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Core capacity

INTERROGATION OF SAVE DATA & SOCIAL SCIENCE LITERATURE REVIEW

INFORMING POSITIVE CHANGE

SSEN

Core Capacity
Interrogation of SAVE data & social science literature review

VERSION	DATE	VERSION SUMMARY	APPROVALS
R1	28.06.2019	First issue	Principal authors: Helen Snodin, Jacopo Torriti, Mary Anderson, Emma Jones & modelling by Timur Yusunov
			Approved by: Emma Jones

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Executive Summary

This report covers a wide range of issues on the concept of core capacity and capacity charging, exploring areas for discussion and development should the concept be taken further. It has been written as a follow-on from our work for Citizens Advice, which is very much focused on Ofgem's Network Access and Future Charging Review. Specifically, Citizens Advice asked three questions – could a capacity limit be set; what might it be; and how might it be implemented? In seeking to answer the second question, we have drawn on three Ofgem innovation-funded Distribution Network Operator (DNO) projects with smart meter data, of which Scottish and Southern Energy Network's (SSEN's) Solent Achieving Value from Energy Efficiency (SAVE) has been one.

The SAVE data offered additional scope for exploring questions around household activities and characteristics, through enhanced survey data collected from participants and time-use diaries. SSEN is keen to contribute to the debate and capitalise on the use of SAVE data for real-world application. As well as interrogation of SAVE data, SSEN has commissioned us to develop some of the more social angles on capacity-based access and charging – through a literature review and commentary on some of the more vulnerable groups of consumers.

The two reports, for Citizens Advice and SSEN, should be read together – the former introducing the concept of core capacity and its derivation, the latter looking more widely at the social side and extracting value from the SAVE data.

Literature review

Setting a capacity core or cores links into issues of basic need, as well as the timing of energy services and sufficiency under different circumstances. There is a branch of social science literature which has been seeking to define services, needs and sufficiency which we review here for insights into energy use. Using Joseph Rowntree's Minimum Income Standard, we have been able to establish the electrically-powered appliances that households need to maintain their basic needs and function in society as social beings. From this we have derived maximum power requirements for different household compositions.

Fixing a level of core capacity is not straightforward because services and needs change, as do technologies. Future-proofing core capacity implies taking account of demand-side technological developments, such as the electrification of vehicles and heating and the growth of domestic microgeneration coupled with storage.

We also review international experiences of progressive and social tariffs for domestic electricity users. This follows on from our review on capacity limits and tariffs for Citizens Advice, drilling down to explore: tariffs which reward efficiency of use; and tariffs with built-in protections for low income and other disadvantaged groups.

Progressive tariffs, for example in California and Italy, date back to the 1970s and aim to promote energy efficiency. More recently, new business models are starting to break the link between consumption volume and cost, including in the UK. Explicitly social tariffs do also exist, but appear to be less common.

Interrogation of SAVE data – further findings on core capacity

Analysis of SAVE data for Citizens Advice found that household's peak capacity (95th percentile) ranged from 2kW for low income gas-heated households to 4.5kW for very high income consumers. In this report we further analyse differences for households with low carbon technologies (LCTs) and energy efficiency measures.

There is no clear association between energy efficiency measures installed and peak demand. This is perhaps unsurprising given that energy efficiency measures are largely targeted at reducing heating requirements, and that for most households this is provided by gas. Whilst SAVE data does shed some light on the impact of LCTs on household peak demand, the sample sizes are small and this would benefit from further monitoring and analysis. In summary:

- Electric vehicles (EVs) in the SAVE sample are having no impact on household peak demand, which we assume (but do not know) is due to these households slow-charging overnight using a low capacity charger;
- Heat pumps (HPs) are having a significant impact on household peak demand, with the morning heating peak overtaking the evening peak; and
- Peak photovoltaic (PV) output is matching the evening peak, but at the wrong time.

We have also explored the impact of selecting a core capacity value by analysing the occurrence of peak household values. 3kW broadly aligns with the most common household capacity limit in other countries and with the majority of gas-heated households in the UK.

- At 3kW, all income groupings show peaks outside 3kW, up to greater than 20kW, suggesting the need to change behaviour or pay extra to stay within the limit.
- Electric-heated households show a flat distribution of peak values between around 3-7kW which supports the need for a differentiated core capacity for these customers.

Interrogation of SAVE data – timing of household demand peaks and associated activities

Activity data from SAVE has allowed us to understand what people are doing at periods of high and very high demand. We had hoped to be able to analyse what, if any, activities are flexible, but this has not been possible due to limitations of the time-use diary data. The key findings confirm that:

- Cooking and showering are the key electricity-using actions associated with household demand spikes at any time of day.
- Despite changes in working patterns, the evening peak remains a feature of most households and there are no surprises in what people are doing at this time – cooking and relaxing.

Core capacity - implementation

Core capacity could be introduced to ensure energy bills remain fair and cost reflective, but there is the potential for disproportionate impacts on vulnerable and disadvantaged consumers. Existing protections could be adapted, as well as new protections introduced.

There will be a need to consider consequential changes from reform of the structure of charging. This might include how policy costs are passed through to consumers, the structure of any future price caps and updating of relevant network planning standards. There will be a need to monitor and future-proof core capacity levels.

Lessons and further work

SAVE data has helped us to generate insights into the application of a concept like core capacity. The combination of 15 minute resolution meter data alongside household-matched survey information and time-use diaries is extremely powerful. Some areas for future consideration include:

⇒ There are clear income-related effects on peak capacity and, at the same time, new business models are offering households rewards for shifting or reducing demand. There are questions of parity here, where lower income households don't have the luxury of avoidable consumption. Charges for additional capacity may go some way to addressing this.

⇒ Time-use diaries generate extremely valuable data but are difficult to get in a format which provides comparable, complete and accurate data for an entire household. There is scope for improving our understanding of the day-to-day workings of households, but recruitment of participants willing to (in some way) record activities 24/7 is inevitably challenging.

⇒ There is a need to gather more and ongoing data on the impact of LCTs on household demand, and to collect information which aids interpretation – rated capacities of the new technologies, noting combinations of LCTs and household characteristics.

⇒ The impact of energy efficiency on electrically-heated households would also benefit from further study.

1 Introduction

CAG Consultants, working with Professor Jacopo Torriti and Doctor Timur Yunusov, have been commissioned by Scottish and Southern Energy Networks (SSEN) to expand on our core capacity research for Citizens Advice. This report and our sister report for Citizens Advice are being published together. The Citizens Advice report[1] provides a description of and background to, the concept of core capacity and why it is of interest.

The current commission draws on SSEN's recently-completed five year Solent Achieving Value from Energy Efficiency (SAVE) project, funded under Ofgem's Low Carbon Networks Fund. Residential energy data has been analysed to gain further insight into household peak capacity requirements, and to develop the conversation on commercial and regulatory implications.

There are three parts to the work: a literature review; interrogation of SAVE domestic monitoring data (hereinafter referred to as smart meter data, although note that SAVE did not use Supplier data) and time-use diaries; and commercial / regulatory and consumer impact implementation issues.

1.1 Literature review

The literature review is split into three parts:

Setting a capacity core or cores links into issues of basic need, as well as the timing of energy services and sufficiency under different circumstances. There is a branch of social science literature which has been seeking to define services, needs and sufficiency. The first part of our literature review, Section 2, examines this body of evidence.

Secondly, fixing a level of core capacity is not straightforward because services and needs change, as do technologies. Future-proofing core capacity implies taking account of demand-side technological developments, such as the electrification of vehicles and heating and the growth of domestic microgeneration coupled with storage. We consider international experiences of maintaining capacity limits and capacity charges in Section 3.

Finally, in Section 4, we review international experiences of progressive and social tariffs for domestic electricity users. This follows on from our review on capacity limits and tariffs for Citizens Advice, drilling down to explore: tariffs which reward efficiency of use; and tariffs with built-in protections for low income and other disadvantaged groups.

1.2 Analysis of SAVE data

SSEN's SAVE project has recruited just over 4000 households across the Isle of Wight and the Solent mainland. Smart meter data is available for control and intervention groups. Participants were also asked to fill in detailed questionnaires, providing information ranging from income levels to installation of energy efficiency measures. 15 minute time-use diaries are also available for periods in which residents participated in demand reduction and demand shifting trials.

[1] Snodin, Yunusov, Torriti, 2019. Consumer network access, core capacity. For Citizens Advice.

We have interrogated this data, focusing on understanding how household activity relates to electricity demand, and how electricity demand varies with the installation of energy efficiency and low carbon measures. Our analysis is presented in Sections 5 and 6.

1.3 Implementation

The Citizens Advice report looks at practical issues on implementation of core capacity and capacity charging, with reference to smart meter functionality. It looks at changing the access and charging rules through industry code changes, as well as whether there could be voluntary action by Suppliers.

In Section 7 of this report, we consider consequential regulatory and policy implications around supplier levies, data access and system planning. We also, in Section 8, expand on ethical and social issues that are touched upon in the Citizens Advice report.

1.4 Conclusions

Finally, in Section 9 of this report we summarise key findings and reflect on lessons learnt and further work required.

2 Social science literature

The concept of core capacity envisages an amount of electrical power that cannot readily be flexed and which would provide for consumers' everyday needs. Capacity-based charging might mirror this concept of an affordable level of 'core access' above which charges would be more targeted on those consumers responsible for the costs.

In this section, we examine the social science literature base to establish if it is possible to determine what this amount might be, based on a household's basic needs. We make no judgement on whether this would be desirable and note that it would be a complex undertaking. Social science does, however, include a line of enquiry covering the question of basic need, and there are examples where this has been translated into policy outcomes.

2.1 Energy services

People do not consume energy in the same way that they eat food or drink water. People do not directly handle, control or interact with electricity as they do with a kettle, a TV set or a radio. Energy powers appliances, ventilation, lighting and heating. The direct benefit is not from energy *per se*, but from the services that it provides. Therefore, energy services are usually defined as the benefits which electricity provides.

Social science work on energy services originates from the work of Lovins. About 40 years ago, in putting forward the case for a more effective approach to planning electricity infrastructure, he noted that the qualities of supplied energy did not matter to consumers so long as their needs were still met[2]: *"People do not want electricity or oil, nor such economic abstractions as 'residential services,' but rather comfortable rooms, light, vehicular motion, food, tables, and other real things"*.

The term 'energy service' was then used by Rester and Devine to mean what is "*measured in units of work, of heat at various temperatures, etc., but these quantities are merely surrogates for measures of the satisfaction experienced when human wants are fulfilled via the direct use of energy*" (Reister and Devine, 1981, p. 305). The cost of energy services will vary depending on the fuel which provides such services. Energy efficiency reduces the cost of services or, it increases demand for services within the same cost[3].

A review of energy service definitions[4] shows how the term is used in two ways. First, examples of outputs which can be defined as energy services include lighting, heating, motion and sound. Appliances like washing machines and computers are needed to form combinations of these outputs. Second, the benefits that energy services provide or facilitate are the "*real things*" that are demanded directly or indirectly in the course of everyday life. These real things include comfort, getting to work, sending an email or going on holiday. These are defined as "*end services or states.*" For example, lighting (energy service) is used for the purpose of seeing at night (end

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2 Lovins, A. (1976) Energy strategy: the road not taken. Foreign Affairs, 1, pp. 65-96.
3 Herring, H. and Roy, R. (2007) Technological innovation, energy efficient design and the rebound effect. Technovation, 27, pp. 194-203
4 Fell, M. J. (2017) Energy services: A conceptual review. Energy Research & Social Science, 27, pp. 129-140.

service). Heating (energy service) is undertaken as a means to achieve thermal comfort (end service).

In the two sections below, we expand on both energy services and end services.

2.1.1 Grouping energy services

Table 2.1 is adapted from the literature[5] and groups energy services by end service and time criticality. It does not include luxury items (e.g. hot tub) nor future electrification of transport, where further study is required.

Lighting, heating and cooling of spaces relate to comfort and are related to frugality – for environmental and financial reasons. Seasonality affects the daily rhythms of lighting and heating, which are otherwise inflexible: light and warmth are necessary services.

Cooking, eating and leisure activities play an important role in shaping and maintaining social bonds between members of a household. This makes the timing of food and entertainment – for example, at what times people eat together – a matter of (often complex) coordination between household members with energy considerations likely taking a back-seat. Electricity intensive forms of entertainment like watching TV and video gaming are two more examples of inflexible services during which people relax and not thinking of energy issues

Domestic cleaning represents a separate category of activities most commonly associated with running a household. 'Good' cleaning involves a certain frequency, care, thoroughness, and to a lesser extent, frugality. 'Cleanliness' services vary in rhythm, ranging from daily, to weekly to monthly; social interaction is a key factor in the timing of cleaning, because it is often followed by social interaction (i.e. cleaning the house before visitors arrive)[6]. Domestic cleaning services, such as laundering, are relatively flexible in time.[7]

Table 2.1 Groups of services, appliances involved and issues around timing

Groups of Services	Appliances involved	Issues around time
Lighting, heating and cooling spaces	Lighting, radiators, HPs, air-conditioning	Light and warmth required Timing is critical
Cooking, eating and leisure activities	ICT, audio/video, kitchen appliances, electric cooking	Timing is critical Comfort and control are significant
Domestic cleaning	Dishwasher, washing machine, tumble dryer, vacuum cleaning, ironing	Timing is not critical

5 Smale, R., van Vliet, B., Spaargaren, G. (2017) When Social Practices Meet Smart Grids: Flexibility, grid management and domestic consumption in The Netherlands. Energy Research & Social Science 34, 132–140

[6] Torriti, J. (2017) Understanding the timing of energy demand through time use data: time of the day dependence of social practices. *Energy Research & Social Science*, 25. pp. 37-47.

[7] Jack, T. (2016) Cleanliness and consumption: exploring material and social structuring of domestic cleaning practices. *International Journal of Consumer Studies* 41 (2016) 70–78

Table 2.2, again adapted from the literature,[8] expands on how services relate to specific appliances and the proportion of dwellings with these appliances. It makes use of information in Table 2.1 to suggest which services are time critical.

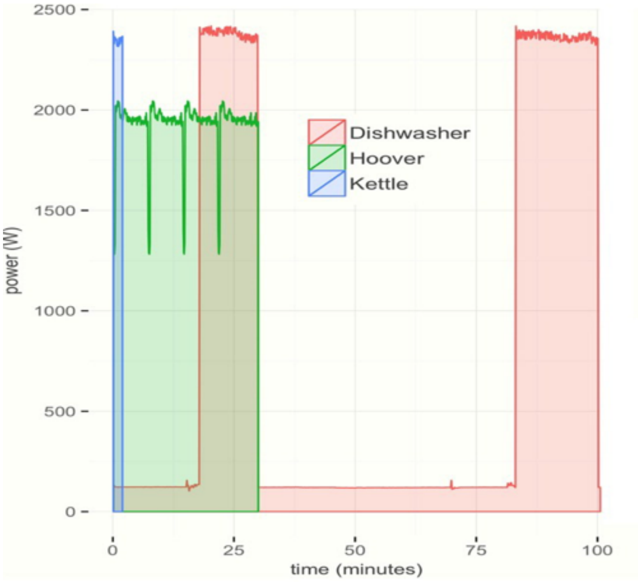
Table 2.2 Services and related appliances, including electrical load, proportion of dwellings with appliance and time criticality

Services	Electricity appliances	Average power demand (kW)[9]	Proportion of dwellings with appliance (%)	Time critical
Preparing food and washing the dishes	Hob	2.40	46.3	Yes
	Oven	2.13	61.6	Yes
	Microwave	1.25	85.9	Yes
	Kettle	2.00	97.5	Yes
	Dishwasher	1.13	33.5	No
	Fridge freezer	0.2	NA	No
Washing	Electric shower	9.00	67	No
	Central heating pump	0.60	90	No
Cleaning	Vacuum	2.00	93.7	No
Washing clothes	Tumble dryer	2.50	41.6	No
	Washing machine	0.41	78.1	No
	Washer dryer	0.79	15.3	No
	Iron	1.00	90	No
Watching TV and listening to the radio	TV	0.12	97.7	Yes
	TV receiver box	0.03	93.4	Yes
	Radio	n/a	n/a	Yes
Using computer	Personal computer	0.14	70.8	Yes

When discussing energy services in relation to core capacities, time criticality is a key consideration. Clearly not all appliances, lighting and heating are 'on' at the same time. By way of example, Figure 2.1[10] illustrates the power and use duration of a dishwasher, hoover and kettle.

[8] Powells, G., Bulkeley, H., Bell, S., & Judson, E. (2014) Peak electricity demand and the flexibility of everyday life. *Geoforum*, 55, 43-52.
[9] This is based on the average power demand of devices in Powell et al. (2014) study, which consisted of 186 UK homes.
[10] Herrmann, M. R., Brumby, D. P., Oreszczyn, T., & Gilbert, X. M. (2018). Does data visualization affect users' understanding of electricity consumption?. *Building Research & Information*, *46*(3), 238-250.

Figure 2.1 Power demand and time-of-use for dishwasher, hoover and kettle



2.1.2 End services

Energy services, as defined above, do not always support 'end services'. Taking the example of cooling, for instance, when room temperature in a building falls within a certain (limited) range, this does not guarantee comfort. The room may be unoccupied; or those who are in it might find it too warm, depending on how they are dressed. Energy services like heating are not inherently useful. Instead, 'end services' are useful in understanding the benefits that energy provides. 'End services' are important, but they have rarely been analysed empirically in the literature. Specifically, comfort tends to be neglected analyses of services, such as the Domestic Energy Factfile and Housing Surveys.[11]

End or final services are categories of consumption that can be achieved in more and less efficient ways, commonly including communication, illumination, hygiene, sustenance or nourishment, mobility or transport, shelter or structure, and thermal comfort[12] (Cullen and Allwood, 2010). Such services are characterised in various ways[13], but there is a tendency to interpret them as enduring and universal types of 'need', desire or function that are always present in some form and that must be satisfied in some way.

Anthropologists talk about 'cultural services' which have cross-cultural variations in the meaning of concepts like cosiness and cleanliness.[14] Sociologists consider end services like comfort and cleanliness as key to sociotechnical change in everyday forms of consumption.[15] According to

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[11] https://www.gov.uk/government/collections/domestic-energy-fact-file-and-housing-surveys
[12] Cullen, J. M. and Allwood, J. M. (2010) The efficient use of energy: Tracing the global flow of energy from fuel to service. *Energy Policy*, 38, pp. 75-81.
[13] Roelich, K., Knoeri, C., Steinberger, J. K., et al. (2015) Towards resource-efficient and service-oriented integrated infrastructure operation. *Technological Forecasting and Social Change,* 92, pp. 40-52
[14] Wilhite, H., Nakagami, H., Masuda, T., et al. (1996) A cross-cultural analysis of household energy use behaviour in Japan and Norway. *Energy Policy,* 24, pp. 795-803.
[15] Morley, J. (2019) Energy Services. In: Rinkinen, J., Shove, E. and Torriti, J. (eds.) Energy Fables: Challenging Ideas in the Energy Sector. Earthscan. Routledge, pp. 15-27.

such views, end services are "*composite accomplishments generating and sustaining certain conditions and experiences*."[16] So, potentially, there are no fixed or universal 'needs'; instead they vary culturally and over time.

For example, concepts of comfort are shaped by the technologies that enable them. It is not uncommon today for people to attribute their own experience of indoor comfort to heating or cooling systems, almost 'forgetting' what they are wearing or what they are doing. The tendency to equate comfort with the operation of heating and cooling is something that has evolved over time alongside the technology.[17]

In terms of core capacity, this means it needs to be culturally relevant and future-proofed. An example of the former is the Minimum Income Standard for the UK, discussed in the following section. Future proofing is considered in Section 3.

2.2 Needs (and wants)

In order to quantify a core capacity of electricity demand which is based on basic energy services, a starting point is to identify basic needs. There is non-energy related literature on basic needs, which assumes these can be distinguished from wants. Basic needs have been classified as follows:[18]

- Nutritious food and water
- Protective housing
- A non-hazardous work environment
- A non-hazardous physical environment
- Safe birth control and child-bearing
- Appropriate health care
- Security in childhood
- Significant primary relationships
- Economic security
- Physical security
- Appropriate education

These basic needs can then be mapped across to products and activities which fulfil the need, with an example given in Table 2.3.[19]

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[16] Shove, E. (2003) Comfort, cleanliness and convenience: the social organization of normality, Oxford; New York: Berg.
[17] Gram-Hanssen, K., Christensen, T. H. and Petersen, P. E. (2012) Air-to-air heat pumps in real-life use: Are potential savings achieved or are they transformed into increased comfort? Energy and Buildings, 53, pp. 64-73.
[18] Doyal, L. and Gough, I. (1991) A theory of human need. New York, Palgrave Macmillan.
[19] Thomas, S., Brischke, L. A., Thema, J., & Kopatz, M. (2015). Energy Sufficiency Policy: An evolution of energy efficiency policy or radically new approaches?.

Table 2.3 Categories of basic needs and how they translate to demands, needs and wants

basic needs/area of care economy production	demands, needs, desires/care economy domain
adequate food provision	storage, cooling, freezing food preparation
adequate provision of cleanliness/hygiene	clothing hygiene/washing clothes drying dish-washing housekeeping personal hygiene
adequate lighting	lighting
adequate room climate	heating/cooling (air conditioning) ventilation
leisure/entertainment/information/communication	leisure/entertainment/information/communication

Traditionally, a basic need is seen as absolute, the minimum physical requirement for human survival. However much of the social science literature on 'energy 'sufficiency' (see next section) suggests that energy services are not fixed or that they are destined to rise.[20] On the contrary, services could be reduced (smaller TVs, lighter and slower cars) or serviced by less energy-intensive activities (using a bicycle instead of a car, buying more fresh instead of frozen food, playing boardgames instead of watching television).

Estimating a core level of electricity power demand which is derived from basic energy requirements implies the separation of needs from wants. On the one hand, this distinction is not straightforward. Complex debates have been had around whether there is a distinction between human needs and wants, and if so, how this can be defined. On the other hand, and on a more practical note, decision-makers often have to face questions about where to draw the line between needs and wants: what is essential and what might be desirable. In policy areas other than energy, judgements around needs and wants are made regularly.[20]

So there are examples in which distinguishing needs and wants by social consensus has been shown to be possible. There has been little debate about whether expert or public judgement should define energy or energy service needs. Consensus on what needs and wants are can be a useful input to policy, but it still is difficult to define. The Minimum Income Standard (see Section 2.3.1) shows that it is possible to reach social consensus on what minimum needs are in a given time and place, and that this consensus may be stable, at least over the short to medium term.

Core capacity based on needs would need to be revisited every so often not only because needs (and wants) evolve with time, but also because there will be improvements in energy efficiency.

[20] Darby, S. (2007). Enough is as good as a feast–sufficiency as policy. In Proceedings, European Council for an Energy-Efficient Economy. La Colle sur Loup

2.3 Energy sufficiency

Energy sufficiency at the household level has been defined as the "*state in which people's basic needs for energy services are met equitably and ecological limits are respected*."[21] In this brief review of the energy sufficiency literature, we aim to capture studies which provide estimates of how much is sufficient.

A focus on services offers the best prospect of achieving sufficiency in terms having enough and not using too much. For example, in commercial buildings the most serious policy challenge is probably the spread and normalisation of cooling as a service. This then goes hand in hand with the growth in buildings that are uninhabitable without air conditioning. There are massive implications for both electricity demand and power capacity.

The academic debate around energy sufficiency (i.e. how much is enough) is paralleled by discussions about 'energy decadence' or 'energy excess' .There is a consensus that the quest for 'energy sufficiency' – a level of energy use that is both fair and sustainable – should involve not only 'floors' (enough for a necessary purpose) but also 'ceilings' (too much for safety and welfare, in the short or long term). Core capacity limits can address some of the ceiling issues from a capacity perspective as they could disincentivise excess consumption of electricity at any particular time.

Various versions of Figure 2.2 below (adapted from the literature[22]) are often displayed as part of the sufficiency literature. These can be explained in four steps as follows:

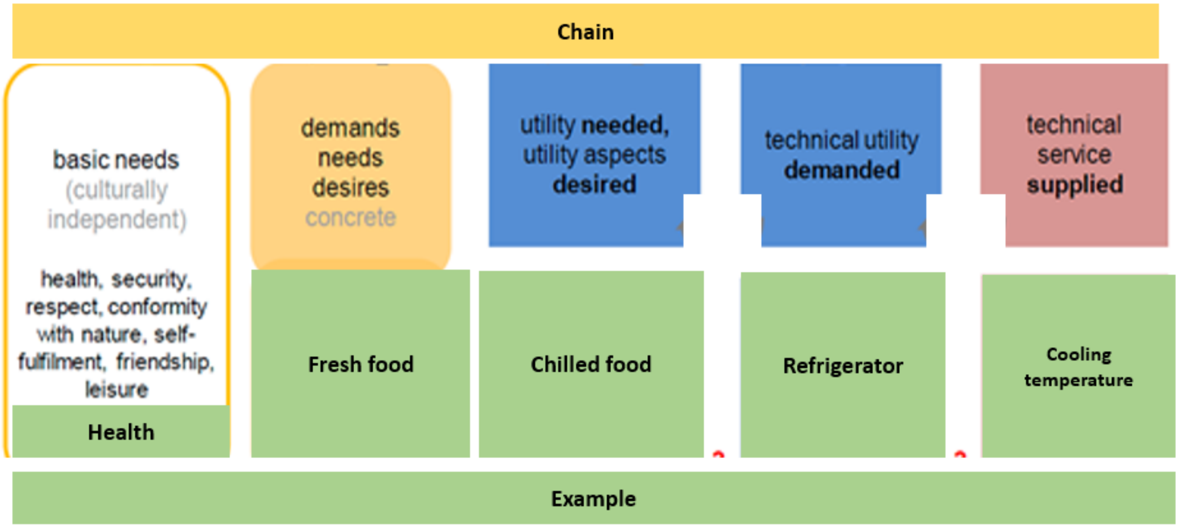
- Step 1: Basic needs (e.g. health) become concrete needs and desires (fresh food).
- Step 2: Demands, needs, and desires are transformed and concretised into utility needed (chilled food) and utility aspects desired (e.g. certain amount of chilled food at home).
- Step 3: The aspects are then transformed into the demanded technical utility (a refrigerator).
- Step 4: The demanded technical utility is met by the service supplied by the corresponding appliance (cooling temperature).

Applying these concepts to core capacity involves distinguishing between needs and wants, moving from abstract concepts to particular descriptions and numbers and applying these to individual (or groups of) households. This is similar to setting energy service standards in housing. The boundary between needs and wants could be set in terms of a current socially acceptable minimum (as in the Minimum Income Standard approach described in Section 2.3.1). Another starting point could consist of identifying luxury or high personal consumption. For example, leisure air travel is not included in basic needs. However, campaigners seeking to

[21] Darby, S. and Fawcett, T. (2018) Energy sufficiency – an introduction. Concept paper for eceee.
[22] Brischke, Lars-Arvid, et al. (2015) Energy sufficiency in private households enabled by adequate appliances. Wuppertal Institut für Klima, Umwelt, Energie, https://epub.wupperinst.org/frontdoor/deliver/index/docId/5932/file/5932_Brischke.pdf

reduce air travel suggest making a distinction between frequent flyers, and other flyers, with one tax free flight per person per year – suggesting this is a basic entitlement.[23]

Figure 2.2 Causal chain of transformation from basic needs to technical service supplied, energy sufficiency approaches



Consumption limits should be defined not only on an individual level, but also on a societal one.[24] Defining limits of resource- and energy-intensive behaviour is one of the most difficult and debated aspects of sufficiency. Even though there might be a broad consensus in the literature of the existence of certain thresholds, determining these thresholds is highly contested. Most of the empirical literature on sufficiency thus far has focused on energy (kWh) rather than capacity (kW). Some examples are provided below.

2.3.1 The minimum income standard

The Joseph Rowntree Foundation has sponsored research on incomes required to reach a minimum, socially acceptable standard of living in the UK today.[23] This Minimum Income Standard (MIS) is calculated by specifying 'baskets' of goods and services required by different types of household in order to meet these needs and to participate in society. The minimum is defined, based on consultation with communities, as more than just, food, clothes and shelter. It is also about access to opportunities and choices necessary to participate in society.[25]

The original research for the MIS was carried out in 2007 and findings presented in 2008, using April 2008 prices. Every July, new MIS figures are published in the UK reflecting not only inflation but updates to the list of minimum needs, drawing on two-yearly primary research. This process

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[23] Davis, A. K., Hill, D. Hirsch and M. Padley (2016) A minimum income standard for the UK in 2016. York, Joseph Rowntree Foundation.
[24] Princen, T. (2003) Principles for sustainability: From cooperation and efficiency to sufficiency. *Global environmental politics*, 3(1), 33-50.
[25] Padley, M. and D. Hirsch (2017) A minimum income standard for the UK in 2017. York, Joseph Rowntree Foundation.

ensures that the MIS is continuously refined to reflect social and economic change, although the overall pattern of minimum household requirements has remained relatively stable since 2008.[23]

The researchers note "…*a minimum is about more than survival alone. However, it covers needs, not wants; necessities, not luxuries – items that the public think people need in order to be part of society.*"[25] The social aspect of this definition is noteworthy, bearing some relation to the 'capability' approach to wellbeing and the need to function as a social being.[26] The assessment of minimum standards for household energy use in the MIS (see Box 1) relies heavily on expert rather than lay judgement. A fuel expert calculates energy requirements for cooking, lighting, heating etc. based on typical room dimensions and insulation levels for housing relevant for each of a number of household types and sizes.[27] Estimates are in yearly kWh consumption. The standard of energy services used in the modelling is not explicitly stated and was not opened up for discussion by researchers or the research participants during the process of drawing up the standard.

Items discussed during consultation, but which are excluded from the budgets comprise: dishwasher and tumble dryer (other than for large families), games console, and high-end smart phones. The rationale for these exclusions rests in the distinction between needs and wants as cost-effective ways of "*living life in a practical way*".

BOX 1 – Energy in the Minimum Income Standard

Heating: it is assumed that typical housing has gas central heating with a radiator in each room. In 2014 working age singles and single and partnered pensioners were associated with an additional small electric heater as a backup in case of failure of the central heating system. This is also supposed to be used occasionally as an alternative to heating a whole flat.

Lighting: a central light fitting in each room for all budgets. In addition each householder has either a lamp either for softer lighting or, in the case of pensioners, additional direct lighting for reading.

Home entertainment: a 32" television with built-in Freeview for all budgets and in households with a secondary school aged child a second smaller television (19") with an integral DVD player. Pensioners' budgets include a small analogue radio.

Computers and internet: provision of computer to all households in working age.

Communications: each member of households with parents and secondary school children with basic mobile phone.

Kitchen: cooker, fridge, freezer, kettle, microwave oven, toaster.

Cleaning and laundry: washing machine, vacuum cleaner, iron, tumble dryer only for households with three or more children.

Personal care: women and secondary school girls' budgets include hair dryer and straighteners.

Bedrooms: portable CD/MP3 player for households with children in secondary school children.

[26] According to Darby and Fawcett (2018), 'sufficiency in terms of demand reduction takes attention away from the need to ensure adequate energy services for people who do not yet have them. That is, sufficiency can be understood in terms of social wellbeing and equity'.

[27] Davis, A., Hirsch, D., Padley, M. and Marshall, L. (2015) How much is enough? Reaching social consensus on minimum household needs. Loughborough, Centre for Research in Social Policy, Loughborough University.

For the ten years over which this definition has been reviewed in the UK, perceived needs did not increase significantly and some decreased. However, this has been a period of low economic growth and austerity in public services). Over longer time scales we might expect the minimum needs identified to increase. This example seeks to cut through much previous debate about what can legitimately be considered a need within a society, by asking the members of that society to make a collective judgement about what to include. It enables and records public discussion that produces not just lists of agreed necessities but a set of rationales that tell us why certain items are included and others are not. Such discussions could themselves be seen as part of a process of creating and maintaining a sufficiency-based society.

2.3.2 Minimum policy and legal standards

In areas where absolute needs have been agreed and adopted into policies and standards, these have typically been set by experts. Public Health England's[28] (2014) guidance for minimum indoor temperatures in winter is an example of expertise-driven setting of minimum acceptable levels. The literature indicates that, despite arguments against the existence of objective human needs, everyday language suggests that laypeople instinctively feel that they do exist and can be identified.[27]

A core capacity could include derivation of energy needs from legal minimum standards. Such standards are generally designed for people to thrive and carry out their work satisfactorily, but there is arguably a need to revisit these in order to assess their fitness in different situations (e.g. Energy Performance in Buildings Directive definitions of comfort; the adequacy of Energy Performance Certificates as a predictor of consumption).

2.3.3 2000 Watts Campaign

One example of sufficiency that is expressed in capacity terms is the Swiss 2,000 Watt society.[29] Similar to campaigns for personal carbon budgets, which seek to rebalance global inequities, this is a project whose ambition is to reduce the a Swiss person's yearly average requirement of 6,000 Watts to the global average of 2,000 Watts.

2.3.4 Austrian Energy Regions

The Austrian energy regions, also known as Climate and Energy Model Regions, are 'organizations who envision energy self-sufficiency by using regional energy sources and by building a decentralised energy infrastructure'. Launched 'bottom up' by local people, the regions are small in size, undertaking a range of actions from advice to householders and businesses to investment in low-carbon transport infrastructure such as cycle lanes. The energy regions are expected to deliver a range of social, economic and environmental benefits (such as those in the inner ring of the doughnut), to municipalities, businesses and residents[30] (Fritz 2017).

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[28] Public Health England (2014) Minimum home temperature thresholds for health in winter - A systematic literature review. London, Public Health England.
[29] 2000-Watt society. https://www.stadt-zuerich.ch/2000-watt-society
[30] Fritz, M. C. (2017) Energy efficiency in Austrian Climate and Energy Model Regions. INBEE project: Publication on case studies, report D 4.2, http://in-bee.com [Accessed April 2019]

2.4 Core capacity implications – summary

We have found that there is a body of literature and branch of social science that considers the concept of sufficiency or basic need. There are examples of this being applied to energy, where the focus is on the 'end services' that energy provides. Neither the energy inputs which provide these services, nor the definition of need, remain constant – the former changes with technology and the latter with cultural norms.

Translation of basic needs into policy or regulation is of course difficult and inevitably risks controversy. There are examples of minimum regulated standards such as indoor working temperatures, but even then different people feel comfort at different temperatures. One way of overcoming this difficulty is to develop standards through public consultation, a key example being the Joseph Rowntree-funded Minimum Income Standard (MIS).

Most definitions of energy sufficiency are described in terms of energy or services. We have combined information on average rated capacity of appliances with assumptions on need and sufficiency made in the MIS for different household makeups, shown in Table 2.4 overleaf. Clearly the household-combined capacities are very high, 13-18kW – representing the total draw from the grid should everything be used at once at maximum power. Interestingly these values are in the same ballpark as the typical rating of a household mains fuse. A typical household peaks at only around 2-4kW (as shown in the Citizens Advice report).

Ofgem's definition of core capacity talks about an amount of capacity that cannot readily be flexed, meaning that it is concerned with services that are time-critical and essential. The literature helps us to understand these essential, time-critical energy services – in particular space heating and cooling and activities around food. Our analysis of SAVE data described in Section 6 looks not only at household peaks, but what people are doing, when, to inform this debate.

The MIS case study confirms what we already know from international experience of capacity limits and from analysis of smart meter data (detailed in the Citizens Advice report) – that a core capacity would need to be differentiated for a range of household circumstances, namely number of household occupants and their age profile.

Table 2.4 Combined electricity capacity estimates for MIS

	Capacity	Single working	Couple working	Pensioner single	Pensioner couple	1 parent 1 child	1 parent, 2 children	1 parent, 3 children	Couple, 1 child	Couple, 2 children	Couple, 3 children	Couple, 4 children
Hob	2.4	√	√	√	√	√	√	√	√	√	√	√
Microwave	1.25	√	√	√	√	√	√	√	√	√	√	√
Kettle	2	√	√	√	√	√	√	√	√	√	√	√
Fridge freezer	0.2	√	√	√	√	√	√	√	√	√	√	√
Toaster	1.2	√	√	√	√	√	√	√	√	√	√	√
Central heating pump	0.6	√	√	√	√	√	√	√	√	√	√	√
Vacuum	2	√	√	√	√	√	√	√	√	√	√	√
Tumble dryer	2.5										√	√
Washing machine	0.41	√	√	√	√	√	√	√	√	√	√	√
Iron	1	√	√	√	√	√	√	√	√	√	√	√
Hair dryer	1.5		√		√				√	√	√	√
Vacuum cleaner	1.8	√	√	√	√	√	√	√	√	√	√	√
TV with Freeview	0.15	√	√	√	√	√	√	√	√	√	√	√
TV with DVD player	0.1					√	√	√	√	√	√	√
Radio	n/a			√	√							
Personal computer	0.14	√	√			√	√	√	√	√	√	√
PM4	n/a	√	√			√	√	√	√	√	√	√
Lighting	0.05p/room + 0.03kW p/ person	0.18	0.21	0.18	0.21	0.26	0.34	0.42	0.29	0.37	0.45	0.53
TOTAL capacity		**13.33**	**14.86**	**13.19**	**14.72**	**13.51**	**13.59**	**13.67**	**15.04**	**15.12**	**17.7**	**17.78**

3 Future-proofing cores

In this section we look at attempts to future-proof capacity limits and capacity tariffs to account for evolving needs, such as the electrification of vehicles and heating and the use of domestic PV with storage. For example, the UK government has set a target to, by 2040, phase out conventional petrol and diesel cars.[31] Scotland plans the same from 2032.[32] So core capacity and capacity limits will need to be monitored and kept up-to-date.

There is significant uncertainty around how the heat sector will be decarbonised, with electrification (e.g. HPs) very likely to play a role. A Committee for Climate Change report suggests installation of around 200,000 HPs between 2015 and 2020, (although the UK's indicative target for 2020 of 12% of heat from renewables is unlikely to be met.[33]) The penetration of storage and PV may have a limited impact on energy services. However, the implications in terms of household grid electricity demand (i.e. peak import capacity) and hence a capacity core which is defined in terms of peak import, is potentially significant.

Adapted from the literature,[5] Table 3.1 provides some commentary on mechanisms in use that might help consumers to stay within core capacity or values and / or manage bills with capacity-based charging.

Table 3.1 Groups of energy services and core capacity mitigation

Groups of services	Impact on capacity	Future proofing instruments
Lighting and heating spaces	Medium	Tariff exemptions and capacity limits 'Smart' HP functions Automated demand response via remote control
Cooking, eating and leisure	Low	Smart refrigeration
Household cleaning	High	Dynamic tariffs
Mobility	High	Smart charging 'Vehicle-to-grid'

3.1 Lighting and space heating

Lighting, heating and cooling of spaces is the largest contributor to domestic energy consumption. HPs can increase power requirements significantly and challenge the design of capacity limits and associated tariffs.

3.1.1 Tariff exemptions

There are international examples of exemption of HPs from extra capacity charges. In Italy, consumers pay more for higher capacity limits. In principle, the use of HPs (and the same applies to EVs) increases power demand, hence enhancing the capacity limit. However, between 2014

[31] https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/38305.htm
[32] Scottish Government, Draft Climate Change Plan - The draft third report on policies and proposals 2017-2032, January 2017
[33] https://www.ofgem.gov.uk/system/files/docs/2016/11/ofgem_future_insights_programme_-_the_decarbonisation_of_heat.pdf

and 2016 exemptions were offered to consumers with HPs. In essence, those with HPs were placed on an experimental tariff which in terms of charges equalled the most basic tariff (i.e. corresponding to those consumers with a capacity limit of up to 3 kW). As of 15 April 2015, 2,900 residential consumers joined the experimental tariff in areas covered by 35 different Italian Distribution System Operators. About half of these contracts are associated with a capacity limit of 6 kW (see Table 3.2[34]). About 60% of consumers joining the experimental tariff declared they also had a PV system.

Table 3.2 Capacity limits of Italian consumers on experimental HP tariffs

Capacity limit	% consumers with HPs
3 kW	5%
4.5 kW	16%
6 kW	48%
10 kW	23%
15 kW	7%
> 15 kW	1%

The experimental tariff includes the following features:

- Voluntary opt-in from consumers (who are informed about this opportunity through bill-related information and suppliers' websites).
- Experimental tariffs are limited to residential consumers who utilise HPs as their only home heating system. There is no limitation in terms of the technology type of HPs, but they must only be used for heating, not cooling[35].
- Consumers could choose between the exemption tariff and the activation of a second meter (point of delivery) dedicated only to the HP.
- The lowest tariff (equivalent to tariffs with capacity limit of 3 kW) is applied without the need for a new meter. Should a second meter be in place, the lowest tariff is applied to the second meter (as the load consists only of HP-related demand).
- Constant monitoring through smart metering is applied to those consumers on the experimental tariff.
- Suppliers with consumers of *maggior tutela* (the Italian correspondent of UK price caps) are obliged to offer their customers the possibility to opt in, whereas suppliers on the *mercato libero* can choose whether to offer this opportunity to their customers or not.

The intention of the regulator was to exempt households from higher capacity limits for all loads provided HPs were the only heating system in place. For the same reason, those with hybrid heating systems (i.e. boilers and HPs) could not apply for the exemption tariff. Where

[34] ARERA (2016). Relazione AIR - Riforma delle tariffe di rete e delle componenti tariffarie a copertura deglioneri generali di sistema i clienti domestici di energia elettrica.
[35] ARERA recognises that many consumers use the favourable tariff for cooling as most HVAC units enable both heating and cooling.

households had additional heating loads, they needed to demonstrate that the HP was the dominant source of heating and that it was capable of heating the whole household.

3.1.2 Smart HP functions

In a pilot project in the Netherlands where households were fitted with a HP and underfloor heating, participants requested 'smart' HPs, to aid them in their efforts to time-shift demand in coordination with a dynamic energy tariff. Several months after installation, 34 out of 38 households had not switched off the 'smart' functionality of their HPs, citing cost-saving without loss of comfort as their main motivation.[5] Smart functions can be set to prioritise operation for hours when electricity costs are lower, or reduce demand during peak hours on the basis of price signals and forecasts.[36]

In the Netherlands residential consumers in the near future will have the opportunity to sign up for a discounted energy contract which includes a flexibility clause. This authorises grid operators to remotely and directly manage demand,[37] for example by adjusting boiler, fridge and freezer temperatures. Such arrangements would have implications for future proofing without the need for active time-shifting by householders.

3.2 Cooking, eating, leisure

Cooking, eating and leisure services contribute particularly to the evening peak (see Figure 3.1 below). The expensive and carbon-intensive electricity required for these inflexible services may instead be suitably provided through domestic energy storage charged with solar power during the day. The consistent energy demand of refrigeration (freezers, fridges), however, does provide opportunities for future proofing in terms of demand response. Smart freezers and fridges will be able to respond automatically to price signals and make small and safe adjustments to the cooling temperature.

3.3 Domestic cleaning

Domestic cleaning services have significant potential for mitigating capacity requirements for three main reasons. First, they are not time critical. As Figure 3.1 shows ironing is less likely to take place at peak time than off-peak. Second, domestic cleaning services are generally infrequent in terms of how often they take place in a day and in a week. Third, there is evidence from studies in Belgium,[38] the Netherlands[5, 39] and Denmark[40] that laundry, tumble-drying and dishwashing machines are highly flexible services.

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[36] K. Hedegaard, Balyk, O. (2013) Energy system investment model incorporating heat pumps with thermal storage in buildings and buffer tanks, *Energy*, 63, 356–365

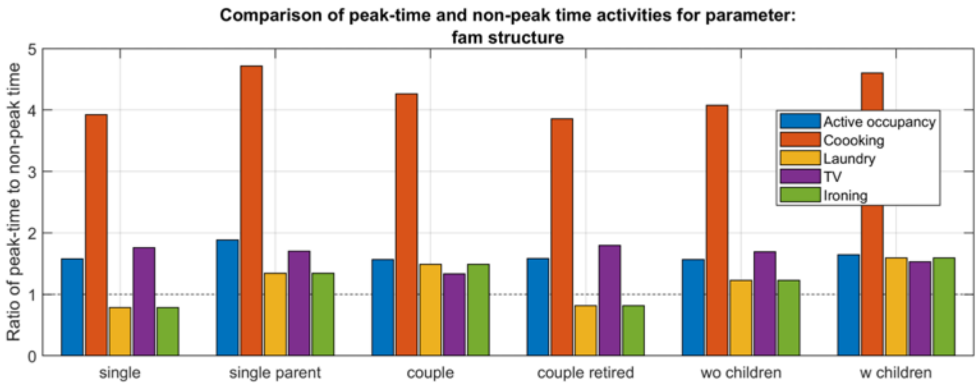
[37] Schick, L. Gad, C. (2015) Flexible and inflexible energy engagements—a study of the Danish smart grid strategy, Energy Research and Social Science, 9, 51–59.

[38] Cardinaels, W., Borremans, I. (2015) Demand Response of Families, Linear Consortium, EnergyVille, Genk, Available online at: http://www.linear-smartgrid.be/ sites/default/files/Linear%20Final%20Report%20-%20lr2.pdf

[39] Kobus C. (2016). A switch by design: user-centred design of smart energy technologies to change habits of using energy at home, PhD Thesis, Delft University of Technology, 2016.

[40] Friis, F. and Christensen, T. H. (2016) The challenge of time shifting energy demand practices Insights from Denmark. *Energy Research & Social Science,* 19, pp. 124-133

Figure 3.1 Ratio between peak-time and off-peak time of main services based on family structure[41]



There is some variation across the different types of domestic cleaning services. For instance, all participants in the Danish study moved dishwashing to off-peak (at night, between 8pm and 8am) with some level of disruption associated with off-loading dishwashers in the morning for families with children. In the Dutch study vacuum cleaning, washing and ironing were considered less flexible. Even if all 250 participants in the Dutch project all received smart laundry machines which could automate time-shifting, a majority (around 80%) did not use the function and still preferred to operate the laundry machine manually.

In a Netherlands pilot project, participants mostly time-shifted the use of their washing machines, tumble driers, and dish washers, from the evening peak to other times of the day. In the Danish study, the off-peak tariff could not be utilised because several people experienced issues with setting the timer on tumble driers, noise disturbance at night and the fact that some participants did not have a tumble drier.

3.4 Mobility

EVs fulfil mobility needs associated with work, education and other social commitments. Running costs might comprise energy tariffs (kWh) as well as power (kW). In Italy it was estimated that for the following four consumer types, there will be different capacity limit implications:[42]

- For a residential consumer with a capacity limit of 3 kW consuming 1,500 kWh per year with a city car, purchasing an EV involves no increase in capacity requirements.
- For a family with a capacity limit of 3 kW consuming 2,220 kWh per year with a small car, purchasing an EV involves an increase in capacity requirements of 0.5 kW.
- For a family with a capacity limit of 3 kW consuming 2,700 kWh per year with a medium-size car, purchasing an EV similarly involves an increase in capacity requirements of 0.5 kW.

[41] UK 2014 National Time Use Survey
[42] http://www.gse.it//it/CertificatiBianchi/

- For a family with a capacity limit of 6 kW and yearly consumption of 6,000 kWh with a large-size car, the purchase of an EVs does not induce and change in capacity requirements.

Table 3.3 shows that implications for capacity requirements depends on the charger and required charging duration. In Italy, with a typical residential capacity limit (3 kW) it is possible to charge the equivalent of a 16 km trip in one hour and full charging in 10 hours. This level of charging is adequate for the majority of people travelling less than 150 km per day. Night time charging would secure minimal if any impact on capacity limits.

Table 3.3 Power used to charge EVs and charging hours

Capacity limit	EV charger	Charging hours									
		1h	2h	3h	4h	5h	6h	7h	8h	9h	10h
3 kW	2.3 kW	16km	32km	48km	63km	79km	95km	111km	127km	143km	100% 150km
4.5 kW	3.7 kW	26km	51km	77km	102km	128km	100% 150km				
6 kW	4.5 kW	31km	62km	93km	124km	100% 150km					
10 kW	7.4 kW	51km	102km	100% 150km							

Consumers in Italy with higher capacity limits can benefit from the maximum power associated with EVs currently on the market in Italy, which is approximately in the range of 3.7 kW to 7.4 kW. For a charging power of 3.7 kW, it would not be advisable to increase the capacity limit to 4.5 kW as much of the power would not be utilised. As a way of future proofing EVs, some charging systems have a current controller which can set the level of power used to charge the vehicle. However, in Italy at the moment in the market there is no option to automatically adjust the power level of EV charging based on available residual power.

There are various EV charging options which limit power demand during charging. Smart charging solutions can ensure charging does not take place at the same time as other electric loads:

- Vehicle-to-grid (V2G) charging would turn the EV into a temporary storage unit to compensate power demand from other loads. This enables active power support to the grid.
- Smart charging will involve more than an 'ON/OFF' switch. The rate of charging should vary to allow for the optimisation of power flows within the electricity system. For instance, smart charging capabilities can be built into the vehicle and the supporting electricity system platforms. Fundamentally, the charge point will need to incorporate a

series of controllable aspects in order to enable any smart charging solution which limits capacity at the individual user level.[43]

- There needs to be a communication and control system in place between the charging point and the local grid operator, to manage the charging process.
- Interoperability with other grid users will be critical for smart charging in order to coordinate data between the grid, the charging point and the EV. Interoperability will be a necessary condition for managing power demand associated with charging patterns based on available electricity generation. The integration of local distributed energy resources involves adjusting charging profiles to the supply from renewable energy generation. Distributed energy resources optimisation is experiencing significant tests in terms of feasibility in Germany and Switzerland[44]. The system consists of a battery storage system in homes to stock power produced from solar PV systems. The stored power can be used to power the home and the customer's EV, and a smart feature predicts the energy needs of the home and EVs and sends power automatically where it is required.
- Smart variable tariffs and lower tariffs for charging EVs outside of peak hours would relieve power demand.
- Regulation setting into law the requirement that all EV chargers are equipped with smart technology will foster scheduling of non-charging periods of the day by setting price caps on the price per kWh. If the price exceeds the price cap, the car will not charge

In summary, technological, tariff and regulatory changes can be implemented in order to future-proof EVs and limit their impact in terms of capacity requirements.

3.5 PV and storage

Combining PV and storage has the potential to mitigate capacity requirements. PV resources are the most common form of distributed generation at the residential level. Depending on their capacity, rooftop solar PV can part-serve local load. The application of storage devices integrated with residential PV systems enables storage of surplus power generated during the day. Stored electricity can be used to support the evening peak load. In essence, storage batteries are technically effective at addressing mismatches between electricity demand and electricity supply by PV. Several companies in the PV industry have started to develop and sell storage solutions based on battery technologies.[45] However, whilst the returns of combining PV and storage should be higher, because shifting supply of electricity to different times of the day increases the value of the electricity produced, most domestic consumers are not exposed to time-of-use tariffs and adding storage technologies to a PV system raises the capital costs.

So one question in terms of future-proofing PV and storage is the extent to which this is economically viable. For instance, a cost-benefit analysis using 1 year of data from a medium-

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[43] Developing standards for electric vehicle smart charging https://www.energy-uk.org.uk/publication.html?task=file.download&id=6576
[44] Smart Energy Network Project https://www.engerati.com/energy-management/article/electric-vehicles/vehicle-grid-audi-joins-growing-market
[45] Eltawil, M. A., & Zhao, Z. (2010). Grid-connected photovoltaic power systems: Technical and potential problems—A review. Renewable and sustainable energy reviews, 14(1), 112-129

sized house in the UK[46] shows that the integration of a battery yields no added benefit in terms of utility savings and export revenue. In addition, when the cost of battery degradation is included, the homeowner is subject to a significant financial loss (Table 3.4).

Table 3.4 Cost-Benefit Analysis of PV and storage in a typical UK home[46]

Year	Electricity generation and export revenue without battery	Electricity generation and export revenue with battery	Savings on electricity without battery	Savings on electricity with battery	Estimated battery degradation cost	Effective profit without battery	Effective profit with battery	Net benefit of electricity storage
1	£542	£533	£185	£193	£399	£727	£327	−£400
2	£542	£533	£185	£193	£107	£727	£619	−£108
3	£542	£533	£185	£193	£77	£727	£649	−£78
4	£542	£533	£185	£193	£61	£727	£665	−£62
5	£542	£533	£185	£193	£44	£727	£682	−£45

A German study[47] has assessed when and under which conditions battery storage is economically profitable in residential PV systems without policy support. The study simulates the profitability of battery storage from 2013 to 2022 under eight different scenarios for PV investment costs and electricity prices in Germany. The results show that investments in battery storage are already profitable for small residential PV systems. The optimal PV system and storage size rises significantly over time if they are provided access to the electricity wholesale market. Developments that lead to an increase in retail or a decrease in wholesale prices further contribute to the economic viability of storage. Under a scenario where households are not allowed to sell excess electricity on the wholesale market, the economic viability of storage for residential PV is particularly high. The authors conclude that additional policy incentives to foster investments in battery storage for residential PV in Germany are necessary only in the short-term. They also note that the increasing profitability of integrated PV-storage-systems may come with major challenges for electric utilities and is likely to require increased investments in technical infrastructure that supports the ongoing trend toward distributed electricity generation.

3.6 Regulatory changes

Where capacity cores and limits need to remain current, there is an implication that regulators would need to continually review and update the framework. For instance, in Italy, as part of

[46] Uddin, K., Gough, R., Radcliffe, J., Marco, J., & Jennings, P. (2017). Techno-economic analysis of the viability of residential photovoltaic systems using lithium-ion batteries for energy storage in the United Kingdom. *Applied energy*, 206, 12-21. https://www.sciencedirect.com/science/article/pii/S030626191731190X
[47] Hoppmann, J., Volland, J., Schmidt, T. S., & Hoffmann, V. H. (2014). The economic viability of battery storage for residential solar photovoltaic systems–A review and a simulation model. Renewable and Sustainable Energy Reviews, 39, 1101-1118. https://www.sciencedirect.com/science/article/pii/S1364032114005206#bib3

2017 reform of capacity limits,[48] not only were rules around capacity limits modified, but also HP tariffs and welfare benefits for vulnerable consumers (*bonus sociale*). In its impact assessment in 2016 the Italian regulator (ARERA)[34] suggests that each year there should be a review of developments associated with capacity limits.

Whilst we did not find evidence of the costs for different market actors of future changes to core capacity, with regards to benefits to consumers, two are often cited: (i) improving comfort and energy efficiency installing new electric appliances; and (ii) bill savings based on fine-tuning the excessive levels of power made available in relation to end users to power which is actually used.

3.7 Summary

The literature review in Section 2 predicts that as technology develops, the energy inputs required to meet energy-related end services will not stay the same. As well as efficiency gains, we can see here that fuel switching will put greater demand on the electricity system. This is the case for a move over to HPs for heating (and cooling), as well as for the growth of EVs.

There are two ways in which this expansion of electrical inputs has been addressed, in the context of capacity charging, in other markets. One is to exempt households from capacity payments related to this 'extra' basic need. We presume this is a transitional measure until the majority of households move over to, for example, HPs, and the mainstream charging structure is adjusted accordingly. In Italy there is the suggestion that customers have been able to 'cheat' the system of tariff exemptions which are targeted at heating but which also benefit HPs used for cooling.

The second option is to mitigate higher capacity charges is smart controls or simple time shifting of activities. There is still a long way to go before these practices become commonplace, with trials having varied outcomes. Timers on appliances may make life easier but consumers need to be engaged and night-time washing may be impractical on noise grounds. Larger households, especially with children, show lower levels of flexibility than smaller households.

PV in combination with storage makes perfect sense, storing midday generation when demand is low and offsetting peak requirements in the evening. However, the economics are not favourable under current GB market conditions. Sharper electricity time-of-use signals could improve the case for storage, as would falling battery costs.

It is difficult to see how a concept like core capacity could be introduced without a system of periodic regulatory checks and balances – ensuring that core values and associated charges remain aligned to the shifting picture on capacity requirements. We consider this point further in Section 7.5.

[48] The reform provided increased granularity of choice in customer capacity limits – explained in detail in the Citizens Advice report.

4 Further analysis on charging – progressive, social and 'packaged' supply options

The concept of core capacity, as set out by Ofgem, is to provide a basic access right to all consumers. Ofgem has not set out exactly how this would be treated in charging terms. One option would be to charge for capacity in a way that is designed to be broadly cost reflective. We have reviewed international experiences of this kind of capacity-charging for Citizens Advice.

There are also other ways in which energy and / or capacity could be charged for, and which would align with the core capacity concept.

Progressive tariffs are tariffs which are designed to incentivise consumers to change consumption patterns or investment decisions by rewarding energy savings and penalising higher consumption. This is one step further than simply structuring tariffs by capacity or energy amounts. Progressive tariffs are often introduced with the purpose of reducing electricity consumption, load and independency, but also as a social instrument to redistribute rising costs of electricity from low consumption to high consumption households.

Social tariffs are electricity tariffs which seek to protect vulnerable members of society by providing affordable energy that is linked to an ability to provide for basic needs. This approach could work well with core capacity where it is explicitly designed to provide for basic needs and at affordable cost to consumers.

Connection packages are a relatively new concept that break the link between energy consumption and cost, providing energy services such as comfort and light, in return for a flat or flatter fee. That is, similar to broadband charges for example.

4.1 Progressive tariffs

We have touched on progressive tariffs in the Citizens Advice report with some examples of Increasing Block Pricing in California, Italy and South Africa. In the case of California and Italy these date back to the 1970s.[49]They are non-linear tariffs where consumers are charged more, per kWh for high consumption levels than low consumption levels, and where the tariffs increase in blocks of consumption (see Figure 4.1 below).

Progressive pricing and individual behaviour: the Italian experience

Italy has implemented both Increasing Block Pricing (in 900, 1800, 2640 kWh/year blocks) and capacity-based charges. Although the Increasing Block Pricing may ensure fairer and more affordable outcomes for consumers, it is thought not to have produced significant behavioural change in terms of reduction in energy consumption. The reasons for this are thought to be[50]:

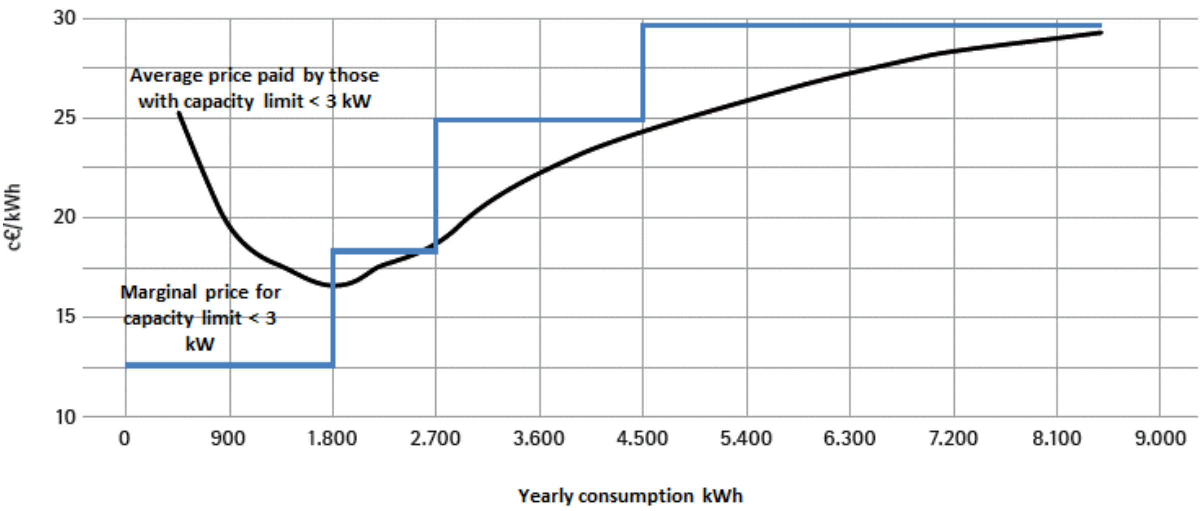
[49] Non-linear tariffs are also known as 'progressive tariffs' and 'increasing consumption-block tariffs'. In Italy this structure is applied to ~50% of the total household electricity bill (transmission, distribution, RES incentives and other levies).

[50] Koichiro I, (2010) *Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing* University of California, http://www.economics.utoronto.ca/index.php/index/research/downloadSeminarPaper/4174 and

- Knowledge of progressive tariffs by Italian residential consumers seems to be extremely low because of the absence of any systematic information campaign.
- The Increasing Block Prices lack any variation across regions. This puts more importance on price elasticity of demand. For example, the 1,800 kWh/year threshold, on the one hand, can be too high for a single-person household and, on the other hand, can be too low for a family with several children.
- The fixed nature of the steps disregards actual electricity needs in relation to different climatic conditions and the availability of different fuels (e.g. fuel switching for heating purposes).
- Capacity limits have contributed more strongly to constraining growth in electricity consumption than has the Increasing Block Pricing.
- Consumers tend to respond to average price signals (i.e. the ratio between total bill price and consumption in kWh) and not to marginal prices (i.e. c€/kWh of the specific step)[51]. The split in tariff steps implies average price signals which are hardly perceived by residential consumers and hence is unlikely to influence behaviour. Most residential consumers' consumption is between 1,000 and 2,700 kWh/year and average price varies between 16.5 and 18.7 c€/kWh.

Figure 4.1 compares the marginal price of tariffs with capacity limit lower than 3 kW with the average price of the same tariffs. The average price is higher than the marginal price for residential consumers with yearly consumption lower than 1,800 kWh per year

Figure 4.1 Marginal and average tariffs for sub 3kW capacity limit (from[34])



Borenstein S. (2010) *The Redistributional Impact of Non-linear Electricity Pricing*. NBER Working Paper No. 15822,
http://www.nber.org/digest/jul10/w15822.html

[51] Kahn M.E., Wolak F.A. (2013) Using Information to Improve the Effectiveness of Nonlinear Pricing: Evidence from a Field Experiment.
http://web.stanford.edu/group/fwolak/cgibin/sites/default/files/files/kahn_wolak_July_2_2013.pdf

In 2013 the French Parliament approved a bill introducing progressive tariff structures. Following a complex legislative journey, the *Conseil Constitutionnel* blocked a few articles of the proposal, hence removing the progressive aspects of the tariff, including: (i) consumers whose yearly demand is either below (or above) a threshold would receive rewards (penalties) defined according to bands varying from 100% to 300% compared with benchmarks; (ii) the benchmarks would change every year based on the number of householders, location, and type of fuel for space and water heating; and (iii) there would be a new organisation in charge of collecting data about demand, setting benchmarks and managing rewards and penalties. The reason why these reforms were not implemented were because of the complexities with blocks of flats and premises with a mix of commercial and domestic use.[52] In blocks of flats with the same centralised heating for a range of commercial and domestic use it would be too complex to define core capacities and progressive tariffs.

4.2 Social tariffs

In principle EU legislation favours socially-aimed tariffs. According to the EU Directive 2006/32/EC on energy end-use efficiency and energy services "*Member States may permit components of schemes and tariff structures with a social aim, provided that any disruptive effects on the transmission and distribution system are kept to the minimum necessary and are not disproportionate to the social aim*."

In practice, examples do not abound. Since 2007 Italian consumers with lower income and/or the need to use high power consuming life-saving health machinery receive a social discount (*bonus sociale*) for their energy consumption. A similar scheme for vulnerable consumers exists in California, where lifeline rates were introduced in 1975 for social reasons. The California Public Utilities Commission made new progressive rates for basic consumption compulsory.[53] An algorithm was utilised to calculate the rate: 50-60 % of the average consumption in summer and 60-70 % in winter for households with electric heating.[54]

In South Africa, in addition to operating Increasing Block Pricing, Free Basic Electricity (FBE) was introduced by the Government of South Africa in 2003, to support indigenous households in meeting their basic energy needs. The Government proposed that an allocation of 50kWh per month should be allocated to all poor households connected to the national electricity grid. This was chosen because it was enough to provide basic hot water using a kettle, basic ironing and power for a small television set and radio. A study undertaken in 2016/17[55] found that approximately 1.8 million South Africans have access to FBE and that tariff relief varies between implementing agencies, ranging from 20kWh to 100kWh per month. The study found that only

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[52] https://www.conseil-constitutionnel.fr/decision/2013/2013666DC.htm

[53] Dehmel C. (2011) "Progressive electricity tariffs in Italy and California – Prospects and limitations on electricity savings of domestic customers", ECEEE Summer Studies, http://proceedings. eceee.org/papers/proceedings2011/2-275_Dehmel.

[54] Hennessy, M., Keane, D. (1989): Lifeline Rates in California: Pricing Electricity to Attain Social Goals. In: Evaluation Review, H. 13, S. 123–140

[55] Masekameni, Daniel & Kasangana, Kevin & Makonese, Tafadzwa & Mbonane, Thokozani. (2018). Dissemination of free basic electricity in low-income settlements. 1-5. 10.23919/DUE.2018.8384380.

9% of households were beneficiaries of FBE, with many poor households being unaware of their entitlement.

One electricity supplier (ESKOM) issues tokens to customers who qualify for FBE. In 2014/15, ESKOM identified that 1,177,250 of their customers were entitled to FBE but only 911,075 customers collected their token. ESKOM's users with prepaid electricity meters can see when their free electricity is used up and then have to buy more electricity at their own expense. Users with conventional or credit meters see a credit of 50kWh on their electricity bill, representing their FBE units.

4.3 Connection packages

Providing 'energy as a service' breaks the link between the revenue paid to suppliers and the units of energy supplied. It offers scope for electricity suppliers to offer a level of 'comfort' or 'connection service' through a combination of means that might include provision of a smart meter, subsidised or free equipment (e.g. smart appliances, battery storage), insulation (to reduce heat loss) and/or energy efficiency advice. There is a potential link to capacity limits because connection services could be defined in terms of the maximum capacity that can be used by (or exported by) a household at any given time.

However, connection packages pose several challenges. The most fundamental of these is that a 'flat tariff' for energy services tends to reduce the motivation for consumers to limit energy consumption (kWh). Such tariffs have historically been used only in developing countries with very low metering infrastructure (for want of better alternatives) and have been seen as less equitable and efficient than kWh tariffs because they have not reflected the costs of delivery. Such tariffs push the risks of varying consumption onto the service provider rather than the consumer. In a world where electricity is generated primarily from fossil fuels, this is counter to low carbon objectives. But in a world where electricity is generated primarily from renewable sources and where costs are driven more by capacity than consumption, a flat tariff may become more appropriate (e.g. where service delivery costs relate primarily to investment in renewable electricity generation capacity, battery capacity or connection grid capacity, smart meters or smart appliances). And a flat tariff linked to core capacity would mitigate the risks carried by the electricity supplier.

Other challenges remain. On the one hand, manual management of electricity demand to stay with core capacity is likely to require a high level of customer engagement, feasible only for well-informed, motivated consumers that have sufficient flexibility in their lifestyles to move non-time-critical demand. While automatic management and optimisation of electricity demand may suit a wider range of consumers, it requires a high level of trust the supplier or service provider. Customers may be reluctant to hand over control of smart appliances or EV charging to their electricity supplier if concerned that the food in their fridge may spoil, or their EV would not be available for an unexpected trip. As discussed in the section on ethical issues, there is potential for vulnerable, unengaged or time-constrained consumers to be penalised if they cannot take advantage of opportunities to optimise their consumption or do not stay within agreed core capacity limits. This suggests that connection packages would need to be differentiated by customer type.

Connection packages could be tailored to the needs of different customer types, taking into account:

- Consumer vulnerability, their motivations and understanding of energy issues.
- Consumer lifestyles and the degree of flexibility in their electricity demand.
- Household demand for electricity at peak (higher for those with electric heating, electric cooking, air conditioning and EVs).
- Household capacity to generate electricity (primarily those with solar PV capacity).
- Household capacity to store electrical energy (e.g. EV or other battery storage).
- Household capacity to store thermal energy (facilitating non-time critical electricity use for heating and cooling, such as refrigeration, hot water heating, space heating, air conditioning).

By way of an illustration, a set of connection packages might look something like Table 4.1.

Table 4.1 Illustrative connection packages

	Core service package (lighting, cooking, leisure, cleaning) – no automation	Core service package (lighting, cooking, leisure, cleaning) – with automation	Add-on for electric water/space heating (e.g. ASHP)	Add-ons for EV, PV and battery storage
	Smart meter, existing appliances, energy advice	*Smart meter, smart appliances, energy advice*	*As for basic services plus insulation, energy advice*	*As for basic services plus EV, PV and/or battery storage, access to flexibility revenues to offset costs*
Vulnerable customers	May not be appropriate, depending on safeguards for vulnerable customers	Low cost package for core capacity, automated to provide safeguards for customer protection	Moderate cost package for increased capacity, automated to provide safeguards for vulnerable customers	Unlikely to be appropriate at present
Engaged customers	Low cost package for core capacity, with manual optimisation by customer	Low cost package for core capacity, automated but with potential for optimisation by customer to suit their preferences	Moderate cost package for increased capacity, automated but with potential for optimisation by customer to suit their preferences	Moderate cost for high level of service, subject to strict limits on usage at peak (e.g. no EV charging at peak)
Affluent but unengaged customers	Moderate cost package for enhanced capacity, assuming little optimisation by customer	Moderate cost package for enhanced capacity, with high levels of automation	Moderate to high cost package for enhanced capacity, with high levels of automation	High cost package for high level of service, with fewer constraints on peak usage

4.3.1 Flat rate offers

It is hard to find examples of genuine flat-rate energy services. **Inspire**, in the US, is offering a Netflix-like subscription to wind power. Users pay a monthly fee based on the cost of wind energy per kilowatt-hour, adjusted for past energy-use patterns, the number of people in the home, weather in the consumer's location, and the square footage of their home. Consumers are billed by their existing energy company but a flat-rate Inspire charge replaces the normal energy charge. An Inspire subscription does not guarantee that the home will become, overnight, powered exclusively by wind energy. Rather, what Inspire guarantees is that for every megawatt-hour of energy used, the company will purchase a Renewable Energy Certificate (REC) from a local or regional wind farm. Their business model assumes that the cost of windpower will continue to decline.[56]

Mini-grid projects in developing countries commonly use flat tariffs, capacity tariffs or forms of tariff other than usage tariffs, owing to the lack of metering equipment. Some mini-grids charge fees for particular energy services (e.g. a fixed price for 1 hour of TV usage per person or 5 hours of lighting) or for use of particular devices (e.g. increased charge for additional lighting devices). They use the concept of 'lifeline' tariffs to mean cross-subsidy of poorer consumers by those more able to pay, and use the term 'binomial' to refer to tariffs that distinguish between daily peak and off-peak usage. [57]

4.3.2 Flexibility payments

There are many more examples of early models which start to break the link between the volume of energy consumed and a customer's final bill. These typically involve a payment for 'flexibility' or demand reduction, as an addition to a normal electricity bill. For example, in the SAVE project, one group of trial participants were offered financial rewards for avoiding consumption during peak time.

SSEN is also experimenting with **Social Constraint Management Zones** in Hampshire and Oxfordshire. Working in partnership with National Energy Action (NEA) this is a concept that involves communities and community organisations receiving payments to help ease capacity constraints on the local electricity network, as an alternative to upgrading cables and substations. It aims to provide an easily accessible route for communities to receive payments for reducing their peak demand, time-shifting their electricity consumption or reducing their overall demand. Projects could include LED lighting, battery storage or variable-rate electricity tariffs. NEA's website[58] gives examples of possible projects that suggest a wide definition of 'community organisations' that could include local councils, social landlords and businesses as well as community groups.

Other examples of payments and / or subsidised equipment include:

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[56] https://www.fastcompany.com/40448623/replace-your-electric-bill-with-a-flat-rate-monthly-subscription-to-wind-power
[57] https://energypedia.info/wiki/Impact_of_Tariff_Structures_on_the_Economic_Viability_of_Mini-Grids
[58] https://www.nea.org.uk/technical/scmz/

- EDF offer subsidised batteries for households with solar PV, provided that they sign up to EDF Energy grid services, giving them potential access to revenue from flexibility services. EDF's offer is in combination with Powervault batteries.
- Centrica is developing a Local Energy Market in Cornwall, funded by ERDF.
- Engie offers an energy service approach to domestic as well as commercial customers. Their offer promises consumers 100% renewable electricity and involves smart heating controls using an app connected to a smart thermostat.
- Energise Barnsley is a BEIS-supported initiative, involving Oxford Brookes, Upside Energy, Sonnen batteries and Northern Power Grid, which involves the introduction of a smart battery and control system that have air source HPs and/or solar PV already installed, to test DSR business models.
- Equiwatt[59] is a service that gives households direct access to flexibility revenues on their electricity use. The initiative was developed by the University of Newcastle with support from ERDF, ECCI, the Department of International Trade and Climate CiC. An Equiwatt app, with associated monitoring kit, encourages consumers to reduce their peak demand by sending them notifications at peak times when they can shift demand in exchange for rewards. Customers are rewarded for turning off appliances, with the rewards taking the form of vouchers or discounts at the Equiwatt store. Equiwatt market their service as helping to reduce carbon emissions (by saving dirty and expensive energy at peak times) as well as generating financial rewards. They estimate that customers can typically earn about £10 per month as vouchers or discounts, and suggest that these rewards can be increased if customers can automate their appliances.
- The 'Core4Grid' initiative**,** funded by Phase 2 of the BEIS Domestic DSR initiative, is run by aggregator Upside Energy Ltd with the Cambridge Energy Group Ltd, UKPN, the Housing Associations Charitable Trust, Everoze Partners and EDF Energy Customers Ltd. This builds on an earlier 'Hybrid Home' project. Phase 1 of this project used an automated system to help homeowners manage and optimise their energy use, integrating solar PV and EVs. Phase 2 will roll out the system to households that will benefit most, involving Worthing Homes and Gentoo Housing via the Housing Association's Charitable Trust. Through the system, households that are highly engaged with energy will buy and sell energy to the grid at optimum times so that they can access the energy they need at least cost and sell surplus back to the grid. The project will involve testing consumer response to time-dependent tariffs and grid constraints under simulated future grid conditions, with benefits shared with participating households. The project will install an integrated DSR system as part of the fabric of the home, paid for via the mortgage or rent (as happens with a conventional heating system). The project's theory is that these homes, called 'Hybrid Homes', will be cheaper to run and to build than conventional homes, directly addressing the affordable home challenge.

[59] https://www.equiwatt.com/

4.4 Summary

There are precedents for explicitly **progressive** tariffs which discourage higher usage or break the link entirely between payment and usage levels. A few, such as Increasing Block Pricing (IBP) date back to the 1970s. More recently, there are a raft of novel business models on the market, in the UK and elsewhere, which start to treat energy as a service rather than a commodity or product.

These most obviously link into the idea of core capacity where there are incentives to reduce or shift electricity consumption – offering the kind of 'future proofing' measures we discussed in Section 3. However, just as energy services could include support, advice and measures to cut energy use, new service packages could include advice and technology which helps consumers to reduce capacity needs.

Social tariffs link into the concept of providing a basic level of electricity network access. There are international examples of socially-conceived tariffs, even including a basic level of free electricity in South Africa. However social tariffs do not seem to be very common. In the UK, support for energy costs is separated from tariffs, and is administered through government (Winter Fuel Payments, Cold Weather Payments) or as a Supplier obligation (Warm Home Discount).

5 SAVE data – further cores analysis

5.1 The data

In the Citizens Advice report we profile the average power (in kW) of groups of consumers to understand everyday usage. This makes use of, for the most part, half hourly smart meter data from the Customer Led Network Revolution (CLNR) project and the Low Carbon London (LCL) project, both collected between 2011-13.

The SAVE data allows us to further develop this analysis, offering:

- Higher resolution 15-minute consumption data.[60]
- Detailed survey data which we can match to the meter data.

Firstly, we look at households with efficiency and low carbon measures, which provides some insight into future-proofing core capacity for more widespread low carbon measures. Secondly, we look at the distribution of peak capacity across the SAVE population, to understand the impact of setting core at a particular level and who might need to either shift demand or pay for extra capacity.

5.2 Future proofing

5.2.1 Efficiency measures

SAVE collected information on installed efficiency measures, shown in Table 5.1.

Table 5.1 Efficiency measures installed

Measure(s)	Count
Partial double glazing	66
Full double glazing	847
Secondary glazing	16
Draught proofing of windows and/or doors	132
Loft insulation	667
Underfloor insulation	66
Storage heater dials	17
Cavity wall insulation	449
Solid wall insulation	19
None	8
Total in control group:	947

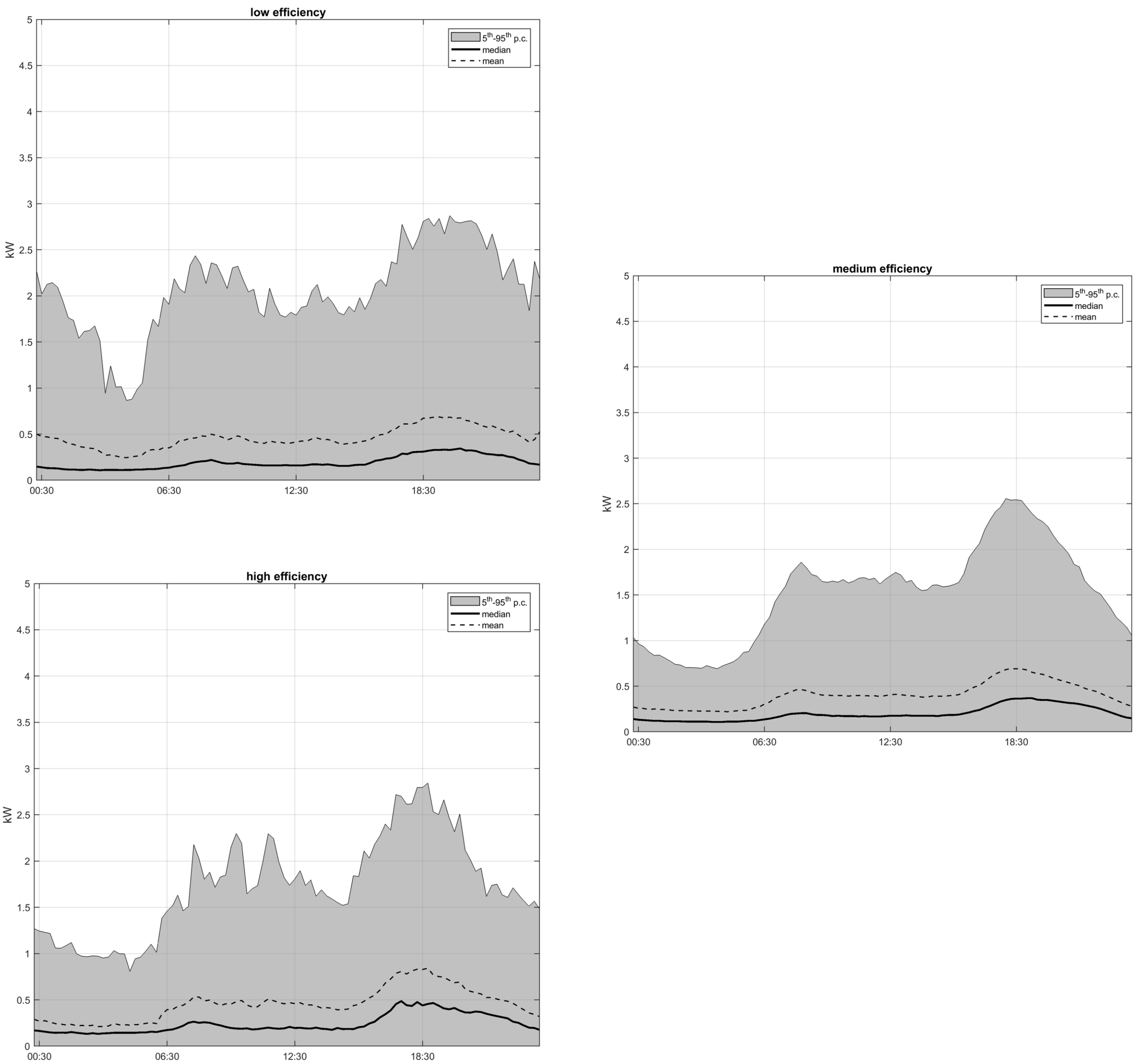
We have experimented with different ways of sampling households for low, medium and high efficiency measures, but it has been impossible to even-out sample sizes and at the same time

[60] We convert the kWh meter data to power, kW, by re-arranging the Energy (kWh) = power (kW) x time (h) to kW = kWh/h or the 15 minute kWh reading divided by a quarter of an hour.

avoid overlap between categories. Figure 5.1 shows the 95th percentile 15 minute average demand for the following split:

- Low – one of secondary glazing, draught proofing or loft insulation (73 households).
- Medium – not falling into low or high categories (836).
- High – full double glazing, draught proofing, loft and floor insulation and wall insulation (38).

Figure 5.1 95th percentile average weekday power by energy efficiency measures installed



⇒ It is difficult to draw firm conclusions here given the differing sample sizes. Nonetheless there is a suggestion that whilst energy use may be reduced by energy efficiency measures, the impact on peak electrical power is minimal.

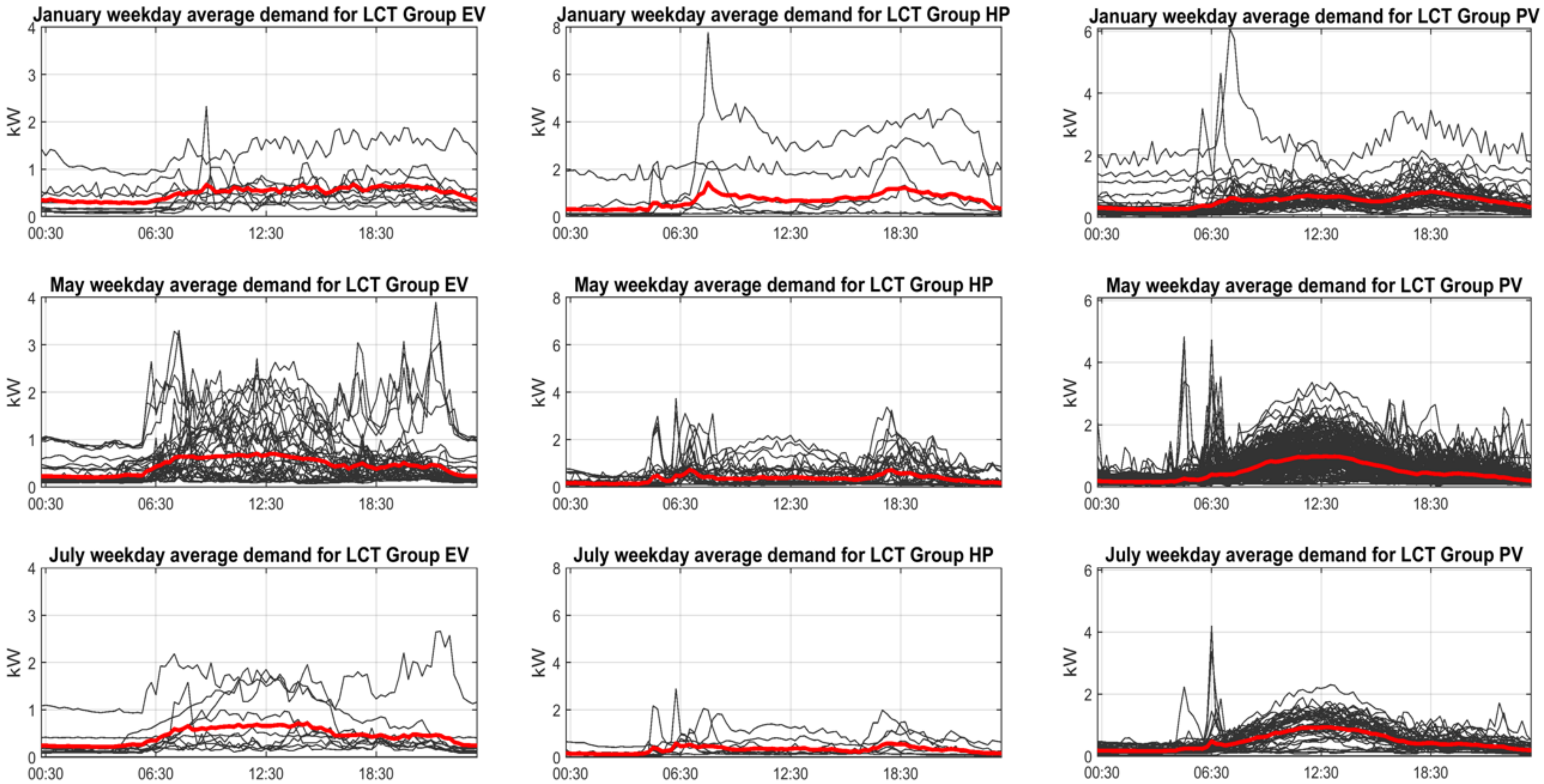
⇒ Efficiency measures such as double glazing are expensive. There may also be income effects influencing the high efficiency demand profile. That is, although it appears that high efficiency measures are not having an impact, they may be bringing consumption down from what would have otherwise been higher levels.

5.2.2 Low carbon technologies

Of all the households recruited for demand monitoring, only 66 said that they had an LCT; 11 reporting EV ownership, 9 reporting an HP and 47 PV panels i.e. 67 technologies. This implies only one household with more than one technology, although as the data shows (see below) we believe that more than one household has more than one technology.

Figure 5.2 shows the average power for a weekday for each household in each of January, May and July for households reporting EV ownership (left), HPs (middle) and PV (right).

Figure 5.2 Average weekday demand for January, May and July, for EV, HP and PV households



Households with EVs
As would be expected by after-work and overnight charging, demand peaks in late evening, but only in May and July. The flat profiles in January are more consistent with an empty house. The peak in demand for midday in some profiles, for May and July, suggests that some of these EV owners also have PV (the meters do not distinguish between flow direction so generation is being recorded as consumption.

Households with HPs
Peak demand is in the morning before work, (but not very early morning as seen in electrically-heated households from other studies). We presume this reflects timers set on the HPs in these households. The winter peaks are very high and much higher than those seen for EV charging. Again, a midday peak for some households in the May profiles suggests the presence of PV.

Households with PV
There appears to be some HP ownership also represented and perhaps one EV owner. A characteristic midday bow in spring and summer months represents PV generation and it is notable that this equals or exceeds the evening demand peak.

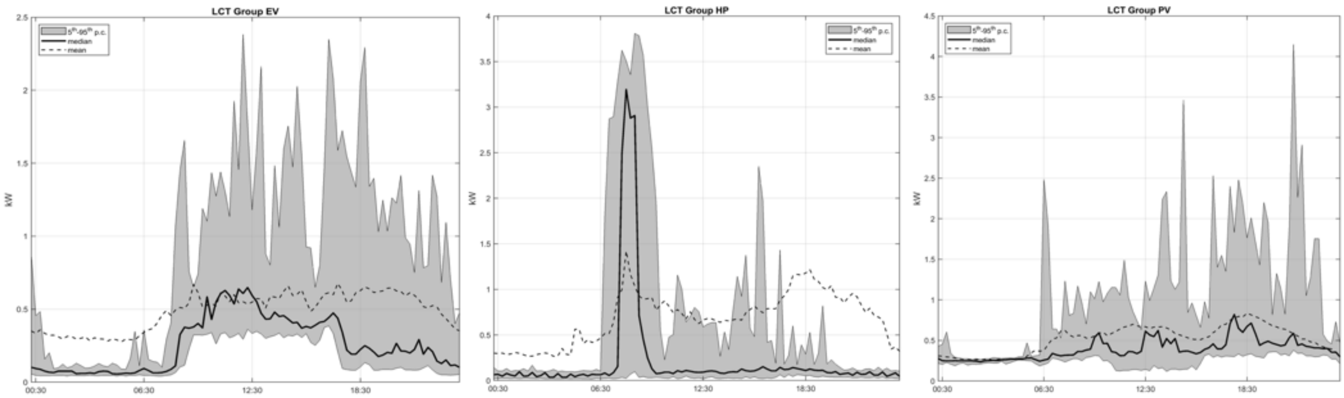
In part because of small sample sizes, we have shown the data for LCT households as individual household profiles. However, to aid comparison with analysis in support of deriving core capacity data (see the Citizens Advice report), we show in Figure 5.3 the 95th percentile demand[61] for each of the reportedly EV, HP and PV-owning households. The peak values are 2.8, 3.8 and 4.2 respectively.

⇒ EV ownership is not having an impact on household peak capacity. We do not know anything about the EV chargers in these households, but assume they are low capacity and slow, which suffice for an overnight charge.

⇒ HPs are having an appreciable impact on peak capacity, the highest value coinciding with early morning as would be expected.

⇒ PV does not appear to be impacting peak, although the relatively high evening peak is difficult to explain. It could reflect the presence of EV.

Figure 5.3 95th percentile demand, year-round, for EV, HP and PV groups



[61] 95% of all values are at or below this number.

5.3 Distribution of peak capacity

In the Citizens Advice report, we postulate referencing core capacity values at the everyday consumption for low income households, corrected where necessary for electric heating. The peak power values, at the 95^{th} percentile are around 2kW for low income households and 6-7kW for electrically heated households.

Figure 5.3 shows the probability distribution for the highest 15 minute demand value in households grouped by income, and

Figure 5.4 the same for households grouped by heating type.

Although there are some very high values in the income groupings for all income levels, their occurrences are at a very low probability. Peak values above 3kW are however not uncommon even in the low income groups, suggesting that all groups would – albeit not necessarily very often – need to reduce or shift demand for a 3kW core value.

The electric-heated households present a more complex picture with a much flatter distribution of peak values between around 3-7kW. This could be driven by different heating loads and / or different types of electric heating.

Figure 5.4 Distribution of highest 15 minute peak, by income group

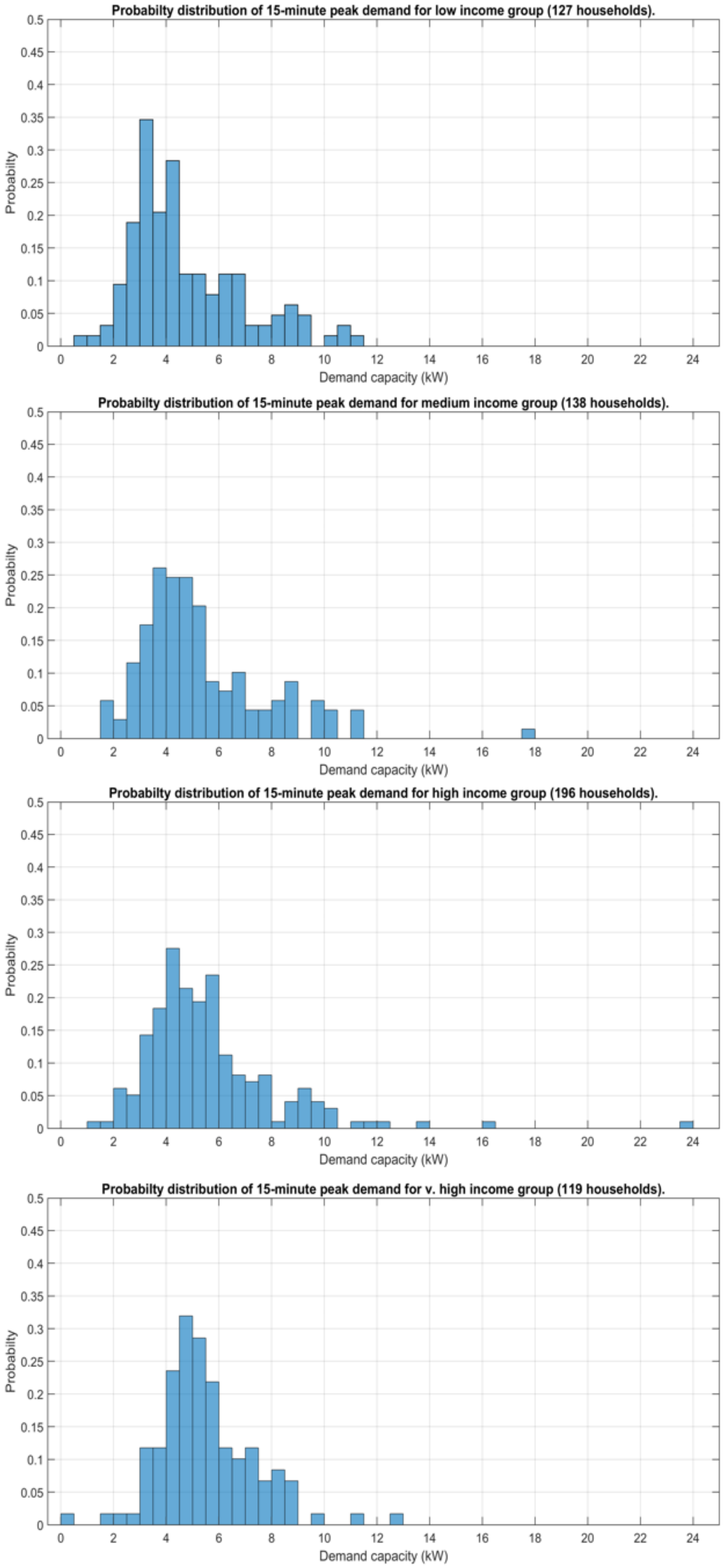
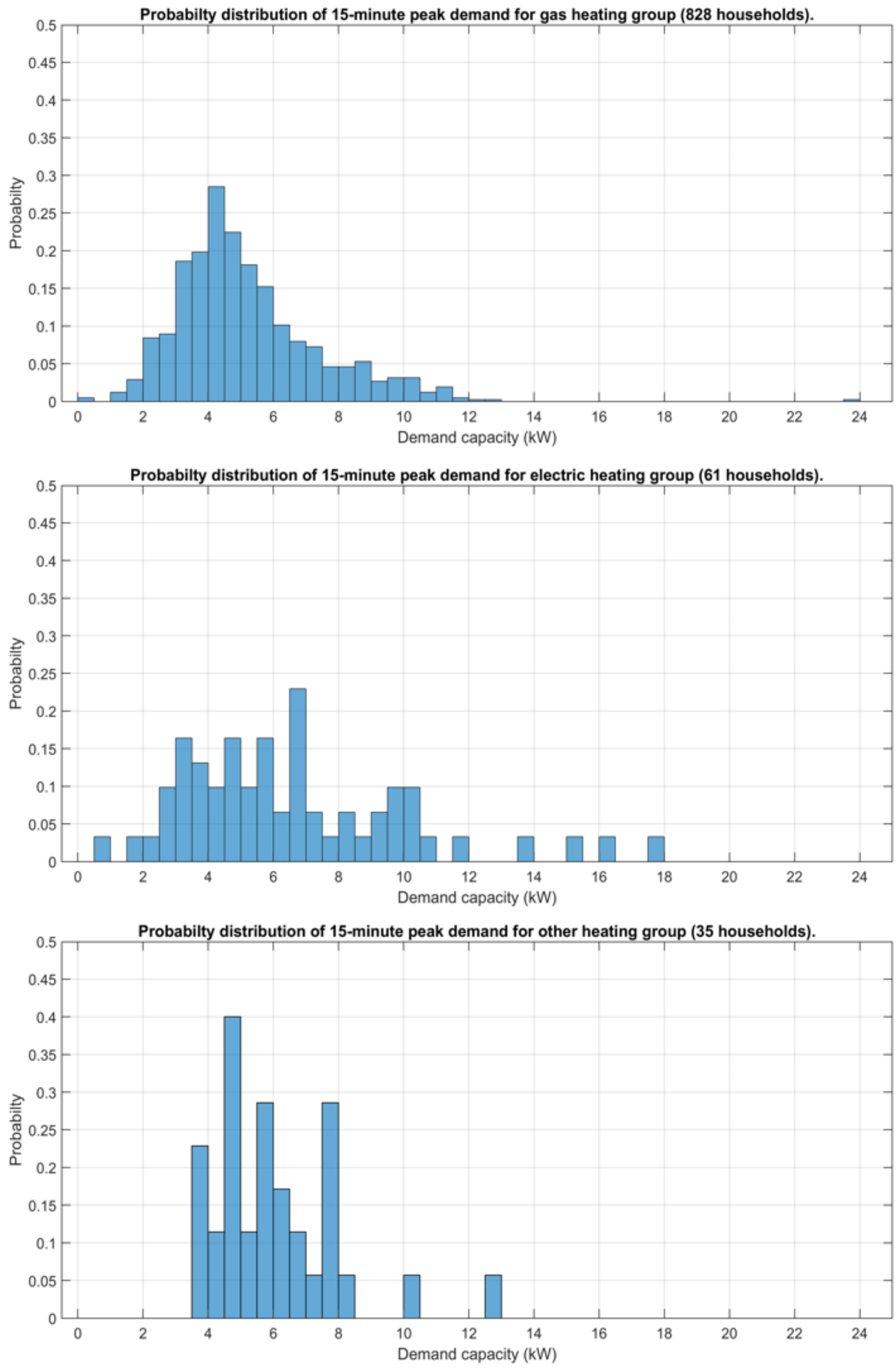


Figure 5.5 Distribution of highest 15 minute peak, by heating group



5.4 Summary

This further exploration of smart meter data provides us with a better understanding of the factors impacting on setting a core capacity value. Specifically:

5.4.1 Future proofing

Most households had some form of energy efficiency measure, the most common being full double glazing, followed by loft insulation and then cavity wall insulation. It proved difficult to allocate these measures to notionally low, medium and high efficiency households. However, we did compare modest impact measures against a combination of high impact measures, finding no clear difference in peak capacity requirements. This is perhaps unsurprising, especially for the gas-heated households.

It would be interesting to examine whether measures which specifically target capacity rather than energy – such as new more efficient appliances, impact on peak capacity.

Only a small number of households in the SAVE population reported LCTs, so our analysis is limited. This in of itself shows that PV, EVs and HPs are not yet commonplace. Furthermore, our analysis shows that of those small number of households with LCTs, a good number have more than one technology – supporting the idea that there is a group of early adopters.

In terms of impact on setting a core capacity value:

- EVs surprisingly do not seem to be having an impact, at least in the households in this study. This differs from findings in the Citizens Advice report and could be because customers here are slow charging at home and fast charging away from home when necessary. But we simply do not know and this would benefit from further research.
- HPs are having a significant impact on capacity requirements, both in size (kW) and time of day (the peak is in the morning, around 6.30am rather than during the night, when more traditional electric-heating peaks).
- PV has the potential to alleviate peak capacity requirements through self-generation, but peak generation occurs in the middle of the day, just as demand slumps. (This is already causing problems for the System Operator which has, on occasion, paid for demand to 'turn-up' in the middle of the day to soak up the excess generation). There are therefore potential benefits from home storage of PV, which offers an alternative to shifting demand during the evening peak.

5.4.2 Income differences

The Citizens Advice report shows that, broadly, higher income households use more capacity than low income households. However, distribution of the highest peak values shown here is more complex. Low income groups still show proportionately lower peak values than high income groups. But low income groups also show more diversity of peak values up to around 12kW and all income groups have peaks outside proposed core levels in the region of 2-4kW.

Some of the high values can be explained by the presence of electric heating. But it almost certainly also shows that if core capacity is implemented, consumers will need to think more carefully about capacity and shift or reduce some activities (or pay more for extra capacity).

5.4.3 Heating differences

We already know from the Citizens Advice report that electric heating roughly doubles a household's capacity use. Analysis of SAVE data shows that the picture is more complex, namely:

- Peak values for electric heated households do not converge on a common value, but rather are widely distributed between around 2-10kW. Further work is required to establish whether this is linked to heating load, heating type or some other factor(s).
- Low income groups seem to show this more distributed spread of peak values, suggesting that low income groups have a higher representation of electric heating.

6 SAVE data – time-use diaries

6.1 The data

Time-use diaries completed by SAVE project participants gives insight into a household's daily life which, crucially, can be matched with the same household's measured electricity demand profile. As we describe here, there are some limitations to the data but we can start to see what kinds of activities are contributing to peak usage, and what kinds of activities are more flexible than others. This analysis expands on the work for Citizens Advice by looking at a range of customer categorisations and the relationship with peak.

SAVE participants allocated to three different 'Trial Groups' were all asked to complete surveys for one or more event days in a 'Trial Period'.

Trial groups differed by the type of intervention being tested, as follows:

- Trial group 1 – control group.
- Trial group 2 – roll-out of LED lighting and energy reduction events.
- Trial group 3 – data-informed engagement, and opt-in price signals.
- Trial group 4 – data-informed engagement and opt-out price signals.

The trial periods (TP) were

- Trial period 1 (TP1): from 1 January to 31 March 2017.
- Trial period 2 (TP2): from 1 October 2017 to 31 March 2018.
- Trial period 3 (TP3): from 1 October 2018 to 31 December 2018.

Within each TP there were one or more event days during which participants were asked to fill in time-use diaries. Two separate questions asked them to record what they were doing (given a choice of 29 activities – e.g. personal care or food preparation) and then specifically how they were doing it (e.g. showering or using the cooker). We have called these activities and actions respectively. Participants were also asked where they were (at home or elsewhere).

In the Citizens Advice work, we look at everyday peak capacity for a range of different types of consumer groups. This tells us how much capacity is being used and that peak usage is mainly in the 4-8pm evening period. The exception to this is electrically heated households, where peaks can occur in the very early morning.

However, this is a picture across-the-board. Individual household peaks may be outside these times and may be driven by a variety of activities. To understand this further, it is instructive to look at a household's activities alongside demand profiles. The time-use diaries in SAVE allow us to 'mine' the peaks to see what households are actually doing during high use periods. We have looked at this as follows:

- What are reported activities during each individual household's peak and what are reported activities in the peak outliers (these are the peaks that fall outside the 95th percentile)?

- What are reported activities during the peak 4-8pm period?

It is important to note that the evidence from time-use diaries should be viewed with caution. Activities are self-reported by one or more members of a household – there may be additional household members contributing to household demand but whose activities are not recorded. The diaries are also incomplete, in so far as respondents do not report what they are doing at every interval in the day and night and there can be unexplained gaps. Furthermore, not all households completed diaries and not all provided additional survey information (which we have used for looking at income-related differences). So sample sizes can be quite small.

In the time available, we have simply interrogated the raw data without any analysis of statistical significance.

6.2 Actions during a household's peak demand

We have presented actions here as they relate more directly to what might be driving electricity peaks. For the control group participants only, Figure 6.1 shows: on the bottom, for the ten highest 15-minute smart meter readings for each household, the corresponding action recorded in the time-use diary; on the top, actions performed when demand exceeds the 95th percentile in January. Figure 6.2 shows the same data, but only for households who also provided income data, and grouped into low (under £15K), medium (£15-£30K) high (over £30-50K) and very high (over £50K) income categories.

⇒ Cooking, followed by showering, is contributing to the highest volume of peaks and this is the same for the very highest outlier peaks.

Figure 6.1 Actions during top 10 peaks and peaks outwith 95th percentile

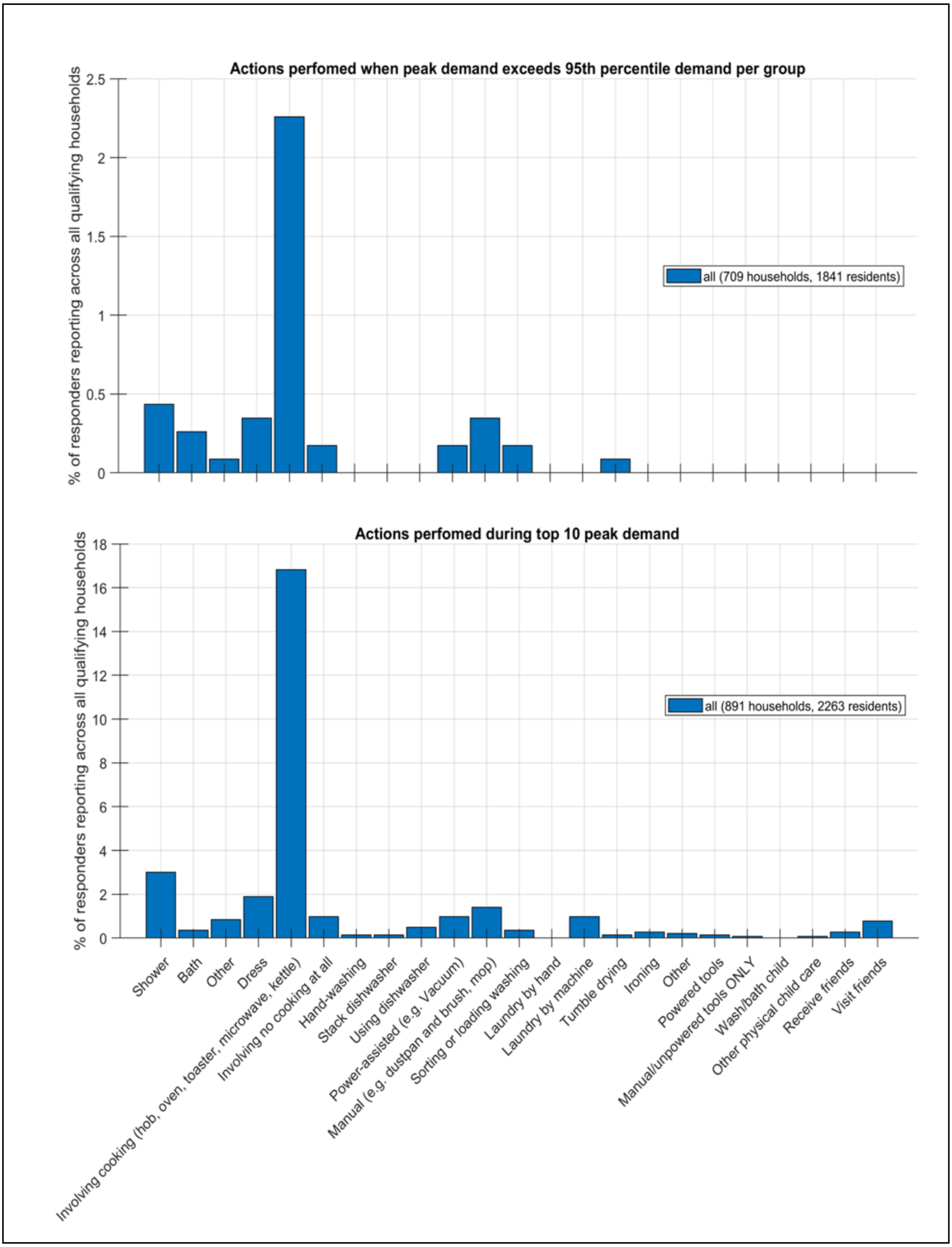
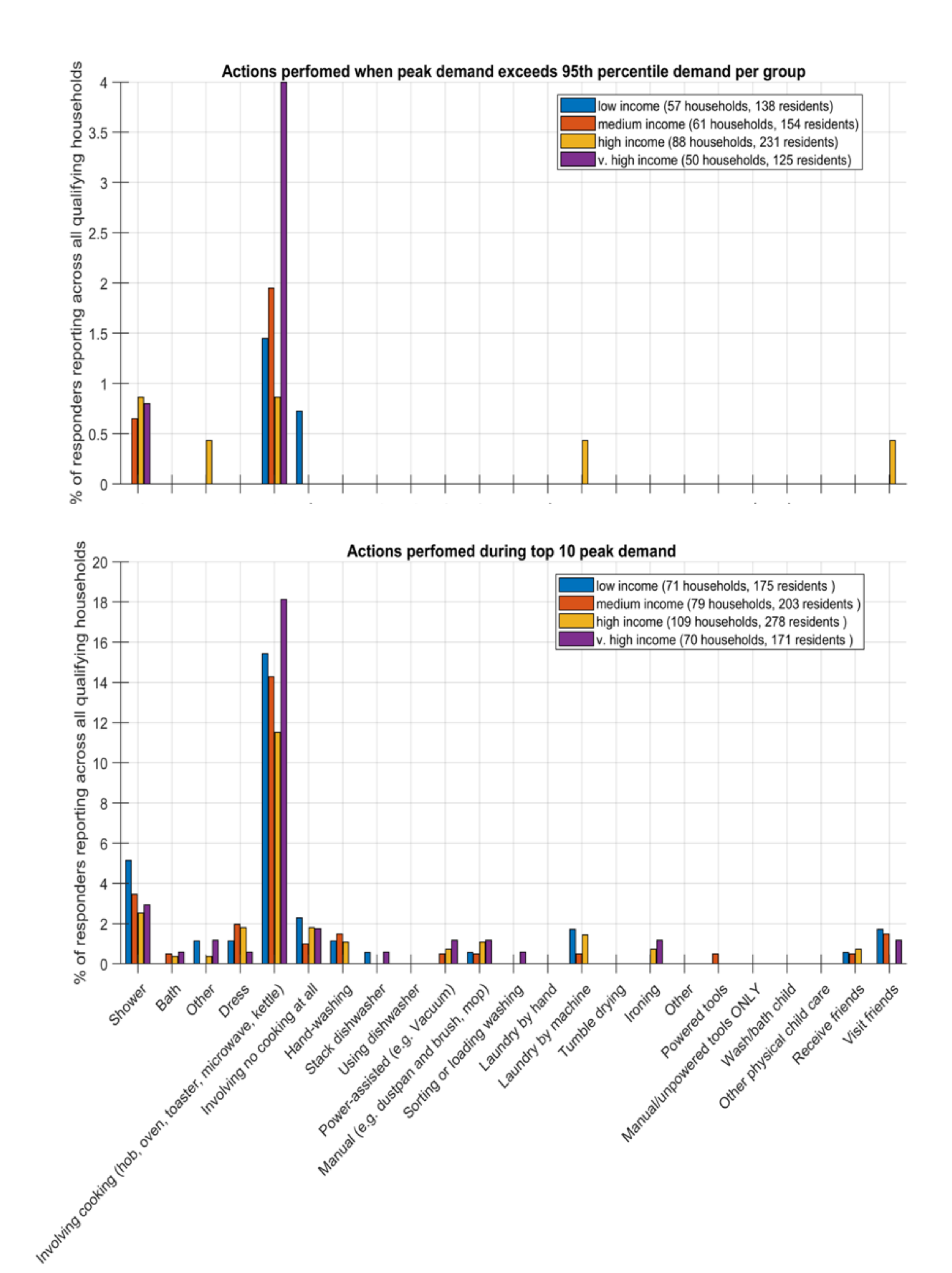


Figure 6.2 Actions during top 10 peaks and peaks outwith 95th percentile, grouped by income



The corresponding timing of the top 10 peaks for all those with time-use diaries in the control group is shown in Figure 6.3 and by income group in Figure 6.4 (the latter is presented as a probability to aid comparison between differently-sized groups).

Figure 6.3 Timing of top 10 peak demand periods

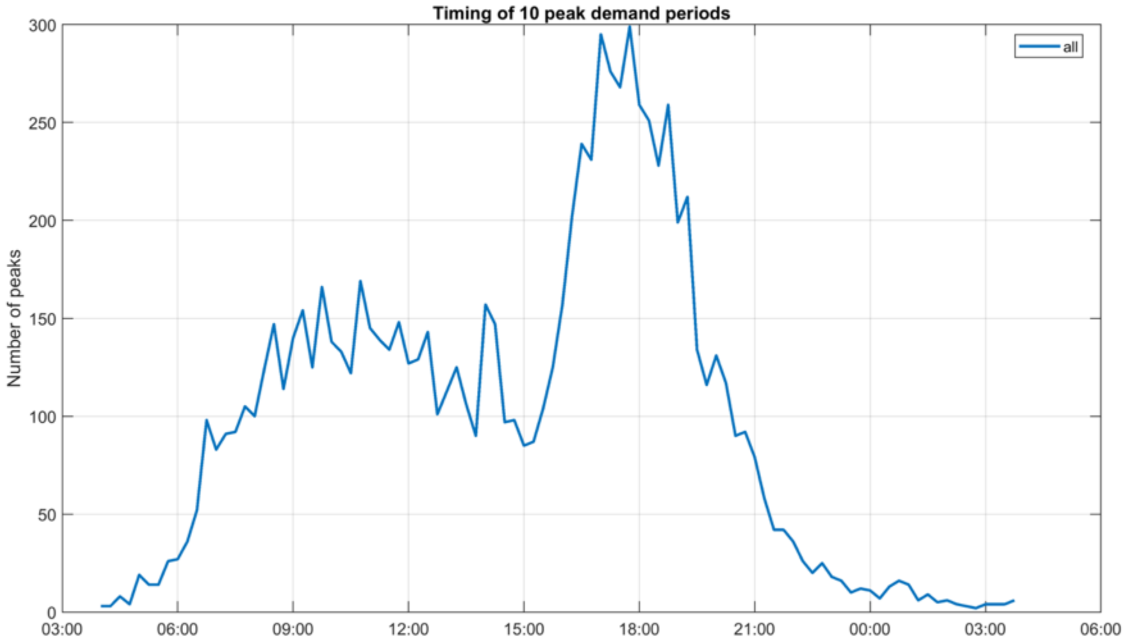
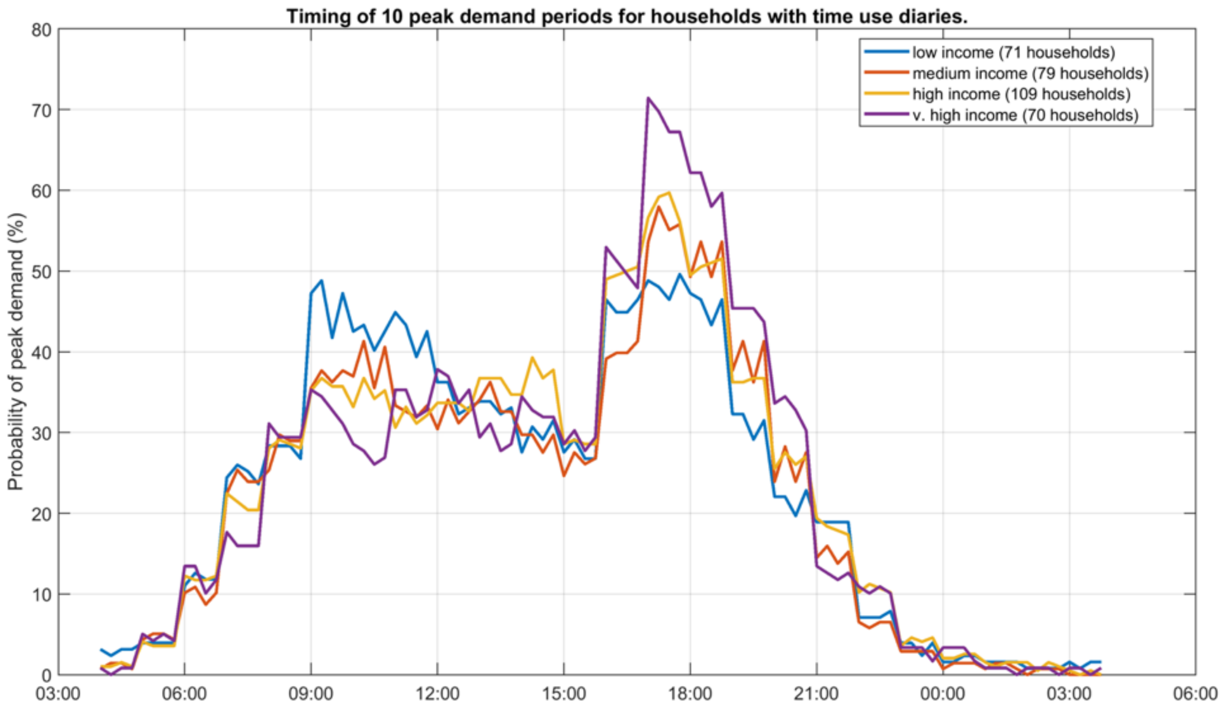


Figure 6.4 Timing of top 10 demand periods by income group



For very high and high income groups, household peaks drop off after 9am and don't exceed the pre-9am number until around 5pm, suggesting the entire household is absent or inactive during the day. For the two lower income groups, household peaks continue to rise in number after 9am through to around lunchtime, suggesting household day-time activity.

Higher income households may more likely be shifting day-time household tasks to the evening peak. There is little evidence for this in the analysis of actions during peak times, but this is hampered by the time-use diaries only recording the actions of one or two members of a household.

6.3 Activities during the evening peak time

Reported activities during and outwith the evening peak time are shown in Figure 6.5, for the control group – these have been scaled by time to support the comparison. (The same analysis split by income showed no clear differences). The same analysis, for actions, is shown in Figure 6.6.

Figure 6.5 Comparison of peak and off-peak activities

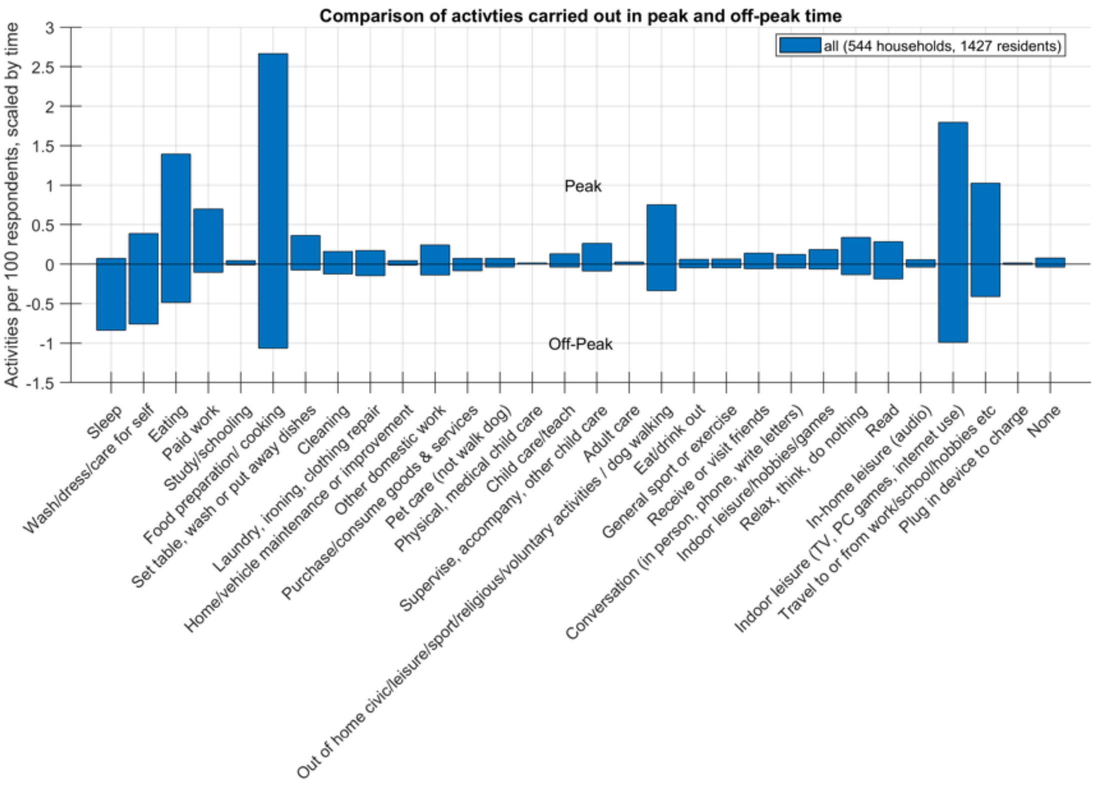


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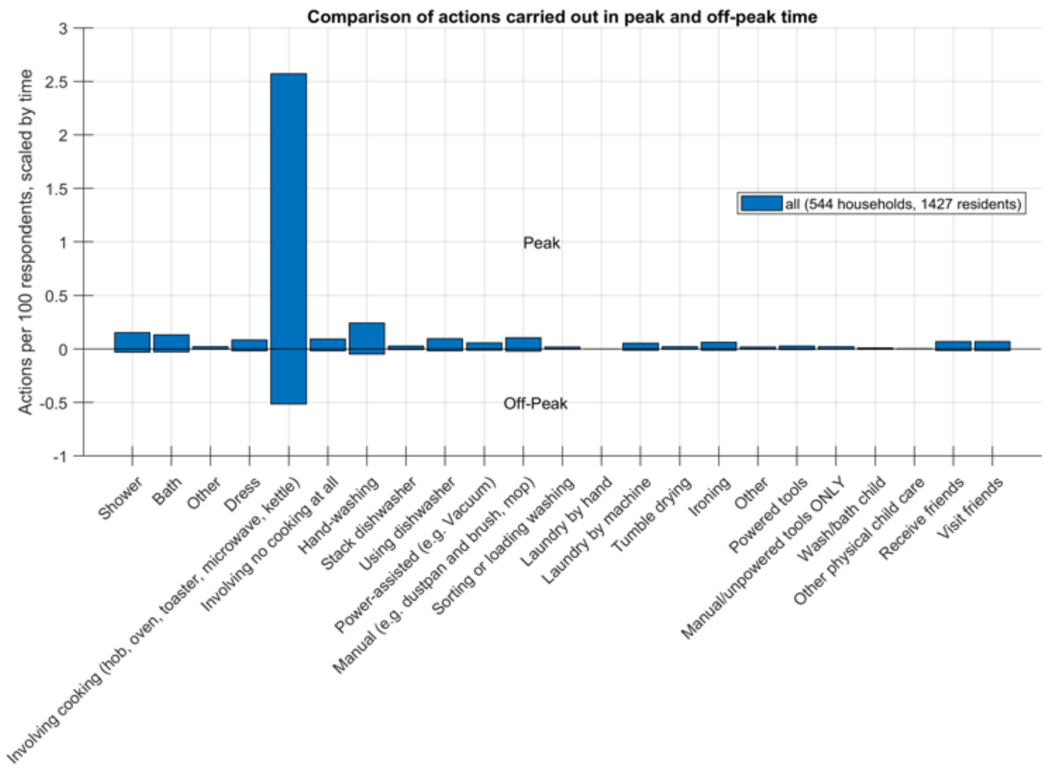
Figure 6.6 Comparison of peak and off-peak actions



⇒ There are no great surprises here, other than households remain very aligned to the traditional peak time for preparing and eating the evening meal and relaxing.

⇒ Some people are still working or travelling back from work during the evening peak[62].

6.4 Interventions – time-use diaries

We have attempted to analyse time-use diary data on intervention days, looking at the difference between control and intervention groups. However, we have not been able to establish any meaningful comparison between the two groups. This is because the diaries are free-form, allowing participants to record, or not, actions and activities as and when they chose. Simple counts of activities are able to provide some insight in the analysis presented above but, when looking for small differences between small sub-groups of participants, the results are counter-intuitive and, we believe, expose some of the difficulties in normalising diaries between different participants.

This is a key learning from the SAVE project which we discuss in Section 9.5.

[62] Paid work is also shown as recorded disproportionately in peak time, which we find difficult to explain and may be an artefact of the way the diaries are structured.

6.5 Summary

Despite the growth of more flexible working, including home-working, the SAVE data still paints a picture of a normal daily demand profile with a small peak in the morning and a larger peak in the evening. Self-care in the morning, and a meal in the evening, dominate the activities contributing to these peaks in demand. Smaller individual household peaks are driven by cleaning and laundry, but few households undertake these activities in the evening peak.

Whilst the SAVE project asked participants if they were participating in leisure activity such as watching TV, this did not feature in the specific electricity-consuming actions reported. So, whilst we can say that leisure time, which might have included TV, video games and streaming, is common during peak hours, it is difficult to say the extent to which this is contributing to peak demand. (There is also an element of off-site consumption associated with streaming, as it draws power in remote data centres).

7 Implementation – regulatory

The Citizens Advice report considers issues on implementation, considering the functionality of smart meters and its limitations, and options for implementing capacity limits and charging through code changes or voluntary action by Suppliers. Here we consider some consequential regulatory impacts of core capacity.

7.1 Policy costs

Environmental and social obligations contribute to 17.5% of an average electricity bill, according to Ofgem's latest calculations.[63] These costs comprise an array of social and environmental schemes paid for as a levy on bills.[64] The precise way in which Suppliers are charged varies, as shown in Table 7.1.

Table 7.1 Supplier social and environmental obligations

Cost allocation	Description of schemes
Obligation to provide renewable electricity, carbon savings, set in proportion to electricity supplied	Renewables Obligation – must source a proportion of supply from renewables electricity or pay a capped penalty Energy Company Obligation – carbon reduction targets to be achieved through energy saving measures
Fixed costs of scheme shared amongst Suppliers in proportion to electricity supplied	Feed in Tariff levelisation fund Assistance for areas of high distribution costs Warm Home discount (based on share of domestic market)
Fixed costs of scheme shared in proportion of gross demand	Contracts for Difference payments and administration costs
Fixed costs of scheme shared in proportion of net demand during high demand periods[65]	Capacity Market payments and administration costs

Suppliers pass these costs on to consumers, (unless they are specifically exempted, as is the case for some energy intensive users). Normally an electricity bill would have a fixed charge (£/day) and a variable energy charge (£/kWh) (although suppliers can offer energy-only tariffs where the fixed element is set at zero). Whilst it might be expected that Suppliers pass on these policy costs as a percentage of a consumer's energy consumption, there is no requirement on them to do so (i.e. Suppliers may decide exactly how these costs are passed through to consumers). However, as the structure of a bill changes, for example through the introduction of capacity-based charging, Suppliers may need to reconsider how they fairly allocate these charges. At the same time, Ofgem may need to consider how the costs are collected.

7.2 Price caps

The current set of mandated price caps, including on Standard Variable Tariffs (SVTs), require Ofgem to undertake detailed analysis of Suppliers' costs. The cap is expressed in per kWh terms,

[63] Ofgem, 2019. Infographic: bills, prices and profits

[64] https://www.ofgem.gov.uk/system/files/docs/2018/04/working_paper_4_-_environment_and_social_obligation_costs.pdf

[65] from 4 p.m. to 7 p.m. on any working day in November, December, January or February

but in setting the SVT cap, Ofgem calculates how much Suppliers might re-charge through the fixed and the variable element of an energy bill for each of the 14 distribution regions.

The introduction of capacity limits would further complicate the process of setting a price cap and may require a separate fixed and variable price cap. However, a core capacity level, introduced with a social objective might offer a simpler alternative to a price cap.

7.3 Data requirements

In the Citizens Advice report we discussed setting and monitoring capacity limits on the basis of half hourly average power, using half hourly readings from smart meters. This is the basis of existing capacity charges in GB for business customers, as well as for capacity limits and charges set in other countries.

This being the case, setting and monitoring capacity limits should be straightforward for customers with a smart meter. However, consumers are able to refuse a smart meter, in which case capacity charging would not be possible. Customers would need a history of smart meter data in order to understand future charges. Suppliers could access this data on behalf of the customer and help customers understand future bill implications.

Third-party access to smart meter data is subject to privacy rules. For example, Ofgem may wish to access anonymised smart meter data to undertake impact assessments on changes in charges. Sustainability First, with CSE, has convened a 'Public Interest Advisory Group' to consider privacy and public interest in the context of smart meter data. The Digital Economy Act 2017 allows the Office for National Statistics to access certain data for the public interest. A Data Access and Privacy Framework has been established specifically for smart meter data, giving customers choice over the use of their data unless it is being used to fulfil a regulatory duty. For DNOs to access smart meter data, they must first have privacy plans approved by Ofgem.[66]

7.4 System planning implications

The transmission and distribution systems are designed to mandatory planning standards which are maintained by industry and the regulator Ofgem, as well as a series of guidance documents which are kept current through industry working groups. Revisions ensure that planning documents are up-to-date with changes in technology and in the nature of generation and demand. Planning standards ensure that enough capacity is built to secure demand under credible conditions, including under fault conditions. They are premised on a detailed understanding of demand, and how it fluctuates in the short- and long-term.

Generally, the network is sized to account for demand 'diversity' – meaning that instead of building enough capacity to accommodate all households undertaking high power activities at the same time, it reflects the reality that there is diversity in what households do when. System planners have the confidence to do this based on years of historical data.

[66] https://www.smartenergydatapiag.org.uk

In the context of sizing the network to demand power peaks, key documents are the Distribution Code,[67] Engineering Recommendation P 2/6[68] and Engineering Recommendation P5[69] for the distribution system and the Security and Quality of Supply Standard (SQSS)[70] for the transmission system. These sometimes leave system planners with scope to use engineering judgement. For example, the SQSS states that:

> *"group demand for future years is equal to the Network Operator's estimated maximum demand for the group which they believe could reasonably be imposed on the onshore transmission system, after taking due cognisance of demand diversity…"*

Demand levels and patterns are however changing. Demand forecasting is a specialism of its own which feeds into system planning activities. It needs to consider, amongst other things, changes to demand 'seen' by the networks as a result of behind the meter generation, as well as energy efficiency improvements. Latterly, system planners are already thinking about electrification of heat and transport.

Just as electricity price rises alter levels of demand, the introduction of capacity charging will likely also alter consumption patterns – especially if a new charging regime is explicitly designed to do this. Core capacity and / or capacity charging will almost certainly require changes to demand forecasts. They might also require system planners to look at adjusting the way the networks are designed.

For example, Engineering Recommendation P5 contains typical demand profiles for homes based on the size of a home and its heating source. If every customer has a capacity limit, network planners will know peak demand capacity from the summation of individual limits. Planners could be conservative and disregard any reduction in demand from the introduction of capacity limits or less conservative, connecting more customers using freed-up capacity or deferring new investment.

Implementation of core capacity charging or capacity limits would also need some protections around the speed at which customers can adjust their limits. Requests for an increase could have implications for the physical security of the system. The 'tightness' of a network is a local issue. There would need to be a way of monitoring local limits and requests for new limits and agreeing thresholds beyond which the network companies would need to plan for new infrastructure and, potentially, delay capacity requests.

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[67] The Distribution code of licensed Distribution Network Operators of Great Britain. Issue 40, 16 June 2019. http://www.dcode.org.uk/assets/files/dcode-pdfs/DCode_v40_16062019.pdf

[68] ENA, 2006. Engineering Recommendation P2/6. Security of Supply. http://www.dcode.org.uk/assets/uploads/ENA_ER_P2_Issue_6__2006_-1.pdf

[69] ENA, 2017. Engineering Recommendation P5, Issue 6 2017. Design methods for LV underground networks for new housing developments. http://www.ena-eng.org/ENA-Docs/D0C3XTRACT/ENA_EREC_P5_Extract_180902050412.pdf

[70] National Grid, 2019. NETS Security and Quality of Supply Standards v2.4. https://www.nationalgrideso.com/codes/security-and-quality-supply-standards?code-documents

7.5 Regulatory burden

In Section 3 we touch on the additional resource implications for regulators of maintaining capacity charges, keeping them up-to-date and ensuring that there is no undue cross-subsidy between different groups of customers. This kind of regulatory burden may give pause for thought in introducing new arrangements in the GB market. However, it is not unusual for Ofgem to invest in monitoring and maintaining regulatory instruments and there is a duty on industry code administrators (e.g. National Grid SO for the Connection and Use of System Code) to keep them up to date and, in the case of charges, cost-reflective. Ofgem also updates price caps regularly with detailed analysis of Supplier costs and margins.

8 Implementation – ethical and social issues

If some kind of peak capacity-based charging were to be introduced, it would likely seek to be fair in the way network costs are levied. It is worth noting though that fixed charges disproportionately impact those who use lower levels of energy, so any fixed capacity-based charges should take this into account. We have considered here the potential for additional unintended outcomes on vulnerable consumers.

8.1 Unavoidable high peak usage

Low income households may have, through necessity, high peak usage. This will either because a household has higher than average energy needs and/or because there is little or no ability to shift energy use to off-peak times. The amount of energy a household consumes depends on a number of factors. Some are related at least in part to income, such as the number of appliances and the size of the home. Others are not related to income, specifically:

The number of people in the home

Work on the Minimum Income Standard described in the social science literature shows that, naturally, more people use more energy – which is likely to have some correlation with peak capacity. While some loads can be shifted to off-peak times, some of it probably cannot (such as additional lighting).

A need for energy services

Some households will have a higher need for energy services, e.g. warmth (older, less mobile householders will need higher temperatures) or medical or support equipment (such as home dialysis machines or stair lifts). In the case of dialysis machines, they help to keep the user alive and therefore would be at the very top of any consideration of what is 'essential'. Home dialysis machines may be rated at 2kW[71] and may be required to be used for several hours at a time, several times a week.

Electric heating and cooling

Electric storage heaters are designed to be charged during off-peak hours and so may not add to the peak if used correctly, though additional electric heating may sometimes be needed to provide additional warmth during the peak evening period. In 2011, around 14.3 million homes (63% of dwellings) had some form of secondary heating, with around 56% of these using them during the 'hometime' period of 3-7pm[72] (some of which will overlap with the peak period).

HPs are generally designed to run continuously and would therefore add to the peak capacity. However, the literature review found evidence of trials run in Italy and the Netherlands that

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[71] Kidney Health Australia (2015), The impact of increased power costs on home haemodialysis https://kidney.org.au/cms_uploads/docs/february-2015-the-impact-of-increased-power-costs-on-home-haemodialysis-northern-territory.pdf

[72] BRE and DECC, 2013, Energy Follow up Survey https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/274774/5_Secondary_Heating.pdf (We have been unable to find any more recent analysis of the useage, including time-of-use, of secondary heating).

involved smart HPs which were set to prioritise operation when electricity costs are lower, thus reducing their impact on peak demand.

Air conditioning would not currently be considered essential. But with forecast climate changes, we are likely to see air conditioning retrofitted to older, more energy inefficient homes. It may come to be considered essential for vulnerable householders living in homes most prone to overheating. Over 7,000 deaths from overheating are forecast by 2050 if the government does not take action to ensure homes are better adapted to cope with the heat, with older people with kidney or heart problems most vulnerable.[73]

Home energy efficiency

Inefficient homes (e.g. solid walled, single glazed) heated by electric heaters will use far more electricity than an energy efficient home with a modern gas heating system, all other things being equal. Low income households are more likely to live in an inefficient home; 92% of England's 2.5 million fuel-poor households live in homes with an efficiency rating of D or below (as of 2015), and 37% live in homes with a rating of EPC E.[74] And lower income households are also more likely to use electric heating; in England, 36% of storage heating customers and 31% of customers with direct-acting heating belong to the lowest income quintile (i.e. lowest 20% of households), with similar proportions in Scotland.[75] Core capacity should allow for households to achieve an adequate level of comfort and, at the same time, not detract from the need for ongoing improvements in energy efficiency.

8.2 Inability to shift to off-peak times

EVs

Smart charging should be able to avoid the highest peaks, but peak capacity may still be higher than a basic core. At the moment, EV ownership is associated with higher income 'early adopter' households. However, the UK government is planning to phase out combustion engine vehicles with only EVs to be sold from 2032 in Scotland and 2040 in the rest of the UK. In areas well served by public transport (predominantly cities and larger towns), car ownership could be considered a luxury except for those who are mobility impaired. However, in more rural locations, car ownership is a necessity for many. Technological, tariff and regulatory changes can be implemented in order to future-proof EVs and limit their impact in terms of capacity requirements. But there will still be some impact, particularly for certain households who can't flex their consumption either because of technological or lifestyle barriers (e.g. no access to a smart meter, or requiring use of their vehicle during off-peak hours).

Ability to flex

Different households have different abilities to flex their energy consumption. Research has found that ability to flex is a function of electrical load, time flexibility and knowledge /

[73] https://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/news-parliament-2017/heatwaves-report-publication-17-19/
[74] https://www.ippr.org/files/2018-07/fuel-poverty-june18-final.pdf
[75] https://www.ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheatingpdf

motivation.[76] The first two of these can work in opposition to limit the available flexible demand. That is, households with large electrical loads are likely to have more occupants and less flexibility as to when appliances are on. These may include multi-generational households with occupants who have differing routines in terms of when they are in the home (e.g. working different shifts), all requiring energy services (such as cooking and washing) at different times. In contrast, households with more control over the timing of their electricity use may be single or two person households with small loads. In addition, consumers may not understand how they can change their behaviour to reduce their peak demand, or they may not have access to technology that can facilitate shifting energy use.

8.3 Potential impacts against measures of exclusion

There are certain groups of consumers who can be or will be considered to be excluded from the mainstream energy markets. Often these exclusions overlap in the same consumers. We have considered these excluded groups and considered the potential impacts of core capacity and capacity-based charging.

8.3.1 Digital

Smart meters

Capacity-based charges are only possible for customers who have a smart meter. Not all households will have a smart meter in the short-term, either by choice or because there are technical barriers, and these households will be unable to access potential savings linked to shifting energy use to off-peak times.

Digital literacy

Customers with a smart meter will be able to access a range of off-peak tariffs and other services including apps that can enable shifting of energy use to off-peak times. However, this will require a degree of digital literacy which certain customers may not have (particularly old customers or those with learning difficulties). There are also economic barriers to accessing these technologies, as detailed below.

8.3.2 Economic

There are a number of digital solutions that will encourage or enable people to shift their energy consumption to off-peak times, thus avoiding the higher capacity charges. However, there is a cost associated with these which means they will only be available to higher income customers. For example:

- Smart appliances are now available that can be programmed to come on at off-peak times. These cost more than 'dumb' appliances and are unlikely to be purchased by low income households who are likely to replace their appliances less frequently than more affluent households.
- Apps and other devices are available to facilitate shifting. For example, in March 2019, Octopus Energy, whose 'Agile' energy tariff tracks the wholesale price of energy, announced a partnership with Alexa (Amazon's voice enabled digital assistant) to allow

[76] UK Power Networks, 2018, energywise SDRC 9.6 report

its customers to 'hack' the domestic energy market. Customers will be able to ask their Alexa products, "*Alexa, ask Octopus; when is electricity cheapest today?*" They will then be able to use Alexa, which is enabled in more than 100 million devices around the world, to adjust energy usage based on half-hourly price changes. The Amazon technology can also manage a range of household appliances including lights and heaters. Octopus Energy claims that using Alexa with the tariff could help save up to £229 compared with large legacy supplier standard deals.[77] Alexa technology currently costs from £70 and, though the claimed savings mean that it would pay for itself in just a few months, this upfront cost will put it out of reach of low income households.

8.3.3 Geographic

In the UK, heating type is largely a factor of geography. The majority of homes located on or close to the gas grid have gas central heating; the majority of those not on the gas grid will have electric heating. In addition, the amount of heat needed is linked to geography; Scotland experiences colder winters than southern England requiring more energy to achieve comfortable temperatures.

8.3.4 Physical: age / disability

Some consumers may simply not have the ability to flex power requirements and avoid high charges due to their age or health. For example:

- Those with medical equipment in the home such as home dialysis machines.
- Older and less mobile consumers who require a higher indoor temperature to remain comfortable and healthy.

In addition, Smart Energy GB has found that certain groups will be less likely to want or to accept a smart meter, or to benefit from a smart meter once they have one[78]. These include those who are over 75; do not have English as a first language; are lacking in qualifications; have poor health or a disability; are lacking in access to certain channels such as internet or mobile phone; or are lacking in digital skills.

8.3.5 Household structure

Ability to flex demand is also a function of household structure. The LCNF funded 'energywise' project tested the ability and willingness of low income households to shift their energy consumption to off-peak hours. Research carried out with participants by UCL uncovered a number of interesting findings[79]:

- In general, small households have more control over when they use energy. Larger households with many occupants have less ability to shift their energy use.

[77] As reported in Energy Live News, March 2019, https://www.energylivenews.com/2019/03/18/octopus-energy-integrates-with-amazon-alexa-for-smart-energy-use/

[78] Smart Energy GB (2015) Smart energy for all – A consultation paper on identifying audience characteristics that may act as additional barriers to realising the benefits of a smart meter

[79] UK Power Networks, 2018, energywise SDRC 9.6 report

- If energy use is being manually shifted (through behaviour change rather than, for example, smart appliances) then all members of the household need to be engaged. In particular, DSR both depends on and affects women. Women are currently responsible for the bulk of domestic labour in the UK related to flexible loads (machine washers, dryers). However, in many cases the bill-payer is not the same person as the chore-doer (probably a relative e.g. husband) and DSR may currently place greater demands on women changing their schedule than men. Therefore, for DSR to be successful and reach its full potential, women must be engaged.
- Some participants engaged enthusiastically with the energywise trial, shifting as much of their energy use as they could out of the peak times. For example, *"One participant has succeeded in making other household members respond to (the trial), and has taken extraordinary measures… e.g. taking the family out of the house during a weekend three-hour event)."*
- Some households felt they were completely unable to shift any of their energy use out of peak times as they get home from work at about 6pm and go to bed at 10pm and must do all their cooking and chores during these hours.
- And, in some cases, householders can be unwilling to shift loads which are generally recognised as being not time critical. *"In the household not actively taking advantage of the (offer), this was because the wife had a set laundry routine … and was not prepared to change this."*[80]
- One participant had misunderstood the scheme and, despite multiple communications, carefully designed to be very easy to understand, believed they should be increasing their consumption during the critical peak rebate periods.

This illustrates how vital clear communication and support for vulnerable households will be in terms of ensuring equitable access to off-peak tariffs and other financial incentives designed to limit peak capacity.

8.4 Existing protection measures

8.4.1 Energy company obligations

There are a number of obligations on energy suppliers and DNOs in terms of protecting vulnerable customers – described in Table 8.1. Consideration could be given to amending or adding to these to ensure protection for vulnerable households from capacity charging.

[80] UK Power Networks, 2017, energywise biannual report December 2017

Table 8.1 Energy company obligations to vulnerable customers

Obligation	Applies to	Details	Is it likely to link to peak capacity?
Priority Services Register[81]	Those who: • are of pensionable age • are disabled or chronically sick • have a long-term medical condition • have a hearing or visual impairment or additional communication needs • are in a vulnerable situation. Each energy supplier and network operator maintains its own register.	The Priority Services Register is a free service provided by suppliers and network operators to customers in need. Those registering as priority services customers may be eligible for free services including advanced notice of planned power cuts and priority support in an emergency.	These registers should include details of customers dependent on electrically operated equipment, thus identifying one cohort of highly vulnerable customers who would need protecting from higher capacity charging.
Warm Homes Discount[82]	Customers of larger energy suppliers (>250,000 customers) who get the Guarantee Credit element of Pension Credit plus those who are on a low income and meet their energy supplier's criteria for the scheme.	£140 rebate on electricity bill	This could be amended to ensure that low income 'energy intensive' homes (e.g. those with electric heating) are eligible to receive the discount to compensate for their having to pay a higher capacity charge.
ECO[83]	Eligibility is as per the Warm Home Discount Scheme (above) or for those receiving certain benefits and satisfying the relevant income requirements, where applicable.	The Energy Company Obligation (ECO) is a government energy efficiency scheme in Great Britain to help reduce carbon emissions and tackle fuel poverty. It provides funding for energy efficiency measures for low income households.	Funding could be targeted at low income 'energy intensive' homes such as those with electric heating.
Price cap[84]	Customers on prepayment meters and customers on Standard Variable Tariffs.	The prepayment price cap limits how much a supplier can charge customers on prepayment meters per unit of energy.	A similar 'capacity charge cap' could be introduced for certain categories of vulnerable 'energy intensive' households.

[81] https://www.ofgem.gov.uk/consumers/household-gas-and-electricity-guide/extra-help-energy-services/priority-services-register-people-need
[82] https://www.gov.uk/the-warm-home-discount-scheme
[83] https://www.ofgem.gov.uk/environmental-programmes/eco/support-improving-your-home
[84] https://www.ofgem.gov.uk/energy-price-caps/about-energy-price-caps

8.5 Summary

This is a short review of the potential impacts of capacity limits and capacity-based charges on those who might become unfairly disadvantaged, without careful implementation. Measures that might alleviate these impacts are discussed here, and there are examples from the international literature as well, discussed in Sections 3 and 4. For example, tariff exemptions covering essential heating or discounts for those with essential medical equipment.

In the UK we already have a number of measures designed to protect vulnerable members of society (Warm Home Discount) and promote energy efficiency (ECO). These could be adapted or amended around new capacity-based incentives, or new protections might be introduced, such as core capacity variations that recognise differing household circumstances. Where Ofgem were to direct universally-applicable changes to access and charging, this would almost certainly be accompanied by detailed assessment, including impact assessment.

9 Summary and conclusions

This report covers a wide range of issues on the concept of core capacity and capacity charging, exploring areas for discussion and development should the concept be taken further. It has been written as a follow-on from our work for Citizens Advice, which is very much focused on Ofgem's Future Charging Review. Specifically, Citizens Advice asked three questions – could a capacity limit be set; what might it be; and how might it be implemented? In seeking to answer the second question, we have drawn on three Ofgem innovation-funded DNO projects with smart meter data, of which SAVE has been one.

The SAVE data offered additional scope for exploring questions around household activities and characteristics, through enhanced survey data collected from participants and time-use diaries. SSEN is keen to contribute to the debate and capitalise on the use of SAVE data for real-world application. As well as interrogation of SAVE data, SSEN has commissioned us to develop some of the more social angles on capacity-based access and charging – through literature review and commentary on some of the more vulnerable groups of consumers.

The two reports, for Citizens Advice and SSEN, should be read together – the former introducing the concept of core capacity and its derivation, the latter looking more widely at the social side and extracting value from the SAVE data.

9.1 Further findings on core capacity

9.1.1 Energy efficiency measures

There is no clear association between energy efficiency measures installed and peak demand

This is perhaps unsurprising given that energy efficiency measures are largely targeted at reducing heating requirements and that, for most households, this is provided by gas. Energy efficiency is likely to be more pertinent to peak electricity demand if and when more homes utilise modern electric heating. There could also be an income effect, in so far as high income households use more energy and may also be disproportionately represented in efficient homes, thus levelling their consumption to less efficient low income homes (low income consumers are more likely to live in inefficient homes, see Section 8.1).

9.1.2 Low carbon technologies

Whilst SAVE data does shed some light on the impact of LCTs on household peak demand, the sample sizes are small and this would benefit from further monitoring and analysis.

EVs in the SAVE sample are having no impact on household peak demand

There is an uplift overnight associated with EV charging. We assume that SAVE households had low rated capacity EV chargers for slow overnight charging. Future work could usefully examine the impact of different chargers and charging duration.

HPs are having a significant impact on household peak demand, with the morning heating peak overtaking the evening peak

Again, we have no information on HP rating, but assume that HPs in the study are sized to household heating load.

PV is matching the evening peak, but at the wrong time

PV generation in the summer peaks at midday at around the same or greater capacity as the evening peak. Whilst domestic battery storage could redress this timing mis-match, the economics are currently not favourable. Time-of-use tariffs coupled with falling battery costs would improve the economics.

9.1.3 Impact of selecting a core capacity value

We have explored the impact of selecting a core capacity value by analysing the occurrence of peak household values. 3kW broadly aligns with the most common household capacity limit in other countries and with the majority of gas-heated households in the UK (see the Citizens Advice report).

At 3kW, all income groupings show peaks outside 3kW, up to greater than 20kW, suggesting the need to change behaviour or pay extra to stay within the limit.

Electric-heated households show a flat distribution of peak values between around 3-7kW which supports the need for a differentiated core capacity for these customers.

There is a wide variation in household peak for electrically-heated homes, pointing to a need to consider heating load and / or heating technology.

The data suggests that low income homes are more likely to have electric heating.

9.1.4 Timing of household demand peaks and associated activities

Activity data from SAVE has allowed us to understand what people are doing at periods of high and very demand and how peak demand varies across households. We had hoped to be able to analyse what if any activities are flexible, but this has not been possible due to limitations of the time-use diary data.

Cooking and showering are the key electricity-using actions associated with household demand spikes

Although the main peak for most households is in the evening, individual household peaks occur throughout the day and night. Low income consumers appear to have more peaks on weekday mornings.

Most people are cooking and relaxing in the evening peak

Despite changes in working patterns, the evening peak remains a feature of most households and there are no surprises in what most people are doing at this time, i.e. cooking and relaxing. Some are still travelling home from work and a smaller number are doing household cleaning.

9.2 Needs-based energy sufficiency

Drawing extensively on social science literature, and in particular Joseph Rowntree's Minimum Income Standard, it is possible to establish the electrically-powered appliances that households need to maintain their basic needs and function in society as a social beings.

If all these appliances were used at the same time, they would account for somewhere between 13-18kW depending on household size and composition. However, in real life households rarely draw more than around 3-6kW of peak power, because we generally don't have everything on at once.

Household cleaning chores and charging EVs are less time-critical to consumers than cooking, eating, heating and self-care.

Trials suggest that consumers can be incentivised to shift demand, especially through automatic adjustments where consumers see no loss of utility. There are however many practical considerations, some inevitably yet to be uncovered – these include for example the night-time noise from setting timers on washing machines.

Energy sufficiency is not constant, both in terms of the energy input required to serve consumers' needs, as well as the definition of need

Technology is changing. Energy efficiency should reduce energy inputs required for an energy 'end service' whilst fuel switching – the electrification of heat and mobility – is driving increases in electrical capacity requirements.

9.3 Vulnerable consumers

Core capacity could be introduced to ensure energy bills remain fair and cost reflective, but there is the potential for disproportionate impacts on vulnerable and disadvantaged consumers.

The introduction of something like core capacity or capacity charging is a significant shift for domestic consumers. It will likely change the way consumers behave, as well as what they pay. Its introduction on a market-wide basis would almost certainly be accompanied by detailed impact assessment, and this will need to include careful consideration of the impact on vulnerable and / or disadvantaged consumers.

Existing protections could be adapted, as well as new protections introduced.

9.4 Regulatory issues

There will be a need to consider consequential changes from reform of the structure of charging.

This might include how policy costs are passed through to consumers, the structure of any future price caps and updating of relevant network planning standards.

There will be a need to monitor and future-proof core capacity levels.

There is an inevitable regulatory burden associated with this which needs to be considered in any impact assessment.

9.5 Lessons and further work

SAVE data has helped us to generate insights into the application of a concept like core capacity. The combination of 15-minute resolution meter data alongside household-matched survey information and time-use diaries is extremely powerful. Some areas for future consideration include:

⇒ There are clear income-related effects on peak capacity, and at the same time new business models are offering households rewards for shifting or reducing demand. There are questions of parity here, where lower income households don't have the luxury of avoidable consumption. Charges for additional capacity may go some way to addressing this.

⇒ Time-use diaries generate extremely valuable data but are difficult to get in a format which provides comparable, complete and accurate data for an entire household. There is scope for improving our understanding of the day-to-day workings of households, but recruitment of participants willing to (in some way) record activities 24/7 is inevitably challenging.

⇒ There is a need to gather more and ongoing data on the impact of LCTs on household demand, and to collect information which aids interpretation – rated capacities of the new technologies, noting combinations of LCTs and household characteristics.

⇒ The impact of energy efficiency on electrically-heated households would also benefit from further study.

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