40 years to shed light on apparent temporal shifts in overall UK electricity demand. The results highlight long term evolution in when and where people work, travel, eat, use media and carry out social activities. In particular they suggest that changing patterns of labour market participation may be contributing to shifts in food related, personal/home care and media activities which correlates with shifts in electricity demand. We conclude that both stable and dynamic social structures and forms of organisation have direct implications for policy debates around current and future flexible demand-side solutions.

1. Introduction

Peaks in electricity demand cause significant negative environmental and economic impacts. In many countries, peak demand periods require carbon intensive and costly dispatchable generation and cause difficulties for constrained capacity local low voltage (LV) distribution networks. With different intensities depending on the season, evening peaks repeat themselves throughout the year and are typically the highest levels of electricity demand in countries with temperate climates, including the UK where the residential sector is responsible for about one third of overall electricity demand and up to 40% of peak demand (Torriti, 2015).

Such peaks cause imbalances between demand and supply so that electricity prices in wholesale markets can fluctuate from less than €0.04/kWh to as much as €0.35/kWh (Torriti, 2015). In a decarbonised future, peaks are likely to remain a daily network balancing issue where capacity margins are slim, particularly in seasons where the problem is exacerbated by weather (e.g. winter in the UK and summer in parts of the U.S.) and where the integration of intermittent renewables in the supply mix has to be set alongside shifts to electric vehicles and heat pumps (Strbac, 2008) which may both exacerbate evening peaks. It has been suggested that with 30 GW of variable renewables and inflexible nuclear generation, this may require the curtailment of up to 25% of wind energy in the UK due to the increased need for fossil fuel generation to operate part-loaded in order to provide required ancillary services (Strbac et al., 2016). Given the policy imperative to move from fossil-based to renewable sources, the need to change demand at relatively short notice is becoming known in the energy demand literature as a flexibility problem (Grunewald and Diakonova, 2018) with an estimated potential market value of ~£8billion per year (National Infrastructure Commission, 2016).

Managing peak demand through interventions to achieve temporal flexibility is therefore likely to be even more important to the future of electricity provisioning. Intervention aimed at mitigating peaks in residential electricity demand is far from straightforward (Strengers, 2012, 2011) and attempts to-date have not always been successful. For instance, in Italy the effects of Time of Use tariffs on peak demand were minimal due to the loss of the price signal in combination with high penetration of zero-cost renewables during peak periods (Torriti, 2012). A wide-ranging review of a number of other studies has shown similarly underwhelming results (Frontier Economics, Sustainability First, 2012) although the quality of this evidence base is in some doubt (Frederiks et al., 2016). More recent trials have contributed conflicting results with some reporting consumer demand response of up to 10%

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(Schofield et al., 2016) but others reporting lower (Carroll et al., 2014) or non-existent effects (Srivastava et al., 2018).

This lack of clarity has lead recent academic and policy research to focus on understanding the activities that make up the peak and thus ‘produce’ the demand patterns observed (Torriti et al., 2015; Walker, 2014). This has illustrated how the timing of energy demand is dynamic, social, cultural, political, historical and bound up with the evolving temporal rhythm of society. It is therefore clear that electricity demand is shaped by the synchronicity, sequencing and inter-weaving of activities and practices (Anderson, 2016; Shove and Walker, 2014; Torriti et al., 2015) so that we should not expect a simple alteration in tariff to automatically shift consumption. Further, a small but growing body of work has focused on improving understanding of which everyday activities contribute to residential peak demand, in part to assess what levels of temporal flexibility there might be when electricity-using activities are enacted (Torriti, 2017; Torriti et al., 2015). However, unless reporting on experimental manipulation or interventions (Higginson et al., 2013; Schofield et al., 2014), such point in time studies are unable to provide empirical evidence of actual or potential change.

Furthermore, in addressing single time-points these studies ignore the constantly changing social milieu into which any interventions must be placed. This risks conceiving current ‘norms’ of temporal social organisation as historically fixed so that fixed solutions can satisfy the ‘need’ embedded within these norms (Shove, 2017). As Shove explains, ‘normal’ patterns of energy demand constantly evolve and so solutions must be devised which avoid lock-in to potentially transitory, and possibly unsustainable, ‘normal’ levels of demand. This risk can be mitigated by understanding how current norms of consumption have evolved and one non-experimental approach is to analyse how temporal patterns of household energy demand have changed over time alongside known changes in overall demand and its associated generation (Staffell, 2017).

As we discuss below, since historical data on temporal consumption patterns are essentially absent, at least for the UK, recent work has turned instead to historical time use surveys as a way to understand how electricity-demanding activities have evolved (Anderson, 2016; Durand-Daubin and Anderson, 2018). Although not able to precisely indicate how current consumers might respond to demand side interventions or tariffs, such analysis can nevertheless provide indicators of how consumption may have changed over time, for whom and why.

Building on this work, this paper presents analysis of the changing timing of high-level aggregates of reported time-use activities using national UK household time use diary data from 1974 to 2014. Having highlighted a number of substantial energy-related changes, the paper then investigates changing patterns of evening peak period (16:00–20:00) activities and consequential electricity demand with a focus on food related activities, personal/home care and media use which are known to be electricity-intensive (Palmer et al., 2013b, 2013a; Widén et al., 2009), have seen notable change and are likely to be driven by wider social transitions such as evolving patterns of employment (Anderson, 2016; Durand-Daubin and Anderson, 2018).

After this introduction, the paper provides an overview of trends over time in household energy demand (Section 2); describes the methods and time use data underpinning this research (Section 3); presents findings from the analysis on changes in activities constituting energy demand over four decades and specifically during evening peaks (Section 4); and discusses the implications of this work (Section 5).

2. Trends over time in household energy demand

In most developed countries long run datasets of yearly aggregated electricity demand are largely available with time spans of decades. In the energy economics literature, these datasets are typically used for cross-section analyses of the dynamic relationship between energy demand and either price (Bernard et al., 2011; Garcia-Cerrutti, 2000) or income (Asafu-Adjaye, 2000; Sari and Soytas, 2007) and in other work to assess the degree of energy demand reduction associated with the uptake of various energy efficient technologies. These datasets are generally intended to capture and analyse trends in annual demand (Palmer and Cooper, 2013). In contrast, whilst historical whole system hourly demand profiles are available[1] and long-running annual energy use surveys exist (Communities and Local Government, 2018; Energy Information Administration, 2015), there is very limited historical information on the sub-daily distribution of demand and thus the shape of *residential* electricity load profiles. Indeed, where suitable data has been collected (Isaacs et al., 2010), we have found no analysis of changes in the timing of demand. Although Palmer and Cooper (2013) offer some time-series analysis of overall demand based on trends in appliance load patterns,the lack of historical temporal demand data makes tracing the changing composition of residential peak demand extremely difficult.

This is unfortunate as it is known that there has been both an overall reduction in whole system demand and changes to demand profiles over the last decade in the United Kingdom at least (Staffell, 2017, p. 469). This is clearly shown in Fig. 1 which further disaggregates overall England and Wales electricity demand data for 2006–2011 by weekdays vs weekend days. Demand profiles have universally reduced but with differing magnitudes according to time of day and day of the week. Evening peak weekday consumption remains high in January but the difference between weekdays and weekend days has diminished. Morning peaks are no longer visible on weekend mornings in January and the trend towards increased evening demand compared to morning or mid-day demand on all days in July is clear. Although it is likely that embedded solar generation contributes to this mid-day summer dip, it may also be that need for increased heat and light in January is masking similar changes in evening energy-demanding habits in the winter.

More importantly for current and future ‘energy flexibility’ policy, when normalised within year and month (Fig. 2) there has clearly been a relative decrease in mid-day demand and the evening peak is relatively higher and later. As noted above, this is especially visible in July but the same pattern is also to be seen in January with a particularly notable relative uplift in Sunday evening demand. Unfortunately, it is not yet possible to disaggregate this data into residential and other customer types and there has also been little analysis of the changes in domestic activities which might contribute to the changing shape of residential and thus overall system demand peak. However recent studies using time-use data have hinted that changing labour market participation and consequential changes in the timing of domestic tasks may play a role (Anderson, 2016; Durand-Daubin and Anderson, 2018).

Whilst there have been a small number of in-depth household electricity-use studies, with the exception of the New Zealand HEEP study (Isaacs et al., 2010) these have tended to focus on a single year in order to capture both intra-day and inter-seasonal variation. For example the Household Electricity-Use Study 2010/11 (DECC/DEFRA, 2011) monitored electricity consumption at an appliance level in 250 owner-occupied households across England (Jason Palmer et al., 2013b; Palmer and Cooper, 2013). Similar studies took place in Sweden in 2008, where 400 households were studied over 12 months (Widén and Wäckelgård, 2010), and in France where a series of studies monitored 100 homes for a year in 2007 (Wilke et al., 2013). Not only are these studies relatively small scale and potentially non-representative, but more importantly they cannot provide insights into the historical components of peak demand. As a result we have no data that can *directly* explain how and why temporal patterns of residential electricity demand have evolved over time, how they contribute to the later and sharper peak identified in Fig. 2 and how this may change in the future (Love and Cooper, 2015; Walker, 2014).

In the absence of such data, time use datasets can potentially shed

[1] E.g. https://www.entsoe.eu/db-query/consumption/.