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Peak electricity demand and the flexibility of everyday life.

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Peak Electricity Demand and the Flexibility of Everyday Life

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Abstract

Reducing greenhouse gas emissions from energy consumption in the UK is increasingly linked to the introduction of uncontrollable sources of power, such as solar PV and wind, and the electrification of energy services (Darby 2012; Department of Energy and Climate Change 2013; Department for Energy and Climate Change 2011). Electrifying heating and personal mobility requires moving them off the gas grid and petrol pump and onto the electricity system, which in turn may have implications for the profound peak in electricity use that takes place in the early evening. While the conventional response would be to reinforce electricity networks, under conditions where there are an increasing range and diversity of sources of electricity generation that are less predictable and controllable, there is increased political and commercial interest in managing demand in these periods. Demand Side Management (DSM) enabled by smart grids promises to bring consumers of electricity into the management of the grid by asking them to provide the flexibility and responsiveness that the industry may lose in the future. In this paper we draw on 186 qualitative home tours in the UK to examine how such forms of flexibility are constituted. Rather than seeing flexibility as related to the characteristics of individuals and their behaviour, as is common in

the industry and policy, we argue that it is the social practices which shape electricity demand curves that need to be at the centre of analysis. To illustrate this argument, we consider how, in what ways and for what purposes consumption of electricity may be or become flexible in response to a time of use tariff designed to reduce consumption in the early evening. We find that practices vary in the degree to which they are flexible even within the same household, and that this flexibility is shaped through the rhythms and meanings associated with different forms of practice in everyday life. Rather than seeking to target only particular socio-demographic clusters, this suggests that interventions aimed at developing the smart grid will also need to relate to the different forms that electricity-intensive practices take and offer new forms of service through which such practices may be engaged and reconfigured.

1 Introduction

As greenhouse gas emissions associated with energy use have become central to climate and energy policy, so too has the demand for energy become a principle area of interest for social scientists across (sub-) disciplines including Human Geography, Anthropology, Sociology and STS. The growing interest in energy demand has been accompanied by a distinct shift in focus away from the attitudes, behaviours and choices of individuals (Shove 2010), towards an engagement with how energy use is constituted socially and materially (Guy 2006, Maassen 2009) (Spaargaren, 2011; Spaargaren et al., 2006; Stephenson et al., 2010; Strengers, 2011, 2009; Wilson and Chatterton, 2011 Gram-Hanssen, 2011). Whilst this research has significantly advanced our understanding of how and why energy is used and the possibilities and limits of 'behaviour change' as a means for reducing demand, its predominant focus on the domestic sphere as the site through which energy use is constituted has limited its engagement with the dynamics of wider energy systems and a rather abstract engagement with the nature and properties of energy itself (Strengers & Maller 2012). This

has led to a disconnect between *energy* use research and the related but distinctively different issue of demand for *power*, the different material forms of energy used to meet such demands, and the ways in which demands for power are socially and temporally arranged (for important exceptions, see (Strengers 2011; Strengers 2013; Southerton et al. 2004; Chappells & Shove 2004; Higginson et al. 2013). In this paper we seek to contribute to the ongoing debate within the social sciences about energy consumption through engaging with a key dynamic that links the everyday contexts of energy use and broader power system transitions in response to climate change, energy security and peak demand. Drawing on work conducted as part of a regulator-sponsored and industry-led project, the Customer Led Network Revolution (CLNR[a]), we examine how peak demand and its flexibility is constituted through everyday life and draw out the implications for the future of smart grids.

The paper proceeds in section two by deconstructing load curves and exploring practice entities and performances as constituents of peaks in demand. The third part of the paper sets out the research process and context from which the paper comes before an analysis of the flexibilities of different practice entities in section four. We then draw conclusions which highlight the diversity of ways in which practices are reproduced, the suitability of laundry and dishwashing for practice-aligned interventions and the opportunities to produce flexibility by working with or around the rhythms, conventions, economies and capacites of practices.

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[a] www.networkrevolution.co.uk

2 Constituting peak demand: load, flexibility and household practices

From a socio-technical perspective, network 'load' is not only a physical phenomenon measured in voltage but is also a social one, representing the aggregation, at different scales, of the multiple ways in which electricity is used across the distribution network, in households and businesses. This is particularly important in thinking about the socially shared and loosely orchestrated practices – such as cooking, laundry, dining and home-comings - that animate the early evening and in doing so create peaks in demand for power which are registered at every scale on the network, from individual street-scale feeders to the national demand curve (Gridwatch 2014). Understanding how load is constituted and the ways in which electricity use may be flexible entails examining the ways in which electricity is used in the everyday contexts and workings of households and businesses. In what follows we first examine the means by which load has become problematized, and in particular how "peak demand" has come to be understood before drawing on theories of practice and rhythm to suggest that while much research has emphasised the socially shared quality of social practices, practice entities have different degrees of variability in how and when they are performed in different contexts with some exhibiting little variation and others being highly differentiated. This has consequences for their contribution to evening peak demand for electricity and, we argue, these differences in the heterogeneity of their reproduction mechanisms makes practices differently able to adapt or respond to changing contexts.

2.1 Changing the curve? Electricity use and flexibility in the smart grid

Load curves represent the daily, monthly, and seasonal variation in how and where energy is used and produced across the low voltage, or distribution, network. In different national contexts, load curves bear the distinct features of the systems of provision and demand they represent. In the UK, annual load curves exhibit seasonal peaks and troughs while weekly or

monthly load curves are saw-toothed in nature, reflecting daily demands for energy services and nightly periods of reduced demand[b] (Gridwatch 2014). The twenty-four hour load curve for electricity magnifies this pattern – with a clear late afternoon/evening peak (Figure 1). Currently, power systems are governed in such a way as to ensure that there is sufficient capacity to meet these peaks in demand – both in terms of available energy resources to produce the electricity required, but also, and most importantly for our discussion here, ensuring that networks have the capacity or 'headroom' to distribute electricity reliably in any given demand scenario (Roberts et al., 1991, p. 51).

Figure 1 - Daily mean demand for Electricity from smart meters customers for 12 months (June 2011 to May 2012 inclusive)(Wardle et al., 2013)[c]

[INSERT FIGURE 1 HERE]

However, in the light of the twin challenges of decarbonisation and energy security, the extent to which networks will continue to be able to serve peak demand under this logic, in which consumers are able to consume without constraint, is coming under question. While energy consumption (KWh) has been widely associated with greenhouse gas emissions, managing power (KW) and its peak demand will become an important part of both ensuring affordable energy provision by delaying or deferring network reinforcement costs and, crucially, in realising the potential offered by renewable sources such as sun and wind energy. Both are relatively uncontrollable, so that that managing output requires either crude

[b] An exception to this is on networks where there are high numbers of night storage heaters that exhibit peak loads after midnight when storage heaters begin to draw power.

[c] Graph shows monthly mean electrical energy demand from a structured sample population of 7,043 domestic customers in the North East and Yorkshire in the UK using 30 minute interval data. Reproduced with permission of the authors.

methods (e.g. turning wind turbines off) or storage solutions which are still in their infancy (e.g. large scale batteries, thermal storage), each of which has significant implications for the economies of investment in renewable technologies. Further, the typical 24 hour generation profile from both wind and solar is not ideally aligned to the dominant 24 hour demand profile for power in the UK. As a result, any realistic argument for climate change mitigation that relies on renewables must also address the issue of matching power generation to demand through new interventions in the electricity grid itself. Framed as a technology problem alone, the infrastructure renewal required would be both technically and financially challenging. Instead, policy-makers and market actors are seeking to examine ways to defer the costs of reinforcement while at the same time meeting low carbon and energy security challenges through demand side management (DSM) of the system as part of socio-technical imaginaries often collectively referred to as smart grids (Jasanoff & Kim 2009).

While different interpretations of what constitutes a smart grid exist, it is defined by the EU Smart Grid Forum as, "an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies. A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies." (SmartGrids European Technology Platform, 2013). Central to the promise of the smart grid is its ability to match new forms of demand and supply through involving users in new initiatives in which use of electricity is made more responsive to production conditions, reducing the need to reinforce the grid to handle the moments of the day / year with highest demand peaks. Achieving such demand side management depends on what is termed flexibility – the ability of users of energy to change how, when (and where) they demand power. The UK's load curve, and in particular the evening demand peak, present a particular challenge in this context in that the predicted need

to move heating and transport onto the grid - envisaged as key features of the low carbon transition - may fall precisely during the peak period (Clastres, 2011).

In order to reduce the risks to the network capacity posed by peak demand, there is a growing interest in ways to not only to reduce total energy consumption (kWh) – through energy efficiency measures which are also aligned with carbon emissions reduction and cost saving initiatives – but also in how to change the contours of power (kW) demand curves by moving load away from the evening peak period to other times of the day or week (Arteconi et al., 2013). (Re)moving the 'peak' of demand is intended not only make the load curve flatter, with potentially substantial effects in terms of reducing the capacity required within the electricity network, but also to open up opportunities to create new forms of demand for power that follow the availability of power generated from the wind and sun. In the UK, energy policy is beginning to create the context for the future development of such projects. The Department of Energy and Climate Change has mandated a roll out of smart meters, to provide households and businesses with real-time information on energy use and to provide suppliers with accurate consumption figures. The energy regulator, Ofgem, has also charged the power distribution companies with the need to innovate to develop new forms of network control and flexibility which include investigating the ways in which end users may offer flexibility to counter the loss of supply flexibility imagined to result from a transition from controllable fossil fuel to renewable electricity generation.

In order to understand how such forms of flexibility might be realised, we need to understand how such peaks are constituted, and the ways in which their constituents may be or become flexible. We begin by arguing that peaks are constituted by social practices. We then suggest that theories of practice can help both in terms of explaining how and why social co-ordination in time and space around electricity use emerges and persists, but also in providing

a means through which to understand how and why the practices that contribute to the evening peak might change in different ways. To do this, we consider practice entities and performances, and the rhythms and materialities through which practice entities are reproduced with differing degrees of diversity.

2.2 Time, practices and peaks

While the body of research inspired by theories of practice is diverse and expanding, together it represents a 'practice turn' in the way social science research has addressed consumptionand increasingly the debates around decarbonising various aspects of everyday life in response to climate change (Schatzki et al. 2001; Shove & Spurling 2013). From this perspective, practices are considered to be the "fundamental unit of social existence" (Watson n.d.) and while there is no unified approach, "most thinkers who theorise practices conceive of them as ... embodied, materially mediated arrays of human activity centrally organised around shared practical understanding." (Schatzki, 2005, P11). Domestic energy research undertaken from a practice theory perspective has focussed on cooking, laundry, bathing, lighting as examples of practises which cause people to use energy. Focusing on the timing and coming-together of practices, theorists suggest that interaction between practices shapes energy use in everyday life, creating habits, routines, rhythms and norms at certain times and in certain places and that the connections between practices are important in organising, ordering and pacing the activities of their practitioners – their humans (Schatzki 2009; Shove 2009).

In this conception, how people string together performances of practices – like cooking, laundry, washing up, TV watching, bed time - is neither the result of the conscious agency of individuals nor is it the inevitable outcome of structural conditions, but is rather is a result of how practices are coordinated and to varying degrees stabilised in spaces and time. In the

UK, among other countries, there is a clear coming together of practices in the early evening which, although not identical house to house, points to the 4pm -8pm period in the UK as a time at which the socio-materially structured reproduction of practices takes place. As Shove observes, "despite an apparent erosion of collective rhythms and schedules, the spreading of the day (thanks to electric lighting, and more recently to 24-hr opening) and the multiplication of discrete episodes the extent of socio-temporal coordination remains impressive." (Shove 2009, p.27). While practices are thought to be coordinated, socially extensive entities and each such entity, of which bathing would be one example, is, "a temporally unfolding and spatially dispersed nexus of doings and sayings," (Schatzki 1996. 89), these practice entities are reproduced through recursive (re-)performances and, "the majority of performances are improvisations within a practice." (Warde 2013, p.21). This suggests that it is not only the social and material configuration of practice as entity that matters, but also how it is 'performed' at multiple sites and scales, within and beyond the household. In particular, we suggest, the performance of particular practices is critical in terms of understanding how resources are used, the orchestration of practices through the rhythms of the day, and the extent to which the performance and co-ordination of practices is amenable to intervention and improvisation in relation to managing demand.

While the material constitution of practice has been central to the conceptual and empirical research in this field, the ways in which practices are connected to and structured through forms of resource use has only recently come to be a subject of inquiry. As Watson argues, there is no such thing as a sustainable practice because of the myriad ways in which any given practice-entity can be performed (Watson n.d.). His argument that cycling fuel (food) can have different degrees of carbon-intensity depending on whether it is a cheeseburger or banana neatly highlights the importance of resource use within practice performances (Strengers & Maller 2012; see also Ropke & Christensen 2013). It is each performance of a

practice, such as how long a shower is, that matters in resource terms. This can be linked directly to rhythms of practices as the time at which a practice uses power affects not only its contribution to collective peak demand but also its environmental impact as a result of the rhythms of energy provision which make night time power much less carbon intensive than evening power due to the daily rise and fall of fossil fuel generation compared to the drone of nuclear base load that powers night time demand. In these ways production and consumption practices can be seen to be in interactively rhythmic relationships.

Southerton (Southerton 2006) argues that because individuals experience modern life as time-squeezed they actively attempt to coordinate their multiple personal and shared commitments and that this inevitably creates 'hot spots' of activity which are characterised by intensities of practices occurring in time-spaces and, in particular, the coming together of shared practices such as family meals or meetings. These ideas are helpful when thinking about how evening electricity use is (re)produced, and in drawing attention to the feelings of stress and intensity of the evening period.

The co-constitution of rhythms in everyday life by commercial, social and other phenomena is not, and authors have recognised that societies are composed of a number of overlapping rhythms (Shove 2009; Southerton 2009) Night shifts, store opening hours, annual school holidays, religious calendars and sports fixture lists are all examples of rhythmic structures which together position performances of practices as many notes on shared staves, and bundles of practices such as evening routines, not as linear melodies but as recurring motifs which come around again and again only in different ways, sometimes involving different relational (or to extend the musical metaphor, harmonic) structures between practitioners, materials and meanings, but which nonetheless are recognisable and have a rhythmic quality.

Accounts of the everyday reproduction of practises which focus on to their rhythmic nature, such as important work on rhythm analysis by Lefebvre (Lefebvre 2004) and more recently by Blue (Blue 2013) theorise, "the co-ordinated and synchronised 'polyrhythmia' of rhythms of practice in 'everyday' life." (Blue 2013, p.2). Our interest here in the effects of deliberate interventions to alter the times at which practices are performed or are made to be responsive to signals from the grid is, in Lefebvre's terms, an interest in 'arrhythmias'; disturbances to the pre-existing rhythms of performance of practices and the possibility of the emergence of new ones. The improvisational way in which practice-entities are reproduced points to an in-built diversity of performances and, we argue, scope for evolution and adaptation to demand side management interventions through the "un-braiding and re-braiding" of practises in response to disruption and intervention (Trentmann 2009). While Trentmann's focus is on the normality of breakdowns in infrastructure and their usefulness in revealing how life is re-woven in response to power cuts, traffic jams, transport shut-downs and so on, his observation that, "disruptions reveal the flexible side of habits and routines so often imagined as stable and stubborn" (Trentman, loc 1566) is relevant to our investigation into demand side management. This is because socio-technical propositions like time of use pricing and in-home displays represent less dramatic but nonetheless significant disruptions to normality and social expectations about what it is to be an energy consumer for UK households. The resistance to or acceptance of the altered rhythms introduced by these interventions is a principal interest in the following analysis.

DSM interventions aim to create moments of arrhythmia, disturbances when new polyrhythms might emerge which work with new structures such as time of use pricing schedules. At such moments of disruption, practice entities do not cease to be reproduced, but rather performances may adapt to the new arrangements of the proposition through their ability to recursively improvise, and through this process, entities such as bathing, cooking or

dining may come to fold together the altered economies and polyrhythms of the newly altered domestic context with its materialities and capacities to create either different performances of practice entities which have different electricity use requirements, or may make the entity take on a more responsive or 'active' state than had previously been the case. We draw on these concepts in analysing the qualitative data below to consider the effects of time of use pricing on the timing and rhythms of evening practices and their associated use of electricity.

The paper now provides an overview of the research process and the wider project with which this work has co-evolved. We then work through an analysis of qualitative empirical data to explore the flexibilities of particular practices as they relate to a time of use pricing intervention.

3 Investigating Peak Flexibility

Schatzki argues that a worthwhile endeavour from the conceptual position set out in Section 3, among other things would be, "Piloting the use of alternative material arrangements and exploring how existing practices react to, appropriate, and hybridize with them." (Schatzki, 2013, p. 44). It is just such an endeavour that the authors are involved in although we extend this to include alternative financial arrangements (a time of use electricity tariff) which are integrated with the new materialities (in-home displays).

In the UK, the Low Carbon Network Fund (LCNF) has been established as a means through which to explore the potential of such forms of demand shifting or 'flexibility'. LCNF is a £500m fund created by Ofgem (the UK's regulator of gas and electricity markets). The fund aims to, "replicate the incentives on unregulated companies to innovate." (Ofgem, 2011).

The authors have been actively involved in shaping and researching the impacts of one of the LCNF projects, the Customer Led Network Revolution (CLNR) in which a transdisciplinary research program has enabled the study of 'flexibility' as a feature of energy users and systems. Engaging with how and why demand is flexible requires that we move beyond the usual conception of load as a physical property of networks and instead explore the forms of energy use that go into making up peak demand .

The research project from which this paper comes is a large inter-disciplinary investigation which is still underway, the CLNR project. There are several interweaving research activities in the project which will produce four data types. First, power system monitoring provides data on network performance at sub-stations, this will principally include thermal and voltage ratings. Second, over 12,000 electricity customers across several sub-trials have submitted electricity consumption data through smart meters and secondary monitoring which provide 30 minute consumption data for statistical and mathematical analysis. Third, all customers were invited to complete a survey about their socio-technical context, attitudes to energy consumption and their habits. This has produced a quantitative data set about practices, materialities and meanings and competencies. Lastly, over 220 qualitative, face to face research visits to domestic customers and small organisations have been conducted to study current and emerging practices and the associated energy use. These included energy tours in which appliances and technologies were used to prompt reports and demonstrations of how practice-bundles were temporally and spatially related and how particular devices were used. The semi-structured interview components of the visits follow Hitchins' argument that interviews can be valuable in generating qualitative data about how individuals perform practices but also, and of particular relevance here, to illicit reports about how and why practice-bundles form, how they adapt to interventions (Hitchings 2012).

As part of the CLNR project a time of use tariff was designed to provide a financial incentive to minimise electricity use in the 4pm -8pm period from Monday to Friday. The details of the time of use tariff are set out in Table 1.

Table 1 - Time of Use Tariff Detail

Time Period	**Description**	**Rate**
07.00 – 16.00	Day	4% below standard rate
16.00 – 20.00	Peak	99% above standard rate
20.00 – 07.00	Night	31% below standard rate
Notes: The Night rate applies all weekend (Saturday / Sunday) A standing charge is applied in addition to the per-unit costs		

This paper draws exclusively on the qualitative data from 186 research visits to 123 domestic research participants who were visited in summer 2012 and / or winter - spring 2013. Of these, 32 had volunteered to take part in a 12 month trial of the time of use tariff detailed in Table 1, while the others were involved in other aspects of the project but were asked about time of use pricing. While the CLNR project has created a large and multi-faceted data set it is not our intention here to report on socio-demographic patterns, but rather to scrutinise the qualities of practice entities as they relate to the notion of flexibility[d].

[d] Detailed quantitative analysis of CLNR data, including interview data, is the focus of other forthcoming papers, and project reports. See www.networkrevolution.co.uk for working papers, reports and publications.

A common method used by other researchers for exploring everyday practices has been semi-structured interviews (Gram-Hanssen, 2010a; Halkier and Jensen, 2011; Hitchings, 2012, 2009; Strengers, 2010). These are often used in conjunction with participant observation. Home tours have however become increasingly popular as a method for researching practices, and are now recognised as a valuable mechanism for engaging participants with the technologies and other materialities in their domestic setting and for eliciting more detailed, context sensitive and socio-technically attuned (Gram-Hanssen, 2010a, 2010b; Hargreaves, 2010; Pink, 2005). The research undertaken for this project included both; an opening semi-structured conversation about the home and its occupants followed by a home tour which in turn was followed by a wider ranging semi-structured conversation about households' current and possible future relationship to the grid. This research is on-going and while this paper draws most explicitly on data created through the qualitative energy tours the analysis process has been socio-technical in nature; with questions moving back and forth between the different data sets such that the qualitative work presented here is the product of collaborative inter-disciplinary enquiry. The qualitative data has been analysed using Nvivo qualitative data analysis software using a list of thematic codes generated collaboratively and modified iteratively by the research team as aspects of the project have progressed. The qualitative research has focussed on studying which practices are currently giving rise to electricity consumption in the UK's peak period, which of these are most electrically intensive and in what ways and why customers are currently fixed or flexible in their use of electricity in the 4pm-8pm (peak) period.

Following from the discussion above, a number of practices have emerged as most directly relevant to peak demand management debates. We include in this list practises that would conventionally be referred to as practice-entities in themselves following Schatzki (T. R. Schatzki, 1996; also Shove, Pantzar, & Watson, 2012) and which participants reported as

taking place in the early evening period and which come together in various ways as practice-bundles in different ways and which are in different rhythms in different households. The authors gave each practice or group of practices a score ranging from very likely to very unlikely to reflect the likelihood of being performed between 4pm and 8pm by reviewing the full range of qualitative data collected from participants in all test cells in the CLNR project (n=186) . Part of the interview and coding process was to link time of day with most likely domestic practices where possible which made it possible to make these judgements. Each practice is also associated with ownership levels and power ratings which are taken from the CREST model of domestic electricity consumption (Richardson and Thomson, 2010). These groups of practices were identified by as being of most direct relevance to debates around enrolling customer flexibility into the management of peak demand on this basis, which is summarised in Table 2. Of these practices, we focus in this paper on contrasting the flexibility of laundry and dish washing practices with the relative inflexibility of cooking and dining practices in order to draw out three factors which we argue affect the ways in which practices respond to the intervention of a time of use tariff. We argue that studying how practices such as these respond to and evolve with infrastructural demand management interventions is an important part of optimising future interventions which, "necessitate repositioning and blurring the roles and responsibilities of resource providers and consumers." (Strengers, 2011).

Table 2 - Practices Performed in the Peak Period

Practices	Employed Electrical Appliances	4-8 Peak Likelihood[5]	Group Most likely to use in peak	Typical Electrical Load[6]	Load Band[7]	Mean Duration (mins)*	Proportion of Dwellings with Appliance *[8]	Ownership Band[9]	Peak / Load / Ownership	Rational for possible DSM Contribution
Use of ICT for Leisure	Personal Computer / Console	High	Almost all Participants. Exceptions are shift workers.	0.14 kW	Low	300 min	70.8%	High	H/L/H	Mass participation in peak
Watching TV	TV	Very High	Almost all Participants. Exceptions are shift workers.	0.12 kW	Low	73 min	97.7%	Very High	VH/L/VH	Mass participation in peak
	TV Receiver box	Very High		0.03 kW	Very Low	73 min	93.4%	Very High	VH/VL/VH	
Cooking	Hob	Very High	All participants	2.40 kW	High	16 min	46.3%	Middle	VH/H/M	Load intensity, mass participation in peak
	Oven	Very High		2.13 kW	High	27 min	61.6%	Middle	VH/H/M	
	Microwave	Very High		1.25 kW	High	30 min	85.9%	High	VH/H/H	
	Kettle	Very High		2.00 kW	High	3 min	97.5%	Very High	VH/H/VH	
Dish washing	Dish washer	High	Middle to High income	1.13 kW	High	60 min	33.5%	Low	M/H/L	Load Intensity in

[5] Likelihood based on CLNR qualitative data analysis

[6] All figures (kW, kWh, minutes and % of dwellings are taken from CREST model of domestic electricity consumption other than Central Heating Pump. See http://homepages.lboro.ac.uk/~eliwr/

[7] Load Band Definition: Very Low = <0.99kW, Low = 0.1 – 0.2.99, Middle = 0.3 – 0.99kW, High = 1kw – 2.49kW Very High = >2.5kW

[8] The % of households with an appliance is taken from the CREST model but in future work we will integrate the findings from the social science survey regarding technology ownership.

[9] Ownership Band Definition; Very Low = <10%, Low = 10 - 29%, Middle = 30 – 69%, High = 70 – 89%, Very High = >90% or more

			Households							Peak
Laundry	Tumble dryer	Middle	Busy working couples and families	2.50 kW	Very High	60 min	41.6%	Middle	M/VH/M	Load intensity, possibly in peak
	Washing machine	Middle		0.41 kW	Middle	138 min	78.1%	High	M/M/H	
	Washer dryer	Middle		0.79 kW	Middle	198 min	15.3%	Low	M/M	
Ironing	Iron	Middle	Busy working couples and families	1.00kW	Hig,	30 min	90%	Very High	M/H/VH	Load intensity, possibly in peak
Vacuuming	Vacuum	Middle	Busy working couples and families	2.00 kW	High	20 min	93.7%	Very High	M/H/VH	Load intensity, possibly in peak
Bathing	Electric shower	Low	Shift Workers	9.00 kW	Very High	5 min	67%	Middle	L/VH/M	Split: Load intensity for electric showering and mass participation of child bathing
	Central Heating Pump	Middle	Households with small children	0.6kW	Middle	5 min	90%	Very High	M/M/VH	

4 Contrasting Flexibilities: Cooking, dining, laundry and washing dishes

In the following analysis we draw on the qualitative data, and our experience of conducting the research visits rather to draw out observations about the flexibility and diversity in performances of practice entities which are found to be not equally likely to adapt to interventions – some responded to the tariff intervention while others did so either far less or not at all. Furthermore, there is enough consistency between households for us to conclude that laundry, household chores and dish washing practices were performed differently as a result of the introduction of the tariff intervention while cooking, and watching TV were much less flexible, as illustrated by these excerpts:.

The washer, dryer and dishwasher we haven't been putting on between 4 and 8. (GP1802)

We try and do washing on a weekend or after 8. … The dishwasher doesn't go on 'til after 8 now either … before we got the [IHD/tariff] we would just put it on when it needed to go on … (GP1902)

In contrast, the least flexible of the practices we focussed on was dining, and in particular the evening meal was for the majority of households (but not all) a fixed feature in their early evening:

Interviewer: Do you think you could do anything differently to take advantage of a time of use tariff?

Participant: Obviously, not our tea … but [I] wouldn't put the dishwasher on [between 4-8], or the washing machine or dryer. (GP0028)

Interviewer: Do you think you could do anything differently to take advantage of a time of use tariff?

Participant: With the exception of cooking, I think you'd have to draw the line there. (GDP046-3-D-WIN)

For the grid this means that the considerable loads associated with washing machines, tumble driers, irons, vacuum cleaners and dish washers might be thought of as more flexible loads because of the flexibilities of the practices which employ them. But what is it about these practices that render them flexible while dining is remarkably unresponsive to the tariff? Understanding this will not only help to develop ideas about how to optimise interventions to work with or on these practices, but might also help to identify other potentially flexible practices.

We identify two aspects of practices that affect their flexibility; their (poly)rhythmic qualities and their position in relation to conventions and shared notions of normality. We illustrate these points with excerpts from interview transcripts..

Rhythm Constraints

First, practices entities have different rhythmic qualities and a consequence of this is that entities which have tighter rhythms are reproduced through more homogeneous performances which exhibit less flexibility than those where reproduction is more rhythmically open to improvisation and more variegated. Practices are performed in time and space, and where practices are performed collectively, "they depend on coupling and uncoupling the paths of all 'partners', implying so called coupling constraints." (Ropke and Christensen, 2013, p. 54). This coupling and uncoupling relates to the idea of polyrhythms (Goonewardena et al. 2008; Lefebvre 2004) which overlap in particular places at particular times, with the rhythms of several household members needing to find a shared 'pulse' – a time and place at which the rhythms cross – in order to perform a practice such as family dining. In most homes we studied dining was a co-performed practice and as such required the

coordination of rhythms which extend beyond the home and into schools, work places, and so on. This is not to say that meal times are always archetypal family occasions, but rather to emphasise that they are pinned into place and time more firmly by other spatially extensive time-structures. Røpke and Christensen observe that, "Collective time structures - fixed working times, opening hours for shops, fixed meals times and recurrent television programmes – make coordination [of practices] easier." (Ropke and Christensen, 2013, p. 54). The inverse is also true however; they make flexibility more difficult. Our data suggest that because of the coordination of spatially external polyrhythms of multiple origins required - most often these are working hours, the school day and social commitments – performances of dining are less improvisational in their timing, meaning that as a practice entities cooking and dining are more reproduced across households with less temporal diversity. The result is that they not only play a significant role in constituting the peak in demand but they are relatively unresponsive to interventions design to manage it.

With two kids they have to be fed before they do homework. They tend to be doing homework while I'm cooking. … If I waited it'd be too late for them … (DL07)

I don't know how I could change the way I cook. … No, 'cause [because of] work. … we cook when people are wanting food. (DL13)

Interviewer: Could you cook your evening meal earlier or later than you do currently?

Participant: No. I wouldn't do it. I couldn't do it. Na, Na. Me' grandson comes for his dinner, [he] says "I'll be here 5:45", so I couldn't. (GPML004)

In contrast, laundry and dish washing were often found to be solitary tasks, indeed in most cases a practice performed by a woman, which simplifies the polyrhythmia of their reproduction. As a result there is much less un-braiding (Trentmann 2009) of the practice to be done in response to the tariff intervention as it is does not require a complex and social re-calibration of rhythms. Instead, the practitioner is given an opportunity through the moment of arrhythmia to improvise. Such improvisation was found to take place in the initial period after the introduction of the tariff, with several alternative performances being trialled before more stable performances emerged. This resonates with Higginson's finding that laundry, "could be readily interspersed with other practices" (Higginson et al. 2013, p.10).

"usually on a Thursday … that's my day off. And throughout the weekend. … I get the whole weekend off. Whatever's left over gets cleared up on a Saturday. … Big washing gets done on Saturday, bed sheets that sort of stuff. Saturday or Sunday. Just depending on how it fits together." (GP51)

In some cases, variation in the rhythm of the practice remained in place and variability in when laundry and dishwashing were performed became a feature of laundry practice.

Convention Constraints

The second point to emerge from the analysis is that conventions constrain the improvisational character of performances of practices to differing degrees. Participants described evening meals as inflexible often through reference to what they and society more widely considered to be normal, and as a result conventional and not open to intervention. Participants we spoke to referred to being 'trained', 'programmed' and in some cases reported anxiety and discomfort when asked about

changes to long established and rehearsed performances. Among everyday practices, evening meals appear in our data as perhaps the entity most constrained by convention to the extent that otherwise effective rationales were unable to lead to lasting improvisation. Even for those with no external rhythms to coordinate with, for example retired couples or individuals, the imprints of earlier societally held norms mean that for many it was difficult to imagine changing evening meal times:

Cooking? Well its about 5 o'clock I'm making 'me tea. I know it's the wrong time to do it but what time am I supposed to have me tea!? You program yourself for it don't you. … the point is what time are you going to start making your tea? To me 8 or 9 at night, that's supper. There again if you have it before 4 it's basically an afternoon snack isn't it, it's not tea as far as most people's programming, is it? (GDP032D-3-D-WIN)

I changed from cooking in the evening to lunchtime but I couldn't get my head around that so we've gone back to cooking in the evening. So now we realise if we're using the oven in the evening we have to pay for it. I didn't enjoy it. I didn't enjoy it. … for now I don't mind the cost. (MRJTL10-9-D-WIN)

These quotations illustrate that the conventions associated with some practice entities trumps the economic rationalities that do effect changes in other less heavily socialised entities such as laundry and dish washing practices (Darby and McKenna, 2012). This is evidenced by the many participants reporting laundry and dish washing moving out of the peak period in response to the tariff intervention. In these examples the taken-for-granted (common-) sense of it being normal to want to save money was invoked to explain why the time of use pricing made modifying laundry and dishwashing an obvious and uncontroversial response to the intervention.

My washing I definitely do over the weekend when it's cheaper, unless it's absolute necessity. (MJRTL06)

She'll do washing after 8 o'clock at night when it goes onto the night time tariff, the lower tariff. (GP2702)

The tumble dryer will be used at night time … Even if I have to stop up later or something. I would rather use it at night time than on the peak [tariff] … (GP0025)

While laundry was reported by some participants to be very important to them and there is a clear preponderance of evidence which suggests that strong meanings are attached to laundry practices the time of day at which laundry is performed was not felt to be positioned by social norms or conventions, rather its timing was either more improvisational or idiosyncratic. Participants who had few other time-structures had often created their own wash day, to which they attached great importance, but for those performing laundry in the peak period it was a considered to be a chore that had to be squeezed in to fit with other, stronger rhythms.

Oh, I couldn't stand it. No. Monday is washing. It's folded ready to go out or in. … No, that would knock me to bits. (GPML004)

Once a week. I go right through the house. I'm in on my own so I can get on with it. Washing and ironing as well. All at the same time. … Beginning of the week … that's what I like to do. (EPJ018)

These observations are of importance to the peak demand debate for two reasons. First, it suggests that laundry as a practice entity exhibits considerable diversity in its performances despite its universal presence as an entity in homes of all kinds, and does not always contribute to peak demand. This diversity in daily life has always been built into network design but when considering how networks might co-evolve with practices, identifying practice entities which h exhibit diversity is an important area for new research. Network managers have for decades reliably assumed that homes in a given street, development or town will never be synchronised in their electricity use and have always specified network capacity with this in mind. This assumed heterogeneity is codified as a diversity factor (DF) in network design which specifies the degree to which network operators can benefit from the non-synchronous nature of demand peaks by avoiding over specification and the associated costs. This is particularly true of domestic distribution networks, as research has found that domestic loads exhibit much greater diversity than other types of load (such as industrial or commercial) (Pansini 2005). Opportunities to inform network management interventions that work with diversity but at the higher resolution of practices rather than aggregated 'load' represent important opportunities for social scientists to play a leading role in shaping policy, product and service design.

Following form this, the second point to come from the analysis of data about how laundry is performed is that the flexibility of laundry as a practice entity is inversely related to its likelihood of being performed in the peak such that when performances are fixed they tend not to be in the 4pm - 8pm period, and when they are in the 4pm – 8pm period they are potentially flexible. These qualities mark laundry out as a potential point of engagement for DSM.

Economies

Economies feature strongly in participants' accounts of when and why practices are performed and we argue that dispositions towards and management of social, natural and financial resources and

investments do significantly affect the performances of practice entities in several ways. We recognize that, in line with theories of practice, energy use is not a 'choice' in the conventional terms of market economics. Rather, the decision to use electricity is usually merely a consequence of courses of action – it's time for tea, What do the children want to do now? Is it going to stay dry enough to put the washing out? And so on. We acknowledge that households do not respond in a 'rational' or simple way to prices but at the same time, we do find that ways of managing the home economy and various forms of financial calculation are significant features of everyday life and that they do affect energy use. Our analysis suggests that economies are vital to the ways in which some practices are configured and undertaken. Furthermore, managing the home economy plays an important part in shaping evening electricity use as people undertake various forms of calculation about resources (both financial and natural), the distribution of these resources (over time, between members of a household), and investments (of finance, time, emotion) in their homes.

Relationships between practices are not fixed, rather their recurrent interaction through calculations about economies as well as the affects of rhythms and conventions leads to the reproduction and patterning of social practices in particular contexts, and in turn can serve to create the potential for alternatives. For practices heavily constrained by conventions about timing such a cooking and dining, economies are at work in determining how a meal is prepared – with what ingredients – but economic rhythms were not usually sufficient to cause arrhythmia in dining routines. In contrast, where the rhythmic constraints are more open, as in the case of laundry, the practice can be performed at diverse times and ways as economic disposition of resource efficiency and cost savings has traction in the absence of conflicting norms. These processes work in contextually contingent ways to shape locally specific instances of bundles (Strengers, 2013) or complexes (Shove, Pantzar, & Watson, 2012) of social practices, and result in socio-geographic variegation in the performances of early evening practices.

5 Conclusions

Managing to sustain the energy services needed to enable people to conduct everyday practices in the face of decarbonisation and electrification of energy provision is one of the many faces of the challenges associated with climate change. The vulnerability of the grid itself as it adapts to the emerging realities of renewable generation, rising investment costs has not been a major feature of climate and carbon research until relatively recently. Through analysis of qualitative data about how social practices responded to time of use pricing we have argued that finding flexibility in everyday life is not a straightforward matter and more specifically for the demand side management (DSM) debates that accompany smart grid discourses, that flexibility varies between practice entities and also between performances of particular practices. We argue that the rhythmic qualities of practices and the degree to which there are socially conventional times and ways to perform particular practices can constrain or open up their ability to adapt to interventions.

Furthermore, we identify that despite valuable work and emphasis on the socially shared nature of practices and their convergence over time in many important ways (see Shove 2003 for example), there are significant differences between how practices like cooking and dining on the one hand and laundry and dishwashing on the other are reproduced and that these differences represent apertures for insight and interventions that could be better targeted than current kWh-based market offerings which are blind to end-uses and seek to segment consumers rather than socio-technical practices. In line with arguments made by Schatzki (2013) and Hitchings (2013) we suggest further research in this area should experiment with socio-technical interventions which go beyond price signals to enable the emergence of new ways to connect practices with grid actors and other stakeholders.

Implications for industry and policy makers include thinking about how interventions and services can be aimed at potentially flexible practices, such as laundry, dishwashing. Alternatively, practices inhibited by tight rhythmic constraints or social conventions could be reconfigured in different ways, for example by energy services which do not challenge their timing or sense of normality but which use differently configured socio-technical capacities to enable peak demand reduction – such as the use of different cooking technologies, such as slow cookers, to enable people to eat together in the evening but without contributing to evening electricity use. These suggestions have in common an emphasis on services that engage with the rhythms, conventions, economies and capacities of practices and those who perform their reproduction – their humans.

We argue that time of use pricing can have some effect on these by changing the economic implications of what it means to perform practices at certain times, in certain ways (slow cookers rather than micro-waves) and using certain resources (gas rather than electricity). Because of the ability of price incentives to affect how some practices are reproduced we conclude that time of us pricing can play a part in a suite of policy and grid management tools but the inevitable diversity and improvisational character of practices and their multiple rhythms, conventions and economies mean that diversity must continue to be central to network planning. While diversity factors have been used to average out diversity across networks, going forward diversity must be a feature of DSM offerings in order to enable different practices to find ways to co-evolve with the smart grids in different ways. However, pricing and commodity supply (kWh) offerings are limited in their ability to engage practices as not only do they re-enforce the status quo of constructing individual consumers as the agents of change whose interests are best served by providing choice, they only imprecisely target the most receptive practices which could be far more radically altered through practice-aligned interventions. Examples of practice-aligned interventions could include, for example, laundry-specific grid-engaged services like a launderette that used stored, solar-heated hot water to clean clothes which could provide services both to communities and to those managing the

distribution network. More generally, we argue that identifying existing forms of flexibility in electricity use will require different forms of stakeholder relationships between networks, electricity users and other local actors such that the network operator comes to understand the breadth of different ways in which laundry, as a relevant example, is being reproduced in a given community and that there is scope to alter this generative process to create local varieties of laundry or other appropriate practices which are attuned to and which will co-evolve with the network as a feature of the, "webs of social and material structures which frame present and future practices" (Ropke & Christensen 2013, p.51). This is a period of considerable potential change in the energy sector with households being re-cast as co-managers of power systems, suppliers re-cast as buyers of flexibility and regulators openly moving out of a period of free-market fundamentalism (Helm, 2007; Rutledge and Wright, 2010) toward an uncertain future of experimentation, innovation and market re-design. In this context we now, more than ever, need to understand the uses to which power is put, and the ways in which the day to day reproduction of social practices might adapt to interventions which aim to re-constitute the grid. We suggest that further research in this area should include participatory action research (PAR) to explore opportunities for new, locally specific ways of configuring grid – practice – practitioner relations (Kindon et al. 2007) through social interaction through practices.

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