CAG CONSULTANTS

Consumer network access, core capacity

A REPORT FOR CITIZENS ADVICE BY CAG CONSULTANTS, IN ASSOCIATION WITH TIMUR YUNUSOV AND JACOPO TORRITI

INFORMING POSITIVE CHANGE

Citizens Advice

Consumer Network Access – core capacity options

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Executive Summary

In December 2018 Ofgem launched a Significant Code Review (SCR) looking at access and forward-looking charging arrangements. Amongst other things it is seeking to clarify "access rights and choices for small users".

Ofgem is considering the concept of minimum "core access" in its proposals. "Core access" (if it can be defined) is an amount of capacity that cannot readily be flexed and that provides for consumers' basic needs. Capacity-based (or time of use energy-based) charging might mirror this concept by considering an affordable level of "core access".

Citizens Advice is participating in the SCR and has commissioned this work to better understand the concept of core access, and understand what it means for consumers. Citizens Advice posed three key questions for this research:

- Is it possible to determine a, or a set of, common core electricity network capacity levels for domestic consumers and micro-businesses?
- What should the core level of access be set at?
- How could this be implemented (technical or commercial solutions)? What are the barriers/risks to consumers, suppliers and networks?

In the same order, we address these questions through:

- An evidence review covering experiences with capacity limits and capacity charging in other electricity markets.
- Interrogation of smart meter data available from DNO innovation projects.
- Commentary on the implementation options, looking at both voluntary and mandatory measures.

Experiences with capacity limits and capacity charges for small users

We have reviewed experiences in a number of countries that have implemented measures to place limits on consumers' capacity requirements. These limits appear to be lower than the physical household fuse capacity in these countries. Capacity thresholds are associated with higher costs for higher thresholds. Typically, customers can choose from pre-defined capacity limits. Retailers provide guidance on how much might be required for smaller and larger households, with or without certain appliances, heating and cooling. Some markets also allow for short periods of disconnection if consumers exceed their capacity limits.

We found that the Southern European countries of Italy, Spain and Portugal offer substantial experience in implementing and refining capacity-based limits and charging. A key driver of this is the capacity-demand of electric air conditioning. Similarly, countries where heat pumps are gaining ground – Sweden, Norway and France – are starting to implement capacity-based charges for domestic consumers.

We have also looked at Increasing Block Pricing (IBP) which involves charging for energy consumption in pre-defined "blocks", with charges increasing as consumers move up the blocks. Under IBP, higher levels of consumption cost more per unit than lower levels. IBP is used as an explicit pricing tool to:

- provide for affordable levels of consumption to meet basic needs, and / or
- disincentivise higher levels of consumption

We have looked at IBP examples in electricity in Italy, the US and South Africa. IBP is considered here as having parallels with the concept of core capacity.

Smart meter data – looking at consumer's current capacity use

Analysis of smart meter data from three DNO innovation-funded projects has allowed us to understand the every-day peak capacity of electricity consumers in the UK. We analysed smart meter data from three projects: Northern Power Grid's Customer-Led Network Revolution (CLNR), UKPN's Low Carbon London (LCL) and Scottish and Southern Energy Network's (SSEN's) Solent Achieving Value from Energy Efficiency (SAVE).

Whilst each project ran trials with consumers on, variously, time of use incentives and low carbon interventions, each had control groups of consumers where half hourly or quarter hourly smart meter data was available for a year or more. We have been able to paint a picture of how maximum demand varied in time, and across different types of consumers (income levels, heating type, rural or urban and other categorisations).

Electric heating and high-income levels contribute to high-end capacity usage, whilst consumers living in adversity contribute to low-end capacity use. Findings from our analysis of smart meter data are summarised in Figure 0.1 below and compared against the capacity limits used in Italy and Spain.

Unfortunately for this report we could not access household-level smart meter data for users of low carbon technologies. Instead we analysed meter data specific to a heat pump (HP) or an Electric Vehicle (EV). This showed maximum demand on a par with an off-gas electrically-heated household, of around 6-7kW. Thus, we would expect HPs and EVs to increase maximum demand for most households, and especially so if EV charging coincides with the evening peak.

Implementation of core capacity

Smart meter functionality, practices in other countries and existing capacity-based charging for business users all point to capacity limits being implemented using half hourly averages. This means that capacity charges would be based on the half hourly energy reading, converted to a capacity value, rather than on shorter spikes in capacity usage. Use of half hourly averages has the benefit of allowing for higher-than-average sub-half hour peaks in capacity associated with, for example, use of electric showers. In implementing core capacity, other mitigating measures might include time-limited capacity limited exceedance i.e. a soft rather than a hard limit. Smart meters can be configured to disconnect customers when limits are exceeded. Although disconnection is practised in Italy, we think it would be unpopular and introduce extra risk for vulnerable consumers.

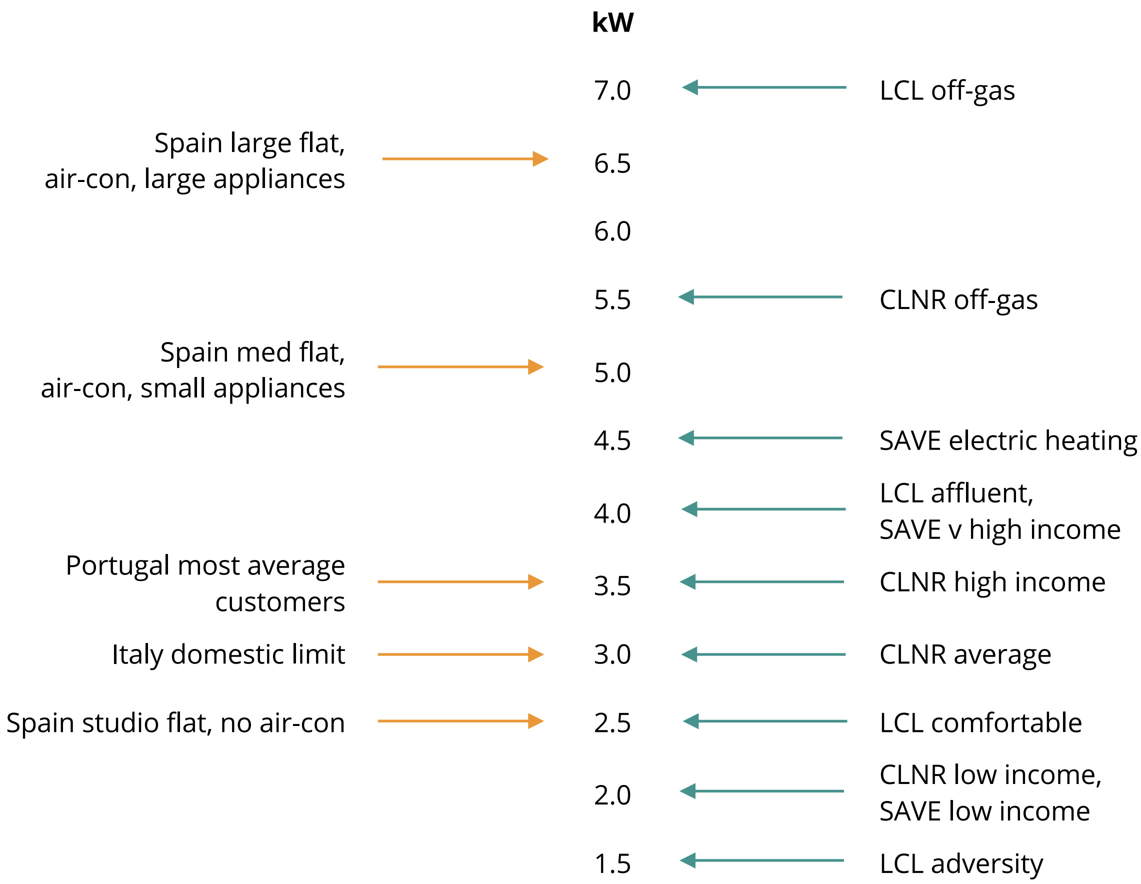

Figure 0.1 Comparison of capacity usage in smart meter data and capacity limits used in Italy and Spain

Ofgem's SCR could culminate in the electricity industry being directed to change industry codes to define and redefine access rights and charges. This is one way in which core capacity and / or capacity charging could be implemented and would result in a set of common rules to which all electricity suppliers would need to adhere.

In the absence of a direction, electricity suppliers could voluntarily decide to investigate different ways of charging domestic consumers. Constraints set by their license conditions mean that electricity suppliers must ensure that tariffs are comparable and that consumers can make informed choices. There would need to be a dialogue with Ofgem on what is achievable under this kind of voluntary arrangement.

Final conclusions and further work

Our overall conclusions are as follows.

- Core capacity is a viable concept and could be implemented to achieve cost reflectivity and / or social objectives.

- The evidence points to a basic core capacity of around 2-3kW, characteristic of low income consumers. However, this research simply looks at current capacity usage, and has not examined the factors contributing to capacity use. Further work is required to understand whether low income consumers are using enough electricity to meet their basic needs – it is possible that the 2-3kW figure reflects suppressed demand.

- Electric heating, traditional or HP-based, can double the basic core capacity to around 6kW, pointing to a need to differentiate core capacity by heating type. i.e. have multiple core capacity levels depending on household heating arrangements.

- Electric cars could also double core capacity, and more than double it if consumers plug in an EV on return from work. It is not clear cut whether an EV should currently be classed as a core need, but it is clear that any judgement on this point will need to be kept under review as EVs become more widespread.

- Based on current consumption patterns, some consumers will exceed this core capacity, reaching peaks of up to 20kW. We do not yet know enough about these outliers, what and who is responsible for them.

- Further insight into these questions are provided in an accompanying report that CAG Consultants and Reading University have prepared for Scottish and Southern Energy Networks (SSEN). This separate report looks into the social science literature on essential needs; and it analyses time-use diary information to understand what consumers are doing at times of peak demand.

Additional further work that we recommend should be undertaken before implementing "core access" charging includes:

- **Cost reflectivity** - Investigating the cost reflectivity of the network element of consumer bills and how this would change with core capacity and / or capacity charging. DNOs need to consider whether half hourly average capacity charging gives the right incentives to consumers from the perspective of distribution system costs.

- **Increasing Block Pricing –** Considering whether Increasing Block Pricing, based on energy use, could meet the same or similar aims of core capacity in a simpler way that would be more readily understood by consumers.

- **Unintended consequences** – We provide some initial analysis of potential impacts on vulnerable customers, in both this and the SSEN report. Further consideration is needed about the possible unintended consequences of core capacity for vulnerable consumers.

- **Small businesses** – the smart meter data available from small business consumers is sparse and points to significant variation in capacity requirements. Extensive further work is required to understand the capacity requirements of small businesses, considering amongst other things the business factors driving capacity requirements.

1 Introduction

1.1 Context

The driver for this work is Ofgem's project, "Reform of network access and forward-looking charges", launched towards the end of November 2017. A July 2018 consultation "Getting more out of our electricity network by reforming access and forward-looking charging arrangements" put forward some draft proposals and in December 2018 Ofgem launched a Significant Code Review (SCR) aimed at, amongst other things, "clarifying access rights and choices for small users."[1]

The proposed reforms start to envisage defined network access rights for domestic and small business users, as well as more targeted network charging for these groups. At transmission and high voltage distribution, large customers and generators are charged based on access rights defined wholly or partly in capacity terms, as well as location and timing of peak usage. At the lower voltages serving small users, access rights are not well defined and the charging model – the Common Distribution Charging Model (CDCM) – makes generic assumptions for a diverse range of customers.

It is easy to see why this issue has risen up the agenda: electricity consumption is projected to rise, driven in part by the electrification of heat and transport at the householder level. Microgeneration installed in the home has already seen a massive uptake, materially impacting on reinforcement plans of the network companies and day to day operational decisions. Future networks need to be sized to peak loads, but only sub-sections of society are, currently at least, responsible for these trends. Electric Vehicle (EV) uptake is on the rise for example, but is still, at the moment, a minority of the population.

Ofgem has suggested the concept of "core access" in its proposals. This is, essentially, an amount of capacity that cannot readily be flexed and which – if it can be defined – 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.

This is a change from the current system, where everyone pays for the extra capacity needed at peak times, whether they use it or not. Around 25.4% of the bill for the domestic consumers comes from network costs, regardless of a consumer's required capacity.[2]

Whilst the concept of a "core" level of access might seem at first relatively simple, there are many questions around its implementation – practically, socially and in what form? For example: what is the right level of capacity for core access; how many tiers of access there should be and should they be time-differentiated; what are the consumer impact issues around implementation?

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[1] Ofgem, 2018. Getting more out of our electricity networks through reforming access and forward-looking charging arrangements. https://www.ofgem.gov.uk/publications-and-updates/getting-more-out-our-electricity-networks-through-reforming-access-and-forward-looking-charging-arrangements

[2] Ofgem infographic, Bills, prices and profits. https://www.ofgem.gov.uk/publications-and-updates/infographic-bills-prices-and-profits

In its 2018 consultation Ofgem states that:

"A key challenge .... relates to the variability in the nature of household demand and in how "essential" usage might be understood. Careful consideration would need to be given to how any limits or thresholds were set."

We start to look at these questions here from the top-down – looking at how much capacity households use, and under what circumstances and conditions. The bottom-up approach, building up a picture of essential needs, is something we consider in our sister report for SSEN.

Charging-wise, although current Distribution Use of System charges do not target specific costs to specific low voltage consumer users, electricity suppliers do have the option of targeting distribution costs regionally. Analysis by Ofgem suggests that suppliers do pass on these costs on a regional basis[3]. Smart meter functionality could be used to target use of system costs on an individual basis, and there are therefore questions around whether this would be desirable and acceptable, or whether alternative options should be explored.

Ofgem's future charging work is an attempt to answer at least some of these questions, amongst others, and it has set up a Challenge Group and Delivery Group to scope out and define the issues.[4] This work is designed to feed into this process.

1.2 The commission

Citizens Advice has commissioned this work from CAG Consultants, working with Professor Jacopo Torriti and Doctor Timur Yunusov from the University of Reading. The research asks the following questions:

- "Is it possible to determine a, or a set of, common core electricity network capacity levels for domestic consumers and micro-businesses?"
- "....what should the core level of access be set at?"
- "How could this be implemented (technical or commercial solutions)? What are the barriers/risks to consumers, suppliers and networks?"

In the same order, we address these questions through:

- An evidence review covering experiences with capacity limits and capacity charging in other electricity markets.
- Interrogation of smart meter data available from DNO innovation projects.

[3]https://www.ofgem.gov.uk/sites/default/files/docs/2015/10/reg_charges_final_master_version_23_october_2015.pdf
[4] https://www.ofgem.gov.uk/system/files/docs/2018/12/appendix_3_-_stakeholders_engagement_1.pdf

- Commentary on the implementation options looking at both voluntary and mandatory measures.

1.3 Remainder of this report

The reminder of this report is structured as follows:

Section 2: Literature Review

Section 3: Modelling

Section 4: Implementation

Section 5: Conclusions and further work

2 Literature Review

The literature review has been shaped around answering the following question in the ITT:

"**Is it possible to determine a, or a set of, common core electricity network capacity levels for domestic consumers and micro-businesses?**"

And specifically, the literature review aims to look at:

- Capacity limits that have been implemented elsewhere, how they vary and why.
- Whether limits impact consumers tariffs and if so how (we have expanded this from the proposal to include consumer tariffs which incorporate or incentivise a capacity element).
- Whether there are any time or otherwise-differentiated network access products.
- How the capacity limits are managed, controlled and whether they have improved system planning and operation, and impacted on overall system costs.

2.1 Capacity limits

For traditional meters, capacity limits are defined by a building's fuse which dictates the maximum current supplied to the property. In turn, the fuse is designed to protect the physical limitations of the distribution network.

In the UK, nearly all residential consumers have single phase supply, with a household fuse rated at 60-100Amps. This translates to around 20-24kW maximum capacity. In Europe three-phase connections are widespread, by virtue of which physical capacity limits are significantly higher than the UK. For example, in the Netherlands, the maximum allocated capacity for domestic customers with a three-phase connection is 3 x 80Amps, which translates to 52.8 - 57.6kW. In Spain, the maximum allocated capacity for domestic customers with a three-phase connection is 3 x 45Amps, equivalent to 31.2kW. Where smart meters have been installed, capacity limits do not have to follow the predefined granularity of the fuse and can be selected at levels up to the fuse limit. Examples of capacity limits and their derivation are provided here.

Isle of Eigg, Scotland

The Isle of Eigg operates its own renewable energy-powered microgrid which relies on islanders observing a 5kW limit for households and 10kW for businesses.[5] The 5kW limit allows a washing machine and kettle to operate simultaneously. A £20 re-connection charge is imposed if the limit is exceeded, but has rarely been used. Each household has an energy monitor to help them stay within their load limits. A red light is displayed on the island pier when renewable generation is relatively low, asking residents to limit their usage; a green light indicates normal conditions.

Whilst residents of community-owned Eigg are highly motivated and may be atypical of UK consumers, they report a level of adaptation which becomes second nature:[6]

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[5] Zbigniew, C., Subhes, C., Bhattacharyya (2015) *Analysis of off-grid electricity system at Isle of Eigg (Scotland): Lessons for developing countries.* Renewable Energy (81), p 578-588.

[6] http://www.bbc.com/future/story/20170329-the-extraordinary-electricity-of-the-scottish-island-of-eigg

"It seems easy enough to manage and residents appear satisfied. At Booth's house, Christine, John's wife, serves me tea and toast separately to avoid using the toaster and kettle simultaneously. With a low wattage kettle, doing so still would be comfortably below the 5 kW cap – but she is conscious of spreading out her energy usage to benefit the system whenever possible. "You get used to doing it that way," she says." (Karen Gardiner, BBC Futures, March 2017)

Jersey

Jersey Electricity offers two maximum demand-based tariffs: Standard and Economy 7. These tariffs are likely to apply to large domestic properties with physical limits of around 100 Amps over three phases. In addition to a standing charge and unit energy charge, consumers are charged for each kVA of their maximum demand.[7]

Romania

In Romania meters do not generally have built-in disconnection capabilities. However, each meter is under a connection contract which stipulates clearly the maximum power allowed. There are also fuses, usually electronic ones, which limit the absorbed current, but these devices are under the consumer's control.[8]

France

In France, household meters contain a fuse that switches off power if the customer's demand reaches a level above the subscribed capacity. After turning off one or several appliances allowing the demand to be below the subscribed capacity, the customer can easily turn the power back on. The customer can also increase subscribed capacity at relatively low cost to have more flexibility in its consumption; however, this means contacting the utility and making some changes to the meter settings.[9]

Italy

In Italy, the capacity limit (*potenza impegnata*) is the power level indicated in contracts and made available by the retailer. It is set when a customer contracts for supply and is based on the customer's needs – the type and number of electrical appliances normally used and, for domestic customers, this takes into account historical monthly maximum demand. The total number of residential users with capacity limits in Italy is 28 million and 90% of residential customers have a capacity limit of 3kW. In addition, capacity limits are also applied to non-residential users up to 15kW.

More choice on capacity limits

Starting in 2017, new rules have come into force that allow customers in Italy to better adapt their limits based on electricity use. Until 2017, 3kW was essentially the default capacity limit for most domestic customers.

[7] https://www.jec.co.uk/your-home/our-tariffs-and-rates/standard-domestic-maximum-demand-kva-tariff/
[8] Information obtained from Romanian energy regulator (ANRE).
[9] https://brattlefiles.blob.core.windows.net/files/14255_electricity_distribution_network_tariffs_-_the_brattle_group.pdf

The granularity of capacity limits for low voltages used to be 1.5kW; 3kW; 4.5kW; and 6kW, which offered alternatives which were either too restrictive (i.e. 1.5 kW) or too expensive (4.5kW with sharp increases in some of the bill components). From 1 January 2017, customers can instead select the capacity limit that best suits their needs: from 0.5kW up to 6kW of capacity limit in steps of 0.5 (0.5 - 1 - 1.5 - 2 - 2.5 - 3 - 3.5 - ... - 6kW) and in steps of 1kW from 6 to 10kW. Over 10kW, increments are in 5kW.[10]

Information to support customer's choice

From 2016, the Italian regulator ARERA has obliged electricity suppliers to provide clear information on peak power withdrawn on a monthly and yearly basis. This needs to be included in bills because the information is not available from the first generation of Italian smart meters.

Maximum load is taken from smart meter measurements of energy withdrawn every 15 minutes. The maximum load is calculated from the 15 minutes in which consumption is highest – making it the 15-minute average maximum capacity.[11] Retailers are free to define their own bill layout, choosing where and how to present such data. Figure 2.1 shows how Enel presents maximum capacity levels[12] - F1, 2 and 3 are standard time bands.

	Gen 2016	Feb 2016	Mar 2016	Apr 2016	Mag 2016	Giu 2016	Lug 2016	Ago 2016	Set 2016	Ott 2016	Nov 2016	Dic 2016
F1 kW	-	-	-	-	-	2	1.6	2.3	**2.7**	2.9	2.9	-
F2 kW	-	-	-	-	-	**2.9**	**2.2**	**2.8**	2.6	**3.3**	**3.3**	-
F3 kW	-	-	-	-	-	2.7	1.8	1.3	2.6	3	2.8	-

Figure 2.1 Example of customer's information on maximum power (Enel)

Spain

In Spain, consumers must choose a capacity limit (*potencia contratada*) according to their needs. Example guidance is shown from energy supplier Podo in Table 2.1.[13] Like Italy, a recent 2018 regulation means that those with smart meters will be able to modify their capacity limits by 0.1 kW – prior to 2018 the "steps" were 1.1 kW.

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[10] Arera (2017). POTENZA DEL CONTATORE, AGEVOLAZIONI E MAGGIORE SCELTA. Nuove possibilità di utilizzo dell'energia elettrica e risparmio per le famiglie italiane.

[11] Maximum load is maximum 15 minute kWh consumption multiplied by 4.

[12] Arera (2017). POTENZA DEL CONTATORE, AGEVOLAZIONI E MAGGIORE SCELTA. Nuove possibilità di utilizzo dell'energia elettrica e risparmio per le famiglie italiane

[13] Translated from https://www.mipodo.com/blog/eficiencia-energetica/potencias-electricas-normalizadas/

Capacity limit	Characteristics
2.3kW	Studio flat without air conditioning
3.45kW	Small flat without air conditioning with small appliances
4.6kW	Medium size flat with air conditioning in some rooms + small appliances
5.75kW	Medium size flat with air conditioning + medium size appliances (oven, dryer)
> 6kW	Medium and large flats with air conditioning and large appliances

Table 2.1 Guidance on capacity limit, Podo

Portugal

In Portugal, capacity limits are similar to those in Spain and Italy.[14] Figure 2.2 shows (red column) distribution of customers by capacity limit.[15]

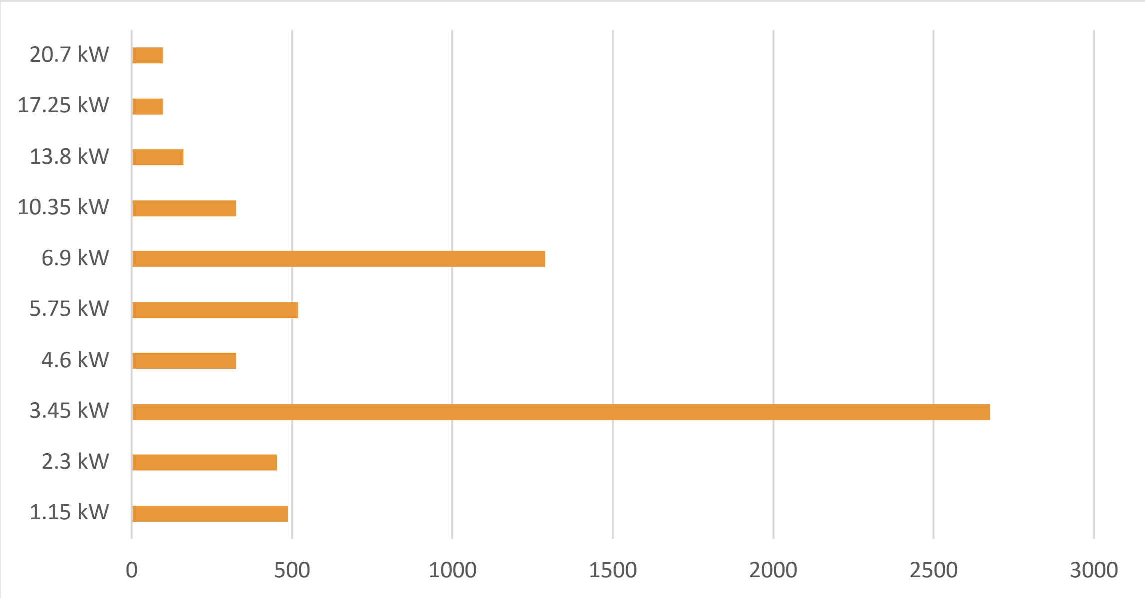

Figure 2.2 Customers (thousands) in different kW limits

Belgium

In the Flanders region of Belgium (Infrax DSO) a capacity tariff has been consulted on, with the expectation of being introduced in early 2019. We do not know if this has been implemented, but the proposal was for a "Capaciteitstarief" specified by the distribution company but matching capacity requirements of the consumer. It would be added to the consumer's bill in addition to

[14] Guerreiro, J., & Ferreira, L. M. Smart meter integration in an electric power system with large renewable energy resources, DSM and energy storage.

[15] http://www.erse.pt/pt/electricidade/tarifaseprecos/2018/Documents/Caracteriza%C3%A7%C3%A3o%20Procura%20EE%202018.pdf

volume-based energy charges. It was designed to represent the cost of network operation and would be regulated by VREG (the Flemish electricity and gas markets regulator).[16]

Overall the proposals for capacity limits and costs vary between the regions and DSOs. In general, the rating of a single-phase electric meter is 9.2 kVA (approximately 40 Amps).[17] There are 7 capacity limits from which to choose, designed to represent existing connections and these are shown in Figure 2.3.[18]

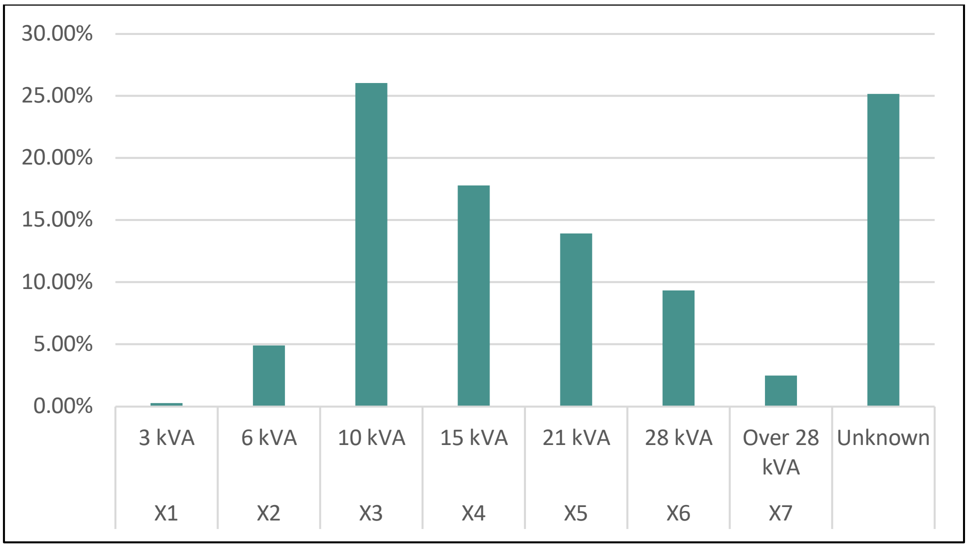

Figure 2.3 Distribution of connection limits in Flanders region

Netherlands

Like the proposed arrangements in Flanders, the Netherlands already has a Capaciteitstarief, regulated by the Dutch Authority for Consumers and Markets.[19] This was introduced in 2009 for small users (the capacity of those users is up to 3*80A for electricity and up to 40m3/h for gas). Consumers were therefore encouraged to reduce their connection capacity to avoid higher costs. There was a 2 year transition period during which customers could reduce their capacity for 50 € or apply for lump-sum compensation if they were unable to reduce capacity (in cases like elevators or sport fields with high power needs and low annual consumption).[20] Compensation amounted to 30 million euros in 2009 and 15 million euros in 2010. A residential consumer on a distribution network operated by Liander (Netherlands) has the following capacity tariff options[21]:

Capacity:	1x10A (**2.2kW**)	1x (25A, 30A, 35A and 40A) (**5.5-8.8kW**)	3x 25A (**16.5kW**)	3x 35A (**23.1kW**)	3 x 50A (**33kW**)
Cost € per year:	96.28	251.96	251.96	973.26	1418

[16] https://www.vreg.be/nl/tariefstructuur
[17] https://www.energuide.be/en/questions-answers/how-much-electrical-power-do-i-need-for-my-home/1855/
[18] https://www.futech.be/nl/capaciteitstarief-elektriciteitsfactuur-loep/
[19] https://www.acm.nl/nl/onderwerpen/energie/afnemers-van-energie/energietarieven
[20] http://www.cedec.com/files/default/cedec%20leaflet%20grid%20tariffs-final-140403-1.pdf
[21] https://www.liander.nl/consument/aansluitingen/tarieven2018/?ref=15691

One-off costs are also applied to change the rating without changing the number of phases (€160.74) and to change the number of phases (€242.05).

2.2 Capacity limits in consumer tariffs

We distinguish here between tariffs which accompany hard capacity limits (this Section), and charges which vary with capacity used (next Section).

Italy

In Italy, a consumer raising their capacity limit from 3kW would, before the recent regulatory changes, move from one tariff (D2) to another (D3). Marginal differences between the power components of tariffs D2 and D3 meant that consumers were not incentivised to optimise loads. Furthermore, the limited capacity bands resulted in cross-subsidies between those on each band, depending on consumption. In short, 3 million customers on D2 (i.e. residential users with a capacity limit of 3kW) with consumption above 3,500 kWh/year and 7.6 million customers on D3 (i.e. residential consumers with capacity limits above 3kW and all non-residential consumers) subsidised 18.8 million consumers on D2 whose consumption is lower than 3,500 kWh/year.

This was identified as a problem by the regulator[22] and D1, D2 and D3 were removed in 2017 and replaced with a single TD tariff, which is the same for domestic customers, and is variable only based on the capacity limit at the meter. Analysis of the impacts on bills pre and post 2017 is shown in Table 2.2. [23]

Capacity (kW)	Annual consumption (KWh)	Description (by way of example)	Post 2017 Fixed amounts in total electricity bill[24]	Yearly net bill 2015 (€/year)	Yearly net bill after 2017 (€/year)
3	1500	Single person household	27.5%	233	304
3	2200	Two-person household	21%	343	393
3	2700	3-4 person household	19%	438	457
3	3200	>4 person household	17%	563	521
3	900	Holiday home used few months per year	-	260	377
3.5	3500	Typical household which electrifies cooker and water heating	16.5%	831	570
3	4000	Multiple occupancy household (e.g. short-term tenancy contracts for students and workers away from home)	-	928	773
6[25]	6000	High efficiency house	15%	1.528	946

Table 2.2 Modelled electricity bills as a result of capacity limit changes

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[22] 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
[23] Source: www.arera.it/allegati/relaz_ann/18/RAvolumeI_2018.pdf
[24] €/year and €/kW/year. This includes fixed network costs and capacity limit charges, and excludes taxes. The €/kW component of the bill is rather limited (i.e. about 10% of the overall revenues). The variable component of the total electricity bill is proportional to kWh consumed.
[25] Most households with heat pumps are associated with a yearly consumption of 6,000 kWh and a capacity limit of 6 kW.

Spain

In Spain, the capacity component of a bill is the kW price multiplied by the capacity limit and the number of days (or months) on the bill.[26],[27] See Figure 2.4 for an example.

Figure 2.4 Endesa example electricity bill

Each retailer in Spain offers different tariffs, but the capacity limit prices do not vary significantly. Table 2.3 shows the types of tariffs and capacity limits.[28] Table 2.4 shows, by tariff, the number and percentage of consumers, and how much they pay in aggregate.

Type of tariff	Capacity limits
2.0A or 2.0DHA – domestic	Between 0 and 10kW
2.1A or 2.1DHA – domestic and small business	Between 10 and 15kW
3.0A and more – business	More than 15kW

Table 2.3 Capacity limits and tariffs in Spain

Tariff type	Number of consumers	%	Charges associated with peak demand (in M€ per year)
2.0	25,906,546	94	1,537
2.1	850,110	3	53
3.0A	734,474	2.6	84
3.1	82,911	0.3	12
6.1	19,603	0.07	3
6.2	1,597	0.006	0
6.3	417	0.002	0
6.4	565	0.002	0
TOTAL	27,596,223	100	1,690

Table 2.4 Customers associated with the different tariffs in Spain

[26] https://www.rastreator.com/tarifas-energia/guias/entender-el-recibo-de-la-luz.aspx
[27] Sudria, C. (1990). La electricidad en España antes de la Guerra Civil: una réplica. *Revista de Historia Economica-Journal of Iberian and Latin American Economic History*, *8*(3), 651-660.
[28] https://tarifasgasluz.com/faq/potencia-contratada

Figure 2.5 illustrates how much - on average - residential and non-residential consumers pay in €/kWh by capacity limit (horizontal axis).[29]

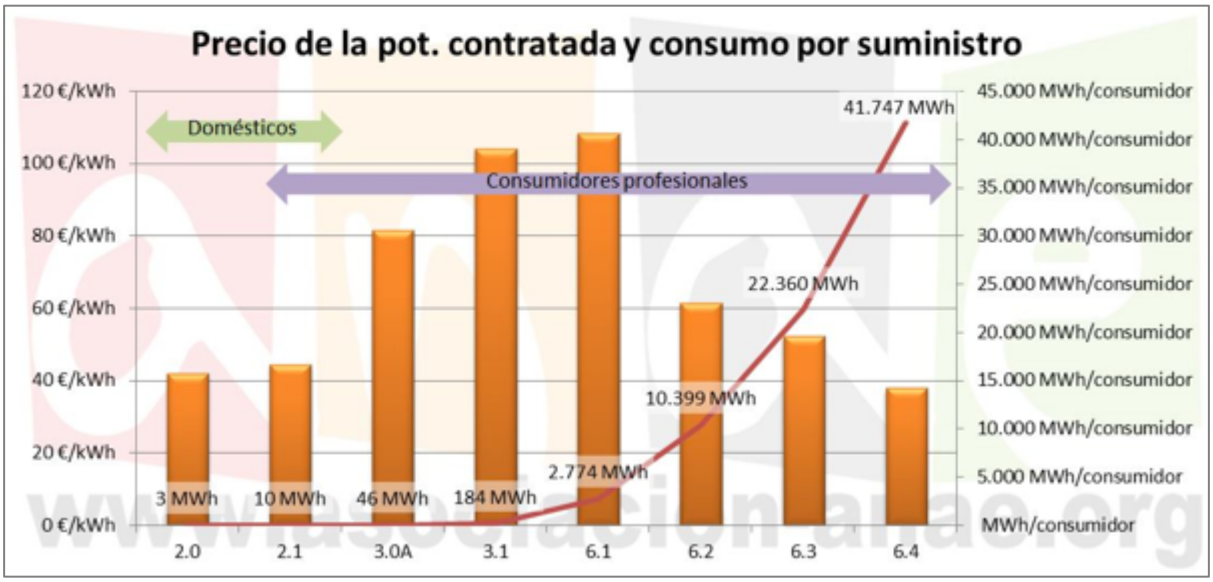

Figure 2.5 Unit prices by capacity limits in Spain

The Spanish Energy Consumers Association (ANAE) claims that in 2014 Spanish consumers were charged €10Bn for extra capacity they did not use. According to ANAE calculations, consumers on tariff 3.0A are the most disadvantaged.

Awareness of the difference between capacity limits and actual power use also triggered civil society campaigns, such as "lower your capacity"[30] amongst others[31],[32]. "Lower your capacity" provides information to consumers about the capacity they actually need. The campaign claims that 14,193 consumers have lowered their capacity limits as a result.

2.3 Charging for capacity directly or by proxy

We have also looked at examples of where there are capacity or capacity-like charges, but where there are no set limits.

Norway

Demand Charge electricity grid tariff in the residential sector

The Distribution System Operator (DSO) "Istad Nett AS" offers a demand (capacity) charge grid tariff for residential customers to cover distribution costs. A choice of an energy tariff (reported to be a fixed annual charge of 300 Euros and variable energy rate of 0.042 euros/kWh) and a demand charge tariff (reported to be an annual charge of 12 Euros, variable energy rate of 0.022 Euros/kWh and demand charge of 82 Euros/kW/year)[33]. The demand charge is settled and billed

[29] http://www.asociacion-anae.org/noticias/el-escandalo-de-la-potencia-contratada-en-el-sistema-electrico
[30] http://www.bajatelapotencia.org
[31] https://www.elconfidencialdigital.com/articulo/dinero/Oleada-peticiones-electricas-potenciacontratada/20140102200255071413.html
[32] https://blog.holaluz.com/potencia-contratada-la-guia-definitiva/
[33] Renner et al (2011) (op cit)

in December, January and February for the highest registered kW consumption[34] on working days between 7am and 4pm. For the other months in the year, the average of the highest demand in each of the three winter months is billed.

The tariff was introduced on a voluntary basis in 2000. It was designed to be revenue neutral if all consumers chose this tariff without changing their demand pattern. Approximately 700 households have this grid tariff, 5% of the DSO's customers. Analysis of consumption data showed average reduction of demand in the active window across all peak hours and all three winter months was 5%, with the greatest reductions being in the morning. No reminders were given to customers, so reductions might have been higher if they received more information[35].

Norwegian DSOs have some freedom on tariffs designed to recover their allowed revenue, as set by the Norwegian Water Resources and Energy Directorate (NVE). Tariffs for households, vacation homes and small commercial customers mainly consist of a fixed charge (NOK/year) and an energy charge (NOK/kWh). By 1 January 2019, all Norwegian electricity consumers should have new advanced metering systems. The ongoing discussion regarding tariff design suggests less energy-based and more capacity-based tariffs.

NVE has undertaken a public consultation on possible changes to the regulation for setting network tariffs for customers connected to the grid with a voltage of 22 kV or lower.[36] Stakeholders generally support the need to make changes to the current regulations. It is NVE's intention to provide clearer guidelines for how DSOs design tariffs. These changes reflect in part the fact that the main network cost is network availability during peak times, rather than year-round usage. NVE has commissioned a survey of consumers´ attitudes. Consumers were very clear that they would accept changes to network tariffs as long as it is possible for them to understand why they are made and what consequences they would have.

Sweden

Electricity tariff with differentiated grid fees

Sweden has around 170 DSOs of very different sizes and characteristics, their asset base varies substantially depending on geography and population, which means that tariff levels vary greatly between different concession areas. There are interesting experiences from DSOs who have introduced domestic capacity tariffs either as business as usual or as part of a pilot project.

For example, Solentuna Energi introduced differentiated grid fees for all household customers in 2001. Customers are charged against their average of three daily 1-hour load peaks during a month.[37] This utility has about 24,000 customers and had installed remote metering and billing for all of their customers in 1997. Consumer metering is hourly but the grid charges are calculated on a monthly basis. The charge was constructed so that the price of electricity was

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[34] Unlike many demand charges, this charge appears to apply to the highest 'needle peak' of demand, rather than average demand across a peak time period.

[35] Stokke, A., Doorman, G., Ericson, T., (2010) *An analysis of a demand charge electricity grid tariff in the residential sector.* Energy Efficiency 3 (3), 267-282.

[36] http://publikasjoner.nve.no/rapport/2016/rapport2016_62.pdf

[37] Pyrko, J., Sernhed, K., Abaravicius, J., (2003) *Pay for load demand – electricity pricing with load demand component.* ECEEE Summer Study – Time to Turn Down Energy Demand, Saint-Raphael, France.

slightly higher if there were no changes in consumption behaviour and more expensive if peak demand grew more than overall energy consumption. The grid fees give customers an incentive to reduce their peak demand. As the load charge is calculated on the average of three daily peaks, customers have an incentive to reduce consumption even after 1 peak load has occurred.[38]

A study on long-term responses to a demand-based time-of-use electricity distribution tariff among Swedish households found that six years after implementation, households still respond to price signals by cutting demand in peak hours and shifting electricity consumption from peak to off-peak hours. However, the average effect is fairly marginal and limited to households living in single-family homes with electric heating or heat pumps (common heating solutions in Sweden). The results further indicate that demand–based tariffs have an effect on household's attitudes and intentions to shift electricity use from peak to off-peak hours.[39]

Australia

Electricity companies in Australia have begun to introduce residential demand charges, apparently in response to the issues posed by high levels of distributed solar generation. They have already been introduced as an option for domestic customers in South Australia and Victoria in 2016. Some commentators are concerned about the risk of higher consumer bills, particularly for vulnerable customers who may not realise the implications of their patterns of electricity use. An example is given of "needle peak" demand causing extremely high electricity bills: *"with the new South Australian demand tariff, some types of electric instant hot water heaters can result in a single, long, hot shower adding over $1,200 to a quarterly bill."*[40]

Increasing Block Pricing – United States

California and other US states use so-called "increasing block pricing" (IBP) which prices energy in volume-based "blocks." Extra volume attracts higher prices. An example is shown in Figure 2.6. IPB is mentioned here as it has been used to incentivise energy efficiency and to provide a core level of affordable energy, i.e. similar to the notion of a core level of capacity. IBP is much more common in water pricing and is used explicitly as a means of allowing a basic, socially acceptable level of water consumption at affordable prices.[41]

Prior to 2000/01, all three utilities in California had two-tiered residential rate structures where the marginal price in the second tier was 15-17% higher than in the first tier, in line with the structure in many other states. After the California energy crisis in 2000/1, the regulators in California adopted a steeper five-tier structure. The prices for the first two tiers were frozen at pre-crisis level so incremental revenue needed to be collected on the top three tiers, which

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[38] Renner et al (2011) (op cit)

[39] Bartusch, C. and Alvehag, A. (2014) "Further exploring the potential of residential demand response programs in electricity distribution", Applied Energy, 125, pp39-59

[40] https://reneweconomy.com.au/residential-demand-tariffs-add-1000s-bill-10067/. This calculation is based on electric instant hot water heaters that can draw over 29 kW, and South Australia demand charges of 14-47 cents per kW of peak household demand, depending on location and time of year.

[41] And in the telecommunications sector, there are tariff structures with cross-subsidies among call categories, where high-rate long-distance calls are used to pay for low line-rentals charges to reduce the bill paid by lower income consumers.

pushed up the prices on these tiers. Criteria were also reformed in 2002 to include the climatic zone, seasonality, and fuel for heating. These factors determine the benchmarks for each consumer and the ceiling for the first step (subsequent steps are determined as a percentage of the first one).

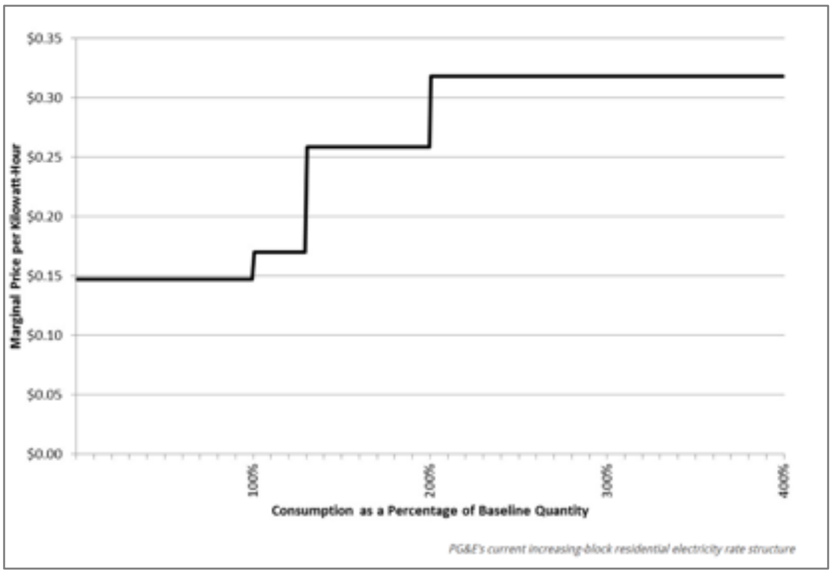

Figure 2.6 PG&E's IBP residential[42]

By 2008, the price on the highest block (which was the marginal price for about 6-9% of all residential customers), ranged from about 80% higher to more than triple the price on the lowest tier. The effects of this "extreme" IBP have been analysed by matching customer bill data with census data on income and looking at income redistribution effects. [43] The IPB structure did redistribute income to lower-income groups, but the effect was fairly modest, particularly compared to a means-tested program also in use.[44]

Increasing Block Pricing – Italy

In addition to capacity-based charges, Italy has IBP for the large majority of households. Lower and upper boundaries of each block are defined in terms of kWh/year or in kWh/month. The residential tariffs (900, 1800, 2640 kWh/year) were defined in 1975 on the basis of information around electricity consumption and have never varied by geography.

Increasing Block Pricing – South Africa

The public electricity supplier ESKOM reduces costs for lower-volume consumers by using an "Incline Block Tariff" for all residential customers.[45] In a given month, the customer pays a low price for the first block of consumption. As the customer purchases more electricity during the month, in one or in several transactions, the cumulative electricity purchase will eventually push

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[42] Rationalising California's Residential Electricity Rates – blog by the Energy Institute at HAAS (29 Sept 2014, posted by Severin Borenstein)
[43] Borenstein, S., (2008) *Equity Effects of Increasing-Block Electricity Pricing,* CSEM Working Paper, University of California Energy Institute.
[44] Some lower income customers were on an alternative programme – the California Alternate Rates for Energy programme - which offered lower rates to low income customers.
[45] http://www.eskom.co.za/news/Pages/Apr18.aspx; http://www.prepayment.eskom.co.za/IBT.asp

them into a second block which is more expensive. Because the blocks increase in price, the customers can save money by deferring extra electricity purchases to the next month when they can start to buy again at the initial low price. Some transactions are made through prepayment meters and through third party vendors, online or via mobile phone.

Figure 2.7 shows how the ESKOM "Incline Block Tariff" works in principle. Different rates apply to customers receiving different levels of electricity service (20 Amp vs 60 Amp). The same tariffs apply both to prepayment and credit meter customers.

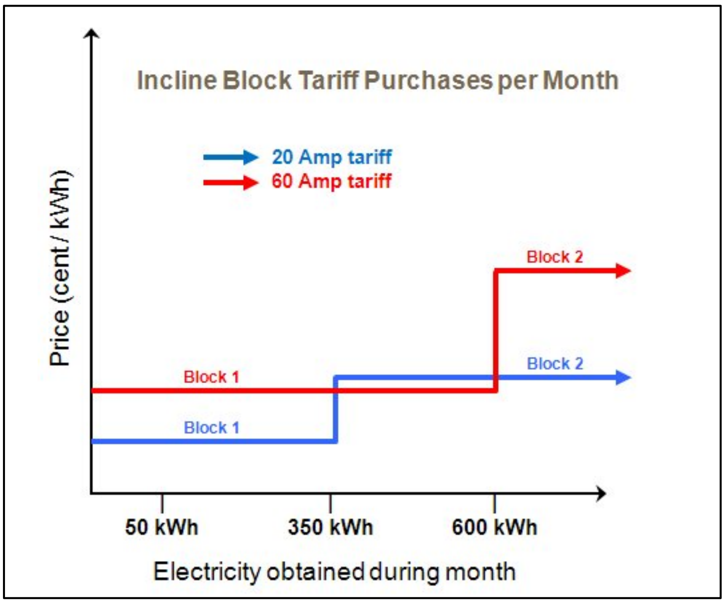

Figure 2.7 Eskom Incline Block Tariff

2.4 Differentiation of access products

Charging for capacity is one way of creating an access "product", essentially a definition of the circumstances under which consumers can draw power from the network. In addition to specifying the amount of power, access could be defined by time (for example by season), by location or in some other way. This is what we mean by differentiation of access products.

Our literature review found very little evidence of capacity-based access being further differentiated. In general, most consumers see just one, year-round capacity limit.

Changing the capacity limit

Clearly in some markets the capacity limit can be changed on request of the customer. This is the case in Italy and Spain. An advantage of this approach is that consumers can adapt their capacity limits to changing needs (e.g. additional electric heaters, new DIY tools, etc.). However, the responsibility falls onto the consumer and this may lead to small end-users paying for significant amounts of capacity which they do not use.

When a customer requests a change in capacity in Italy this is simply a remote management operation (telegestione) where it can be accommodated within the local physical network limits. The customer is charged a fee for increasing capacity and the fee is regulated.

In the Netherlands, the capacity limit can only be changed by submitting a request to the local network operator so the limits are fixed throughout the year until a fuse change is requested.

Seasonal variations

Australia has seasonal variation for capacity costs (per kW at peak time per month): peak (November to March) and off-peak (April to October).[46]

2.5 Management of capacity limits

In Belgium and in Netherlands, the capacity limit is determined by the fuse within the consumer's meter. Once the electricity demand exceeds the allocated capacity the consumer's supply is interrupted.

In Italy, for any capacity limit agreed with the supplier, the consumer can overtake that limit by 10%.[47] For example, for a capacity limit of 3kW, the consumer may use power at 3.3kW for unlimited time. It is possible to demand on average up to 27% more that available power (i.e. 4.2kW), calculated as the average value over a time interval of 2 minutes. Overtaking this value means that the consumer's switch intervenes. The switch has a fairly "soft" disconnection curve. For example, a 3kW capacity limit has available capacity of 3.3 kW can stay in the area between 3.3 kW and 3.96 kW for 180 minutes provided that power never exceeds 4 kW and that by the end of the 180 minutes demand is back under 3.3 kW. This limit is designed for loads such as dishwashers and washing machines. Where supply is interrupted, the consumer have to disconnect appliances and turn the switch back on at the meter level.

Figure 2.8 shows the probability distribution of maximum power levels (in terms of average power over 15 minutes) for residential consumers. The data is obtained from a study performed in 2011 on 918 residential smart meters (15 minute data) with capacity limits of 3kW.[48] The data shows that 47% of users did not demand more than 3.3kW; 15% of users did not demand more than 2.75kW. This seems to indicate that reducing capacity limits by 0.5kW would be beneficial only for a small number of residential customers.

In Spain the fuse box acts as controller (*interruptor de control de potencia*) as it measures the level of power being used and cuts temporarily supply when the capacity limit is reached. The fuse is present in any of the smart meters currently being installed in Spain.[49]

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[46] Robert Passey, Navid Haghdadi, Anna Bruce, Iain MacGill, Designing more cost reflective electricity network tariffs with demand charges, Energy Policy, Volume 109, 2017, Pages 642-649, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2017.07.045.
[47] 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. This study collected smart meter data of real consumers who had agreed a capacity limit of 3kW with their suppliers.
[48] This is based on a 2011 study mentioned in the ARERA 2016 impact assessment, which however is not published.
[49] https://www.rankia.com/blog/luz-y-gas/2046724-que-potencia-luz-tengo-contratar

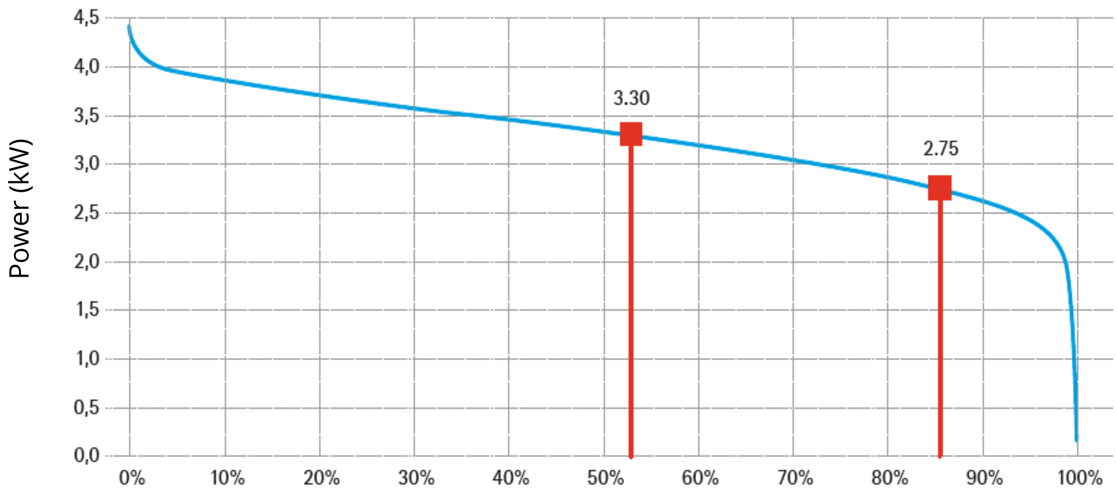

Figure 2.8 probability distribution of maximum power levels for residential consumers

2.6 Summary

Capacity limits and capacity charging are fairly common. We have summarised in Table 2.5 the evidence collected in this literature review. The limits derived from through top-down analysis (network – Eigg – or connection – Belgium – limits) are generally higher than those derived from bottom up analysis of users' needs. Although for higher than average needs, capacity requirements of over 6kW are double the needs of the majority of customers at around 3kW. This, in itself, suggests that smaller users may be subsidising larger users.

Market	Capacity limits	Description
Eigg	**5kW** households, **10kW** businesses	Set by system limits
Italy	**3kW** households	Newly-introduced ability to freely choose although recommended requirement still max 3.3kW in winter
Spain	**2.3kW** for small flat no air conditioning Approx **5kW** for medium flat with air conditioning and small appliances **>6kW** for large flat, air conditioning and large appliances	Can chose but recommendations provided
Portugal	Most customers cluster at **3.45kW** and **6.9kW**	Can freely choose
Belgium	Cluster at around **10kVA**	Proposals – based on connection limits

Table 2.5 Summary of capacity limits in the literature

With the possible exception of Eigg in Scotland, where we do not know how costs are allocated, capacity limits are accompanied by structured charges which increase with the amount of capacity used. There is very little evidence that limits have been explicitly designed around an "affordable" or needs-based core level. But the driver for capacity limits does seem to be fairer charging as well as incentivising customers to manage their capacity requirements.

Increasing Block Pricing is more explicitly "social" in nature, its very design seeking to discourage higher levels of consumption.

We have found some limited evidence of problems around implementation. There have been concerns in Spain and Italy about cross-subsidy between capacity bands. It is difficult to see how the Italian model of interrupting supply via the smart meter would not damage customer relationships.

It is generally the consumer's responsibility to select capacity limits. We found evidence of retailers (in Spain) providing some basic information about typical power associated with different devices. In Italy, since 2016 ARERA obliged electricity suppliers to explicitly include in bills information related to the peak power withdrawn. Retailers are anyway free to define their own bill layout, choosing where and how to present such data.

It would be informative to explore the question of consumer engagement and buy-in further and examine for example the impact of public information campaigns (e.g. in Spain).

We found negligible evidence on differentiated access products.

3 Deriving capacity limits

Drawing extensively on smart meter data available through Low Carbon Network Fund (LCNF) innovation projects, we have undertaken data analysis to answer the question, "….**what should the core level of access be set at?**"

At the heart of this question is whether there is a level of access (capacity) that can adequately provide for basic living and going over which represents non-essential usage. The focus is on making sure that vulnerable customers have appropriate access for capacity requirements that cannot be flexed and that encompass a diversity of need, including electric heating. Affordability may also be desirable.

In so far as the data has allowed, we have:

- Looked at whether electricity usage patterns coalesce around the same or similar peaks, and how this varies by circumstance. This is core capacity.
- Look in more detail at variations by different consumer groupings or segmentations. This is core capacity but informed by an understanding of what circumstances drive capacity requirements.
- Considered some big ticket activities – electric heating, ASHPs and EVs – which drive step changes in capacity requirements. This is core plus thinking more about differentiation and future-proofing.
- Looked at what people are doing when and where, to start to ask if there is merit in multi-core options by time, place or otherwise.

3.1 Measuring and defining capacity

Before we summarise results, there is an important caveat. An issue that emerged thorough modelling is how exactly capacity numbers are measured, and in turn used to define individual consumer's core capacities. In all cases[50], so-called "average" capacity is measured, by taking the measured energy consumption in a half hour or a quarter hour, and converting this to a notionally "average" kW. This is achieved by re-arranging the equation Energy (kWh) = Power (kW) x Time (hours) to Power = Energy/Time. So kWh over a half hour becomes the kWh/0.5 of an hour, or kWh x2. And for 15 minute measurements this is kWh x4.

This can be conceptualised as a weighted average of the kWs that reflects the intensity and duration of power use over the period. It does not reflect instantaneous peak power during the half hour.

[50] Barteczko-Hibbert et al. 2015. Insight report. Baseline domestic profile. Test cell 1a customer subgroup analysis. http://www.networkrevolution.co.uk/project-library/insight-report-domestic-baseline-profile/

3.2 Datasets

We have drawn on three Low Carbon Network Funded (LCNF) smart meter projects:

Consumer-Led Network Revolution

Conducted over 2011 to 2014, Northern Power Grid's Customer-Led Network Revolution (CLNR) project[51] recruited 13,000 electricity customers in the North East of England to develop an understanding of electricity use patterns. Smart meter data is analysed for customers in different circumstances and in response to various interventions. For domestic customers this included a control set of basic demand profiling, and customers with Low Carbon Technologies (LCTs) such as Air Source Heat Pumps (ASPs) and Electric Vehicles (EVs).

Low Carbon London

A UKPN project[52] encompassing energy consumption readings from 5,567 London households, again over 2011 to 2014. Data is available for a control group and a group that were subject to dynamic time of use tariffs in 2013.

SAVE

An SSEN project which has recruited just over 5000 households across the Isle of Wight and the Solent mainland. Smart meter data is available for control and intervention groups, at half hourly as minimum and 15 minute level during trial periods. 15 minute time-use diaries are also available for trial periods.

3.3 Core capacity

CLNR

Figure 3.1 below shows, for **domestic** consumers, the peak winter day in 2013, (January 18th), the 50th (black line) and 95th (grey area) percentile for "average" demand in each half hour of the day (remember, this "average" power is the half hourly kWh x 2). Because this shows the 95th percentile, it captures most of the variation in demand, but does not show outliers or the peak within-half hour values. The data is shown for all 4943 "baseline" households (no LCTs or interventions), and the same households differentiated by income and then by rural or urban (the rural sample size is small – 544 rural and 36 rural off-gas).

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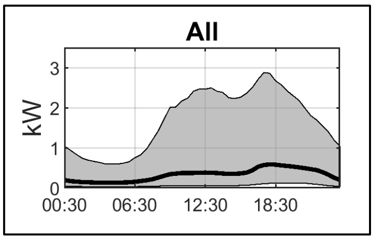
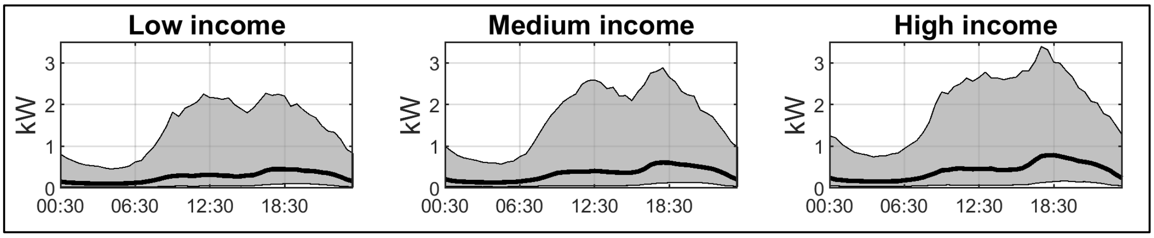
51 http://www.networkrevolution.co.uk

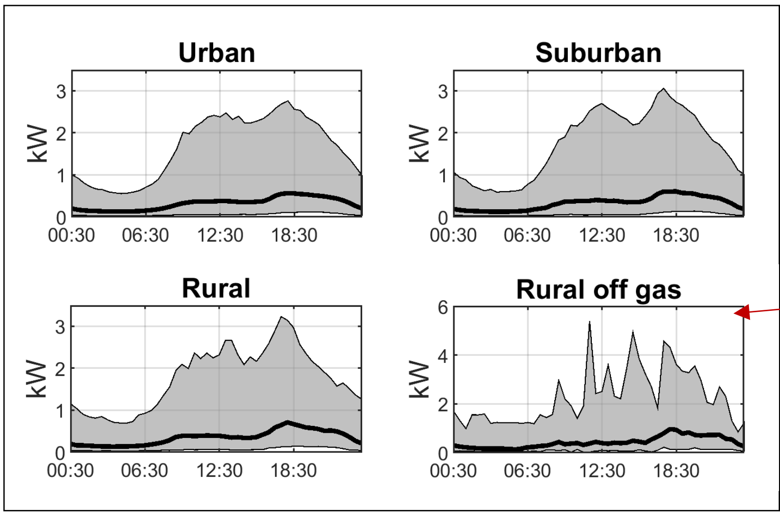
52 http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/



Split by income, low under £15K, medium £15-30K, high over £30K



Split by urban / rural and off-gas



Vertical scale doubled to 6kW

Figure 3.1 Demand profile for peak winter day, 50th and 95th percentiles

The data shows a peak

- for most customers of around **3kW**,
- but this nearly doubling to around **5.5kW for off-gas customers**,
- and dropping to just over **2kW for low income customers**.

Figure 3.2 below shows for **small business** consumers, the 95th percentile demand on a peak day (8th Ferbruary) for eight businesses on a single uniform tariff. The businesses are described in Table 3.1. Excepting outdoor-based businesses, demand shows an expected day-time pick-up and relatively flat for the working day. Peak demand is between around **15-19kW**.

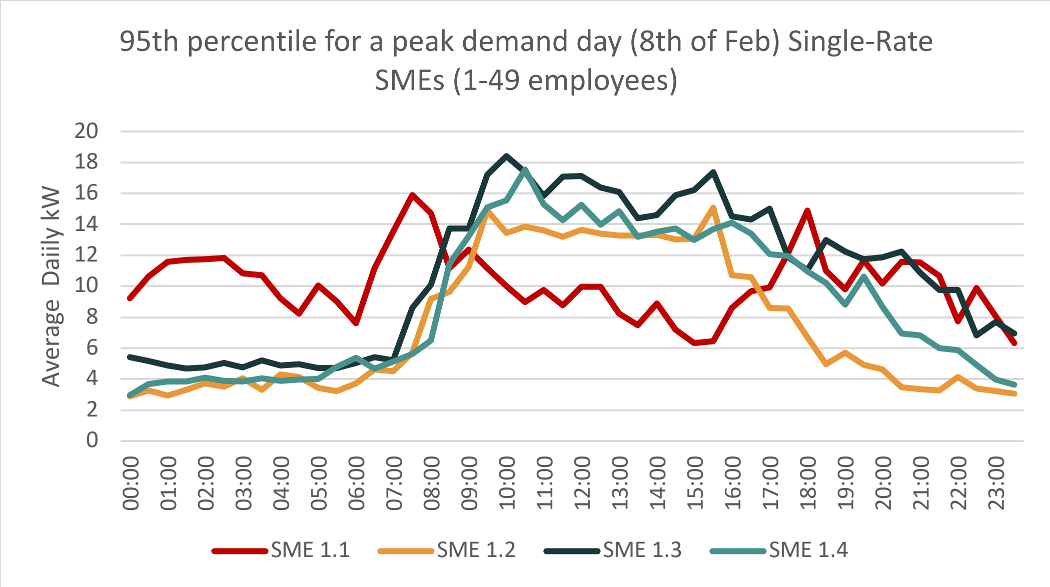


Figure 3.2 95th percentile single day peak, SMEs

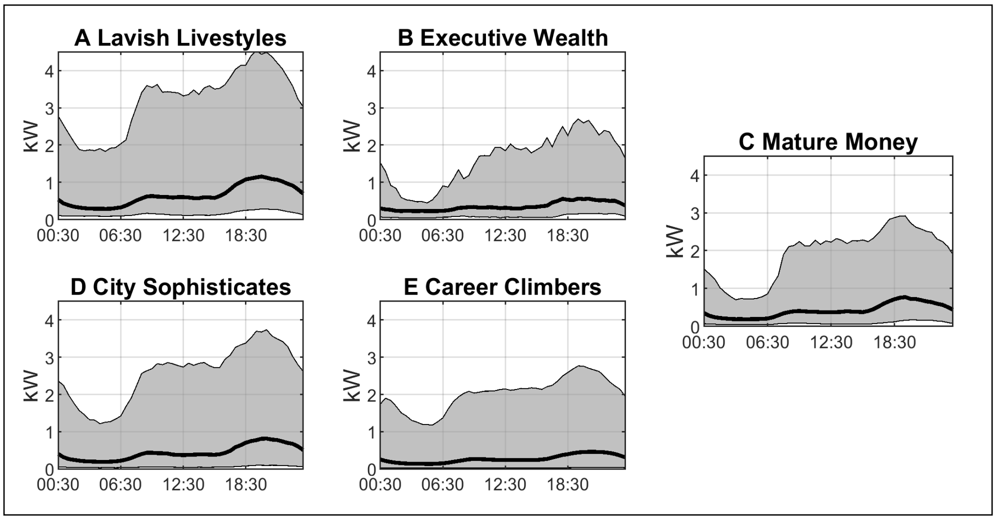
	Size	Sector	Nos. businesses
SME 1.1	1-9 employees	Agriculture, Hunting and Forestry; Fishing	62
SME 1.2		Industrial	111
SME 1.3		Commercial / Office	113
SME 1.4		Public Sector and Other	117

Table 3.1 SME sectors and number of employees

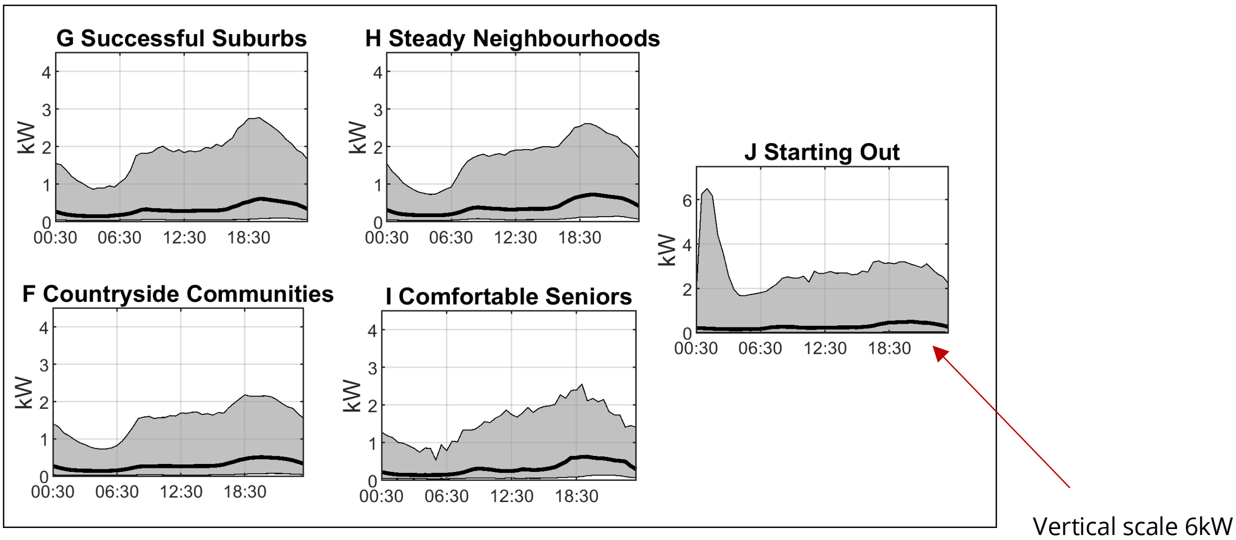
LCL

Like CLNR, there is a control group of 4400 smart meter profiles, this time each household apportioned to an Acorn group. Sample sizes are from 43 for “comfortable seniors” to 1228 for “career climbers.” Again, this shows 50 and 95% percentiles, but for all weekend days in January 2012 (as opposed to the CLNR data which shows one peak day in January).

Affluent



Comfortable



Adversity

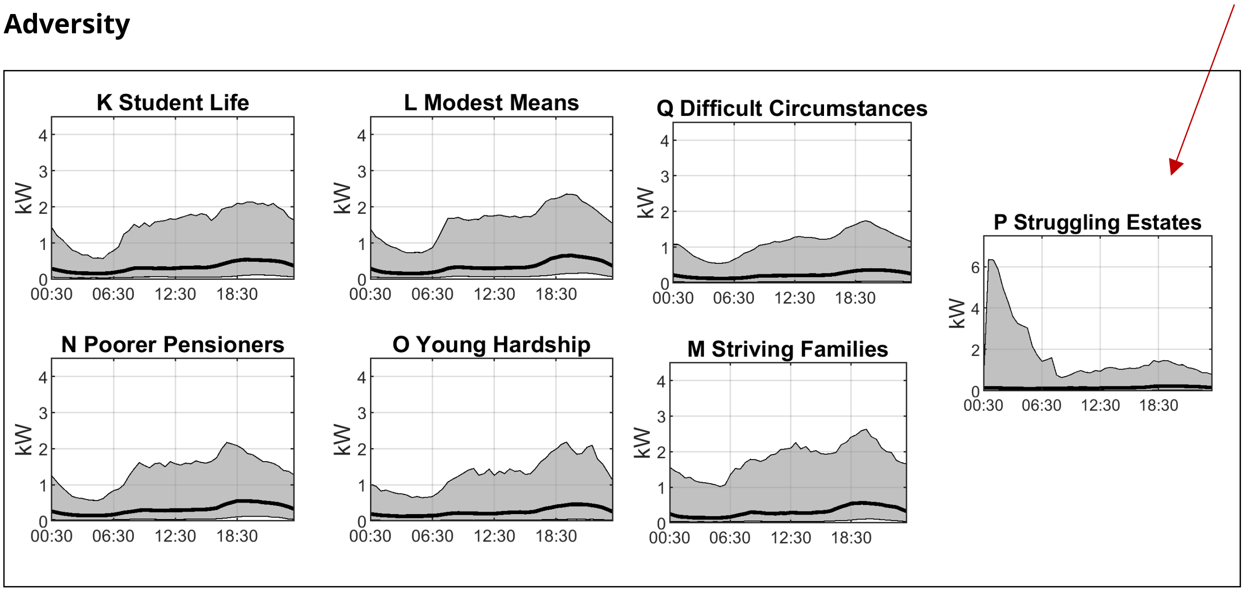


Figure 3.3 Demand profiles for all weekdays in January 2012, 95th and 50th percentiles

The data shows a peak:

- for very affluent customers of around **between 3.5 and 4kW**
- a peak for comfortable customers of **between 2 and 3kW**
- for those on electric heating, a peak of **between 6.5 and 7KW**
- and for customers in adversity, a peak of **between 1.5 and 2kW**

We can start to see that there is no clear relationship between household size and peak capacity – for example striving families have around the same peak demand as comfortable seniors. And student life looks similar to poorer pensioners, even if the former is likely to have dense living.

Affluence levels seem to be having more of an impact, an observation which is supported by analysis of the number of bedrooms in a household, shown in Table 3.2.[53] This shows for example that an affluent household in a studio flat has a higher peak demand than a household in adversity with 3 bedrooms (the data is taken from internal CLNR analysis, and is much closer to actual rather than half hourly averages). Analysis of the highest half hourly average peak demand values for each and every customer in each ACORN grouping, is shown in Figure 3.4.

75th percentile peak consumption (kW) of each household		Number of bedrooms			
		Studio/1	2	3	4+
ACORN Category	Affluent	13	11	13	16
	Comfortable	11	11	12	14
	Adversity	9	11	12	14

Table 3.2 peak power by number of bedrooms and Acorn group

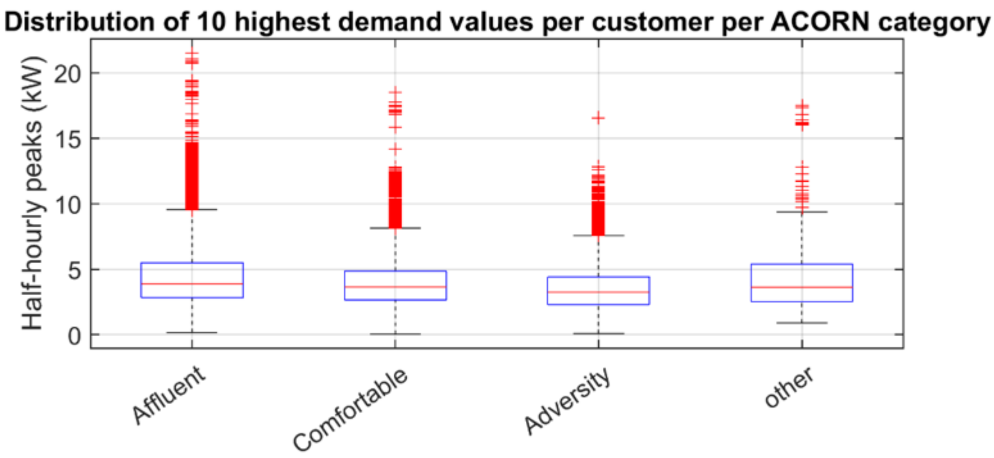


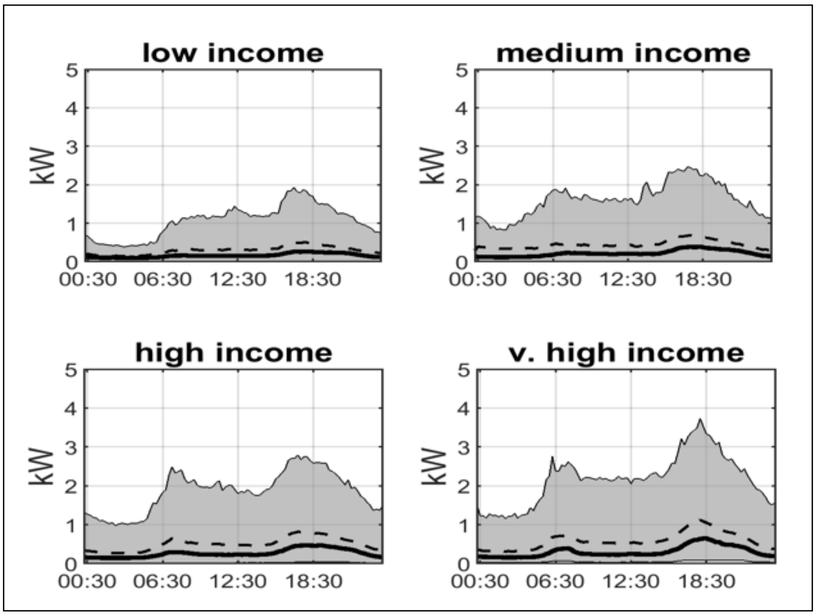
Figure 3.4 Boxplot of ten highest half hourly demand values for each consumer by Acorn Category[54]

[53] average values for groups of households have been scaled up to represent an individual household's peak and rounded up to the nearest kW.
[54] The box contains the middle 50% of the data (25% to 75%), red line in the box is the median of the data, whiskers indicate the middle 95% of the data and red plusses indicate the outliers.

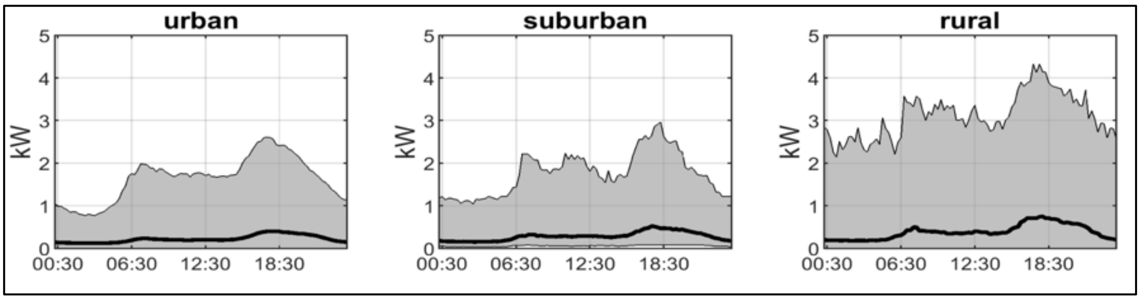
SAVE

In SAVE, there is a control group of nearly 1000 customers whose demand has been monitored on a 15 minute basis over 2018 and into 2019. For those that provided information on income (580), urban / rural (947) and heating type (924), plots show the 50th (black) and 95th (grey) percentile 15 minute average kW (kWh x 4) for January 2018, or 2019 if available.

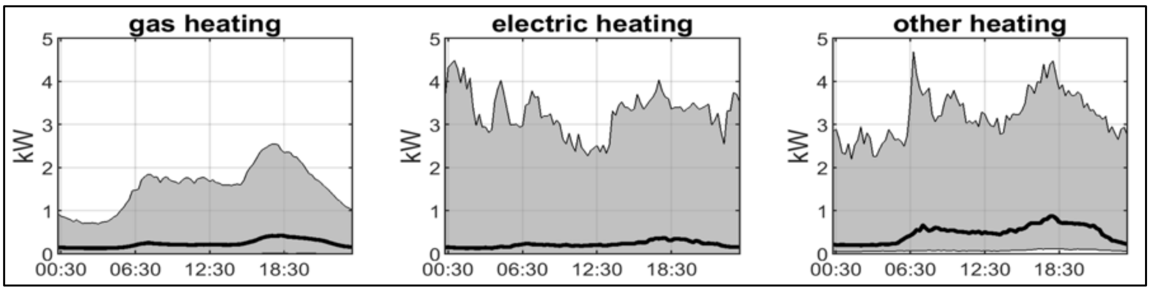
Data split by income, low under £15K (127 sample size), medium £15-30K (138), high £30-50K (196), very high over £50K (119)



By urban / rural, urban (819 sample size), suburban (76), rural (52)



By heating type gas (828), electric incl heat pumps (61), other, incl oil and solid fuel (35)



The data shows a peak:

- For very high income earners of **4kW**
- For electric and "other heating" of **4.5kW**
- And for low income consumers just **2kW**

Boxplots for the ten highest peaks for each customer, by grouping, are show in Figure 3.5 below.

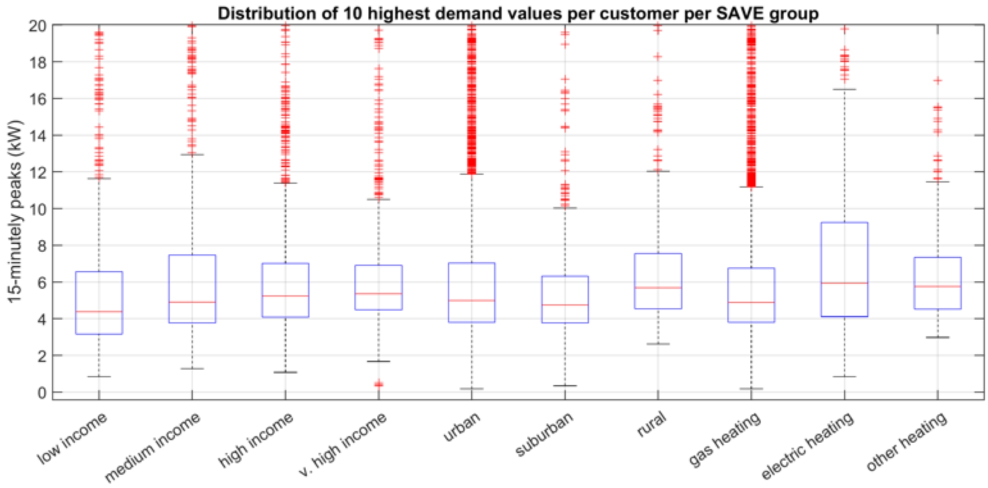


Figure 3.5 Ten highest demand peaks for SAVE groupings

3.4 Core capacity with ASHPs

ASHP and EV data from CLNR is given as a daily profile of half hourly values averaged across all days of a month. The LCL data is better defined, as 15-minute data (for the winter months, the highest 15 minutes of kWh x 4 to convert to an "average" kW), shown in Figure 3.6 for the highest 100 values for each of 18 individual heat pumps. Each colour represents a different heat pump. The rating of the heat pumps are not provided.

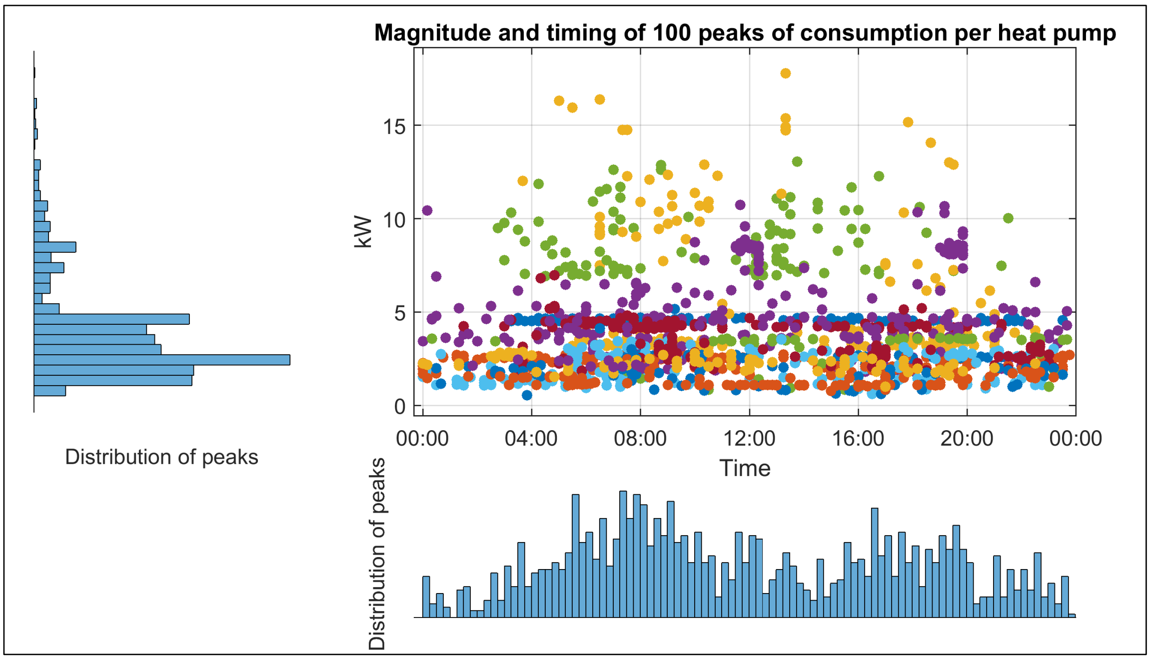


Figure 3.6 ASHP 15-minute average top 100 peaks for winter months

The data shows a roughly diurnal heating regime, but with some early morning peaks which we assume correspond to default settings on water heaters. The most frequent peaks occur around 1.3, 2.4 and 4.6 kW. Power consumption of a heat pump would depend on the heat requirements of the property (including insulation), ambient temperature, and rating and efficiency of the heat pump. The nominal rating of the domestic (single-phase) heat pumps varies from 1.1kW up to 5.5kW, supplying from 5kW to 22kW of heat respectively. The data here shows much higher peaks up to 15kW which we suspect relates to a small number of commercial units.

3.5 Core capacity with EVs

Similar year-round analysis for 60 EV chargers rated at 2.4, 3.6 or 7kW is shown in Figure 3.7 , again the top 100 values, this time for ten minute “average” kW. The peaks coincide the charger’s rated capacities, indicating that like ASPs, power consumption is close to or at rated capacity for most of its in-use period.

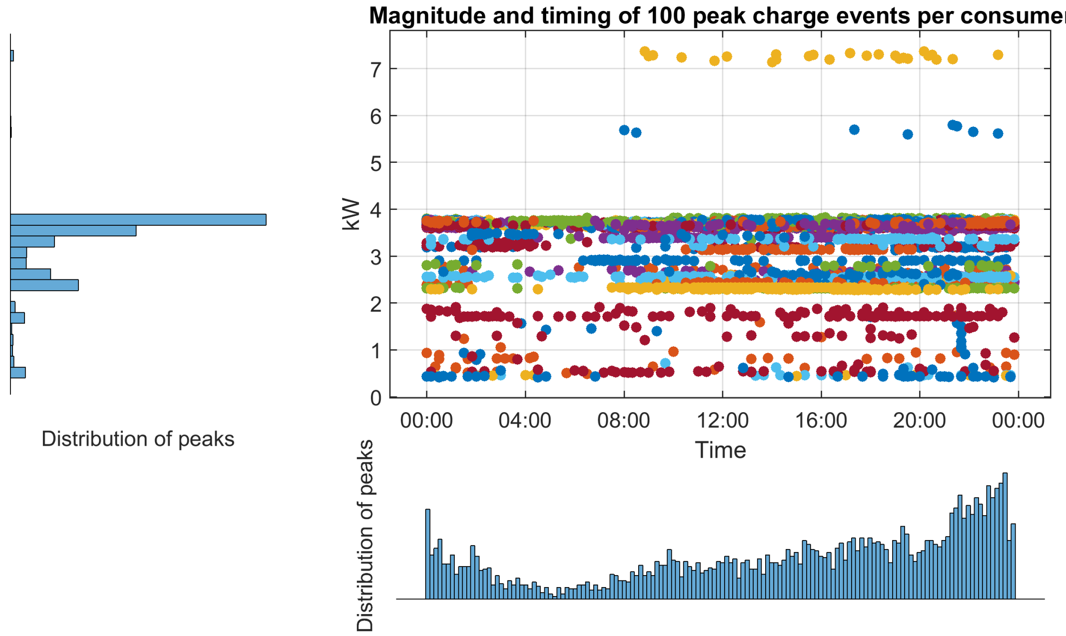


Figure 3.7 EV 10 minute average, top 100 peaks for a full year

Collectively, the ASP and EV data shows that household peaks will be significantly impacted, potentially adding up to around **6-7kW for each (12-14kW for both IF the peaks occur at the same time)**. This is based on high-resolution 10-15 minute data, so equivalent 30 minute averages may be lower. However, for EVs, analysis of charging rates shows near-continuous operation at rated capacity for hours at a time (meaning the 30 minute average will be unchanged).

Household energy use normally peaks around 5-7pm. The distribution of ASP and EV peaks shows a concentration in the early morning late at night respectively, although these trends are not particularly strong. There is certainly latent potential for smarter time of use incentives, to avoid coincidence with the early evening peak – especially so for EVs where a large number of users appear to be plugging in after a day's work.

3.6 Regional differences

The analysis presented so far suggests that households vary significantly in their capacity requirements depending on their circumstances. The concept of peak capacity also already incorporates the crucial factor of time, namely capacity requirements vary depending on, amongst other things, the time of day.

We also wanted to look at whether there are significant geographically-related differences in peak capacity requirements. This has been difficult, due to a lack of comparable datasets across regions. We have however made a start, using the UK time of use survey[55] and data supplied by Elexon.

[55] https://www.timeuse.org/node/10833

Figure 3.8 shows in the top left graph, January 2013 average demand for both the CLNR (North East) and LCL (London data). The remaining three graphs show UK time of use survey results for the corresponding regions (shown as a probability of people undertaking each activity).

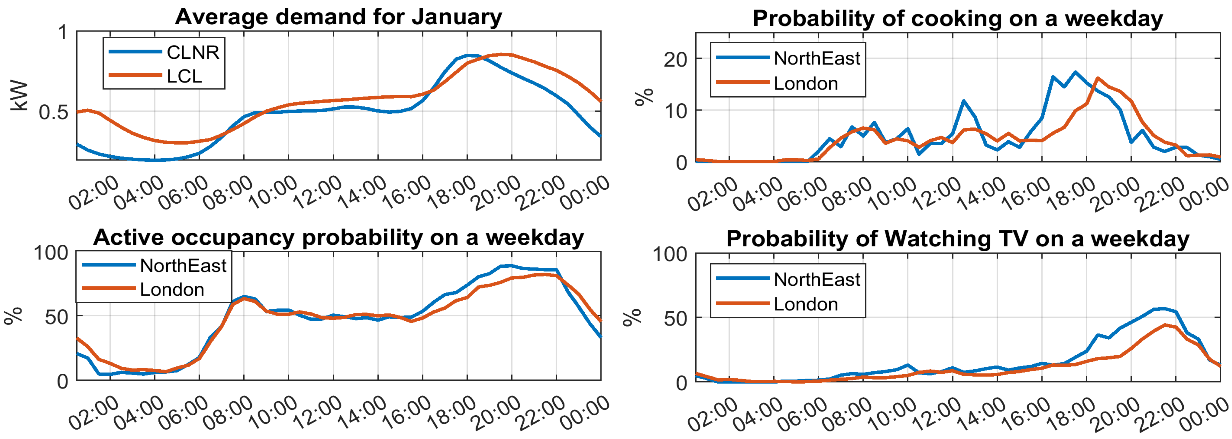


Figure 3.8 Regional and income-based differences in electricity peaks

The data shows regional differences in monthly average demand of up to 0.3-0.4kW, depending on the time of day. Figure 3.8 also shows some slight differences in the timing of activities driving peak usage. According to the data people in the North East on average appear to cook and watch TV more than, and earlier than, those in London. The regional differences appear quite small and would benefit from better understanding – for example the extent to which income and other factors are driving regional differences.

Elexon also kindly provided us with non-half hourly load profile data for 2012-13, by Grid Supply Point (GSP). Based on sampled customer data, this is Elexon's estimate of customer demand across each half hour settlement period. Because it averages out customer diversity, the peaks are relatively low compared to some of the other data we have looked at. However, it does allow us to compare by GSP (one for each DNO license area), differences in peak demand.

Elexon produces load profiles for eight classes of non-half hourly metered customers[56]. Figure 3.9 shows, for the days in which the highest peak demand occurs, a daily profile for each GSP, for Profile Class 1 (domestic customers on unrestricted meters i.e. not including customers with electric heating). Elexon takes into account temperature differences across GSPs, in the form of Noon Effective Temperature (NET) so we have included the NET for each peak day. In requesting NET data from Elexon, we had anticipated a relationship between NET and peak demand, but the data does not support this.

[56] https://www.elexon.co.uk/operations-settlement/profiling/

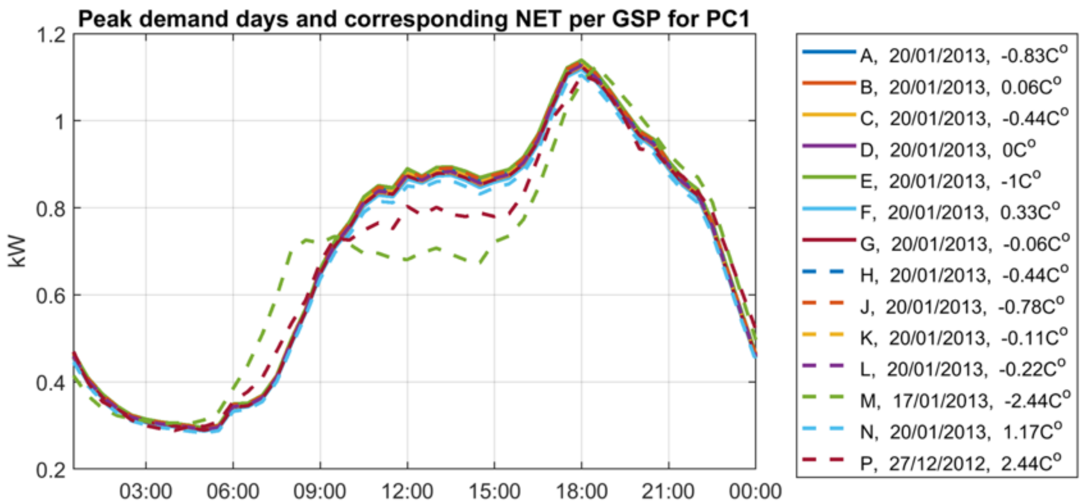


Figure 3.9 Peak demand days for Elexon Profile Class 1, by GSP

The same peak days are shown in Table 3.3 below, alongside the total yearly energy consumption (in kWh) for an average household. Again, we would have expected a positive correlation between peak demand and annual energy, but this relationship is almost inverse – the lowest annual peaks in Scotland correspond to the second and third highest annual consumption.

GSP group	area:	max (kw)	total energy (kWh)
_a	Eastern	1.14	4363.21
_b	Eas Midlands	1.12	4386.78
_c	LE Distribution	1.13	4270.77
_d	Merseyside & North Wales	1.12	4335.15
_e	Midlands	1.14	4378.49
_f	Northern	1.12	4444.20
_g	North Western	1.12	4331.57
_h	Southern	1.13	4270.77
_j	South Eastern	1.14	4295.78
_k	South Wales	1.13	4300.43
_l	South Western	1.13	4279.32
_m	Yorkshire Electricity	1.12	4357.16
_n	South of Scotland	1.10	4409.41
_p	North of Scotland	1.10	4432.96

Table 3.3 Peak demand and annual energy for Profile Class 1, by GSP

The same analysis, but for non-half hourly metered businesses on unrestricted meters, is shown in Figure 3.10 and Table 3.4. This shows a better positive correlation between both NET and peak demand, as well as between peak demand and annual demand.

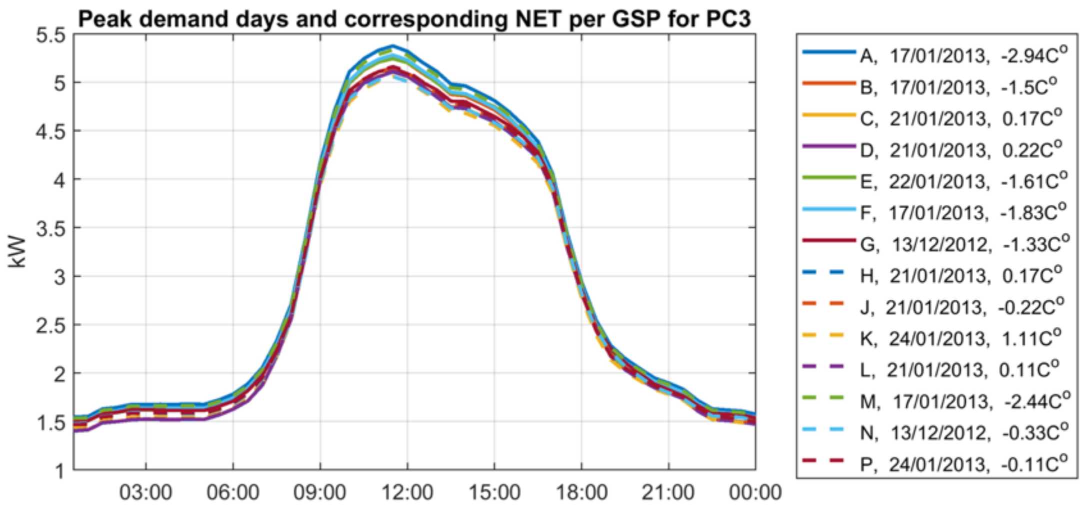


Figure 3.10 Peak demand days for Elexon Profile Class 3, by GSP

GSP group	area:	max (kw)	total energy (kWh)
_a	Eastern	5.37	17439.18
_b	East Midlands	5.25	17461.43
_c	LE Distribution	5.11	17158.90
_d	Merseyside & North Wales	5.10	17251.48
_e	Midlands	5.24	17434.66
_f	Northern	5.28	17578.16
_g	North Western	5.14	17276.73
_h	Southern	5.11	17158.90
_j	South Eastern	5.14	17231.61
_k	South Wales	5.06	17152.67
_l	South Western	5.11	17119.52
_m	Yorkshire Electricity	5.33	17372.46
_n	South of Scotland	5.06	17439.52
_p	North of Scotland	5.16	17518.51

Table 3.4 Peak demand and annual energy for Profile Class 3, by GSP

Like the time of use survey data, the Elexon data raises more questions than it answers. It suggests fractional differences in peak demand by region. For domestic consumers, the effect of temperature on the maximum peak demand appears to be unimportant, but it is difficult to say if this is a real or an effect of the modelling of daily profiles. The inverse relationship between maximum peak and annual energy for domestic consumers is interesting, but again it needs further investigation.

3.7 Summary

Core capacity – domestic consumers

Figure 3.11 summarises findings for the 95th percentile peaks in CLNR, LCL and SAVE studies, alongside usage-based limits in Spain and Portugal, for comparison. Note that SAVE data is 6-7 years on from the CLNR and LCL data.

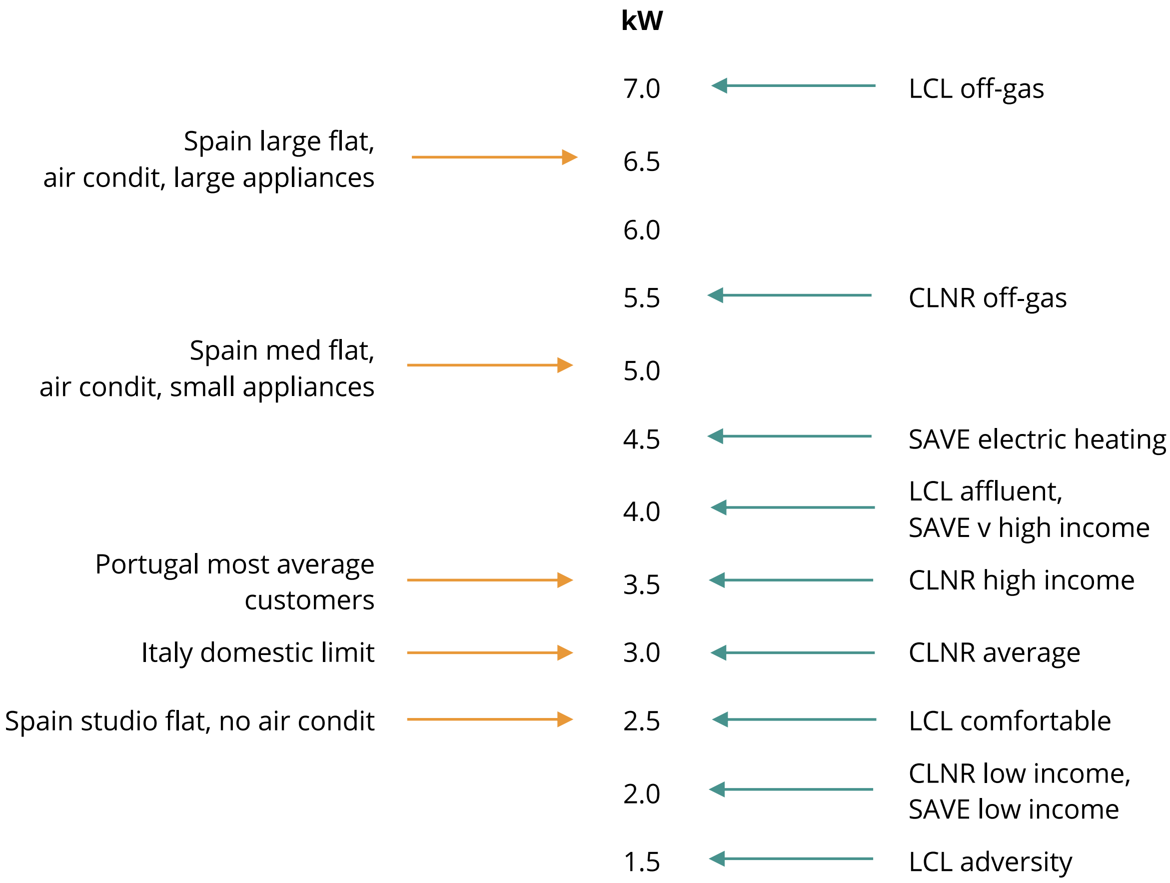


Figure 3.11 Average peaks (30 and 15 minute) from UK studies and international limits

The UK data is based on 95th percentile of consumer's half hourly average kW in January. Boxplots of the ten highest values show outliers of up to 20kW and over for all categories of consumer.

Just as air conditioning does in hot countries, very clearly, electric heating boosts peak capacity significantly in the UK, from around double to triple the average on-gas consumer. There is little consistency between studies on this electric heating premium, with the latest SAVE data showing the lowest peak at 4.5kW. This merits further investigation to see what is driving this – for instance has technology improved over the last 6-7 years or is it simply a mild winter-effect?

Income differentials show more consistency across studies. Struggling consumers peak at around 1.5 to 2kW, affluent consumers double this at 4KW, with an average consumer peaking around 3kW. This is broadly comparable to average consumers in Spain and Italy.

Core capacity – small businesses

There is very little comparable data on small businesses. The daily profile for building-based small businesses typically show a pick-up at the start of the day, a working day peak of around 15-20kW and a drop-off at the end of the day. There is likely though to be large variation between different types of businesses, which needs further study. It is difficult to see there being a consistent core level of capacity across all small businesses.

Core capacity – Air source heat pumps and electric vehicles

Again we have only limited data on ASPs and EVs, and it dates back to 2012-13 (our sister report for SSEN will interrogate SAVE data further on this point). Unsurprisingly, both ASPs and EVs contribute significantly to capacity requirements, at a similar scale to off-gas electric heating. The key for not exceeding a household limit of around 6-7kW, which each of ASP heating and an EV might merit on its own, is avoiding coincidence with the daytime evening peak. However in 2012-13, many EV users were simply plugging in after a day's work, the worst time of day to be adding to peak requirements.

Multi-core capacity

There are very significant variations in capacity requirements across a day, with typical peaks in the early evening for gas-heated homes and early morning for electric-heated homes. We have not had time to look closely at weekday / weekend differences but our analysis shows some small differences in daily peaks. There is therefore scope for time-differentiated core access.

Regional differences in peaks and the timing of peaks can be seen in the available data, but they are relatively small differences. This needs further study using comparable smart meter data across a good regional spread of consumers.

4 Implementation

4.1 Background

As noted in the Introduction to this report, Ofgem's Electricity Network Access and Forward-looking Charging Review is looking at core access. The SCR is developing and potentially directing changes to be made to industry codes in the areas encompassed by the SCR, which includes "*Clarifying access rights and choices for small users*." [57]

Ofgem says that it will "*explore the feasibility and desirability of defining a minimum basic level of access for small users (or a subset of small users), as well as having threshold limits for sharper charging signals*." The latter is a reference to the relatively blunt energy-only network charges for non-half hourly metered customers. Core capacity is seen as a mechanism by which customers can be guaranteed what they need, and face sharper incentives for managing non-essential capacity.

If it proves too difficult to define an "*essential*" level of usage, Ofgem will consider what appropriate protection measures may be required, considering core options and others, such as principle-based obligations.

So with this in mind, this Section begins to answer Citizens Advice final questions "**How could this [core access] be implemented (technical or commercial solutions)?** And**, what are the barriers/risks to consumers, suppliers and networks**?"

We start with some practical considerations on metering which set some current limits on how capacity could be measured and governed. And then we look at implementation routes in reference to who – Suppliers or DNOs or both – lead on introducing limits and charges. Finally we consider the social aspects of limiting capacity and potential impacts on vulnerable customers.

Questions remain, which we have highlighted throughout this report. The intention is to develop discussion points and flags for the SCR and for the various groups looking into core access.

4.2 Practical issues

UK context

Presently in the UK, restrictions on household and micro-businesses electrical supply capacity is set by the rating of the main fuse at the property. The fuse plays an important role in protecting the network from a serious fault at the property and hence preventing interruption of supply to other properties on the network. Placement of the fuse is a requirement of the Distribution Network Operator (DNO) and typically the rating of a fuse is 60, 80 or 100 Amps. To blow the 100 Amp fuse, electricity demand from a property would need to exceed 22-24 kW. For reference, a household with two adults and a teenager on a winter evening could consume as much as

[57] Ofgem, 2018. Appendix 1: Details on decision on the scope of the review. Electricity network access and forward-looking charging review – Significant Code Review launch and wider decision. https://www.ofgem.gov.uk/publications-and-updates/electricity-network-access-and-forward-looking-charging-review-significant-code-review-launch-and-wider-decision

22kW[58] whereas a household of two adults and three children on a winter evening with an Electric Vehicle (EV) and a heat pump could consume as much as 25kW[59].

Smart meter functionality

Smart meters are primarily designed to record electricity consumption per 30-minute period, submit readings directly to Suppliers and provide energy usage feedback to consumers. There are currently two versions of Smart Meters[60] the UK: SMETS1[61] and SMETS2[62]. Overall, the core functions are similar. SMETS2 has enhancements of the SMETS1 functions and introduces a direct load control function.

Load limiting

Both versions require the meters to provide a load limiting function. Suppliers can specify a load limit value (a threshold value) and enable each individual smart meter to switch off supply if the threshold is breached. The load limiting function is expected to operate as follows: if active[63] power import (kW) exceeds a configurable threshold over a period of time, smart meters are expected to notify the supplier and the consumer (via the In-Home Display). For SMETS1 the thresholds must be exceeded for over 30 seconds and for SMETS2 this is configurable.

If load limiting is enabled, then immediately after notifications, the smart meters are expected to interrupt supply to the property – for SMETS1, consumers can re-instate supply using the In-Home Display and for SMETS2, supply will be automatically restored after a configurable period of time.

Maximum demand

SMETS2 smart meters are expected to record the maximum power imported for each 30 minute period. Potentially this information could be used by the suppliers to enable maximum-demand tariffs.

Pricing methods

Both smart meter versions include the requirement to support:

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[58] Assuming dinner is being cooked (electric oven and hob, kettle) whilst an electric shower is being used and washing machine is running. Household has partial electric heating (e.g. electric fire and electric underfloor heating in one room) and energy efficiency is low (e.g. no LED light bulbs and most appliances are rated A+ or lower).
[59] Assuming winter peak time when dinner is being cooked for the whole family (electric oven and hob, kettle, microwave oven and deep fryer), tumble drier and washing machine are running. There are several cold appliances and TVs and other entertainment devices. Energy efficiency is high and house is heated with a heat pump and several rooms have underfloor heating. Electric vehicle is assumed to be plugged in and charging at 7kW.
[60] SMETS (Smart Metering Equipment Technical Specifications) - document defining the technical specification and functionality required of the smart meters.
[61] SMETS1 documentation: https://www.gov.uk/government/publications/smart-metering-implementation-programme-technical-specifications
[62] SMETS2 documentation: https://www.gov.uk/government/consultations/smart-metering-equipment-technical-specifications-second-version
[63] Active power is useful power, reactive power is not useful, it moves back and forth between generation and load and must be maintained within certain limits.

- Time-of-use pricing,
- block pricing and
- time-of-use with block pricing.

These pricing methods are applied to both payment methods: credit and prepayment.

Load control
An additional feature required from SMETS2 meters is the ability to perform direct load control of up to five appliances. Control is expected to work based on an in-built calendar of schedules or by remote request (e.g. from supplier or network operator).

Twin element (circuit) variant
SMETS2 also includes requirements for a twin-element variant of smart meters. Twin element means that the smart meter can measure and bill for two separate circuits: primary supply and secondary supply. Primary circuit would be the main supply to the household and secondary, at a smaller rating, would be for a separate set of loads (e.g. hot tub, heating or EV charger).

4.3 Implementation by DNOs and Suppliers – code changes

Network Charging

Domestic energy bills are mainly energy-only (charged solely as a flat per kWh rate) and this is mainly because this is how wholesale energy is bought and sold, and how the networks charge for non-half hourly metered users. If network charges were to change and incorporate a capacity-based charge for smaller users, Suppliers would be expected to pass on this change to its customers.

Capacity-based Distribution Use of System charges (DUoS) are already levied at higher distribution voltages, and passed on by suppliers to business users. They are based on an energy users contracted kVA. A recent change to the DUoS charging methodology – DCP161 under the CDCM – has resulted in increases to the charge for exceeding contracted kVA. Previously, excess capacity charges were identical to contracted kVA charges – DCP 161 is designed to better reflect the costs of reinforcing the network.[64] There is already, then, a direction of travel which seeks to encourage energy users to better manage, and pay for, their capacity requirements.

Larger energy users

A key question for implementation for residential customers is how are kVA charges (which incorporate a charge for reactive power) implemented for these larger users? As far as we can ascertain, the capacity charge (and exceeded capacity charge) is based on monitoring:

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[64] DCP 161 was approved by Ofgem in 2014 and implemented in 2018.
https://www.ofgem.gov.uk/publications-and-updates/distribution-connection-and-use-system-agreement-dcusa-dcp161-excess-capacity-charges

- The maximum half hourly kWh from settlement meters, converted to an "average" kW, and sent by Elexon to the DNO

- Reactive power is either measured by a meter on-site or estimated by the DNO.

DNOs then calculate kVA and also charge separately for reactive power based on accumulated units recorded on a reactive power register.

All suppliers have sections on their websites explaining the importance of capacity-based charges for businesses. Some offer help in managing these charges, for example offering power factor correction equipment.

Implementation for residential users

There are several considerations arising if something similar were to be considered for residential users.

The charging methodology is complicated

There are seven separate CDCM tariff[65] elements for half hourly metered customers, as well as local Line Loss Factors. This is in addition to wholesale energy charges which may also be differentiated by time of use. No doubt an average business customer will already find this complex. There is a question therefore around whether a residential tariff should be simpler, not least because if it is understood, it has a better chance of prompting behaviour change.

Should residential customers see a reactive power charge?

EV chargers and other devices will impact reactive power at the residential level, so will DNOs seek to levy charges which reflect this?

Suppliers relationship with customers

DNOs would more likely to be driving changes to network charges, but Suppliers would be at the front end re-charging them to customers. As they do so for business consumers, there would likely be an expectation that Suppliers would explain and promote any changes.

Code changes

DUoS charging methodologies are in the Distribution Connection and Use of System Agreement (DCUSA)[66] to which DNOs and suppliers are party. There is a formal governance process for changes to the DCUSA and a steady stream of ongoing change proposals. Ofgem's SCR can direct that changes are made to the DCUSA. Major changes can take years to go through the full development and approval process. That is, it is not an easy or quick route to take, and is not usually a process that is easily accessible to all stakeholders who would need to be well resourced, and able to commit to the lengthy often deeply technical process. Citizens Advice is however represented on the SCR.

[65] A good explanation is provided by SSEN in "How are DUoS charges calculated?" https://www.ssen.co.uk/duos/
[66] https://www.dcusa.co.uk/SitePages/Home.aspx

4.4 Implementation by Suppliers – voluntary action

Suppliers must charge for electricity within the terms of their license. Some already offer domestic time-of-use tariffs, or internet-only tariff options.

License conditions

Although large energy users already see capacity charges, a move to capacity-based charging for domestic consumers would represent a significant change. Supplier licence conditions require Suppliers to offer tariffs which:[67]

- Incorporate all charges into unit rate(s) and / or a standing charge(s) or, into a time of use tariff (SLC 22A)
- Offer "informed choices" which means that different tariff options must be "clear and comprehensible" and that suppliers must help customers to compare different tariff options (SLC 25)

On request of the customer, Under SLC 22:

- Suppliers must also provide historic consumption, including data from an old Supplier when switching to a new Supplier

Suppliers may be able to offer capacity-based charges and still comply with these conditions, but it will be challenging. For example, can a complex capacity charge still reasonably qualify as a standing charge? Can energy-only and capacity-based charges ever be comparable?

Suppliers will be breaking relatively new ground on ensuring that domestic capacity charges are comprehensible, and this doubly applies to first-time capacity charges, where historic consumption data will be required from a smart meter. Suppliers will need to invest in understanding their consumers power requirements and helping them to select the most appropriate capacity levels.

Ofgem's 2018 consultation recognises this in saying that an alternative to specifying core capacity could be "*placing a principles-based obligation on suppliers or another third party to determine the type of access that a small user needs for all their usage, requiring them to ensure they made that recommendation in line with a customer's best interests*."

Block pricing options

Figure 4.1 shows, for the LCL and CLNR datasets, for each customer segmentation (Acorn, Mosaic or the CLNR classifications), the relationship between energy consumed in a year, and peak demand (based on KWh over a half hour). This shows that for some segmentations, there is a very good level of correlation between the two. This suggests, if we can better understand customers, that energy could form a proxy for peak power. In turn, this suggests that IBP could offer an alternative to capacity-based charges.

[67] Ofgem, 2019. Licence guide: tariffs and contracts. https://www.ofgem.gov.uk/publications-and-updates/licence-guide-tariffs-and-contracts

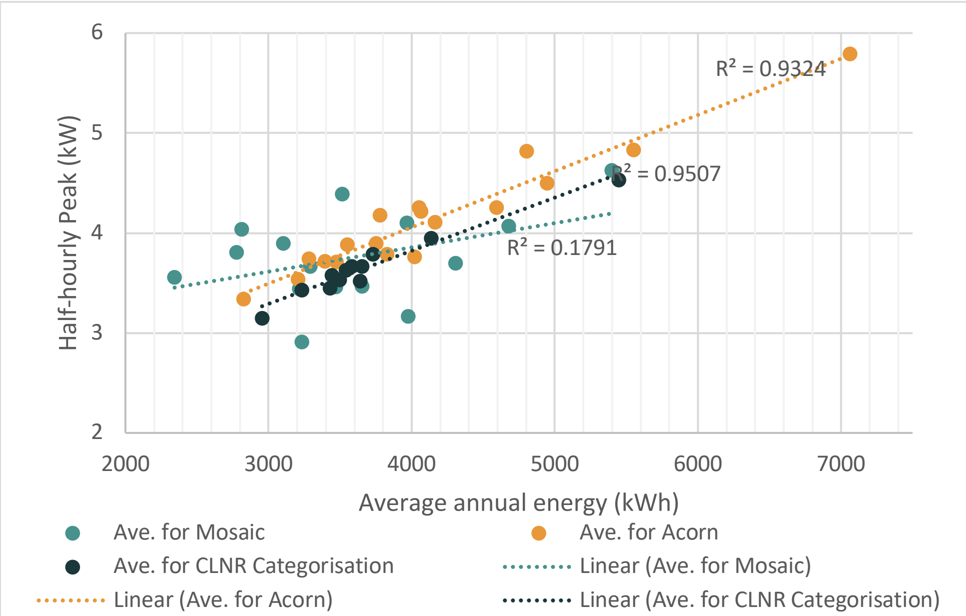

Figure 4.1 Annual energy against peak power for customer categorisations[68]

4.5 Social issues and vulnerable customers

In this work we have not been able to consider, from a social standpoint, what kind of activities might be rightfully considered essential, and which activities are more a function of lifestyle, income and choice. This will be covered qualitatively in our literature review for SSEN. However, by way of guidance, the following observations can be made:

A household's peak capacity varies appreciably by household income

One could therefore take the low income peak capacity levels as an indication of essential activities and therefore as the basis of a core capacity. This "tight" core definition would guard against lower income consumers paying for capacity they do not need (and subsidising higher income consumers). It does not however allow for the possibility of low income consumers under-consuming electricity, to the detriment of basic living standards – something which an affordable level of a slightly higher level of core might rectify.

Heating is a basic core requirement, making a case for higher levels of core capacity for electrically heated homes

This feels like an uncontroversial and sensible position to take, but would be better informed by a more detailed understanding of how different electric heating options compare on capacity

[68] Average peak values against average annual energy per consumer segmentation method. Each dot represents a category or group in the segmentation method. R^2 value indicates how close the data points are to the regression line explaining the degree of linear relationship between annual energy and peak demand. (1= all data points on the line, 0 = data points are far from the line).

requirements. This in turn would help to inform whether there need to be incentives to choose the most efficient systems and to avoid any perverse incentives to go electric.

Load limiting by supply interruption is unavoidably contentious
Just as Suppliers are making good progress in avoiding enforced supply interruptions (for non payment of bills) through a more personal and managed approach to debt, automated load limiting via smart meters is likely to be seen as regressive and impersonal. It could be particularly dangerous for vulnerable customers and could threaten consumer acceptance of and engagement with, smart meters.

Furthermore, the level of the demand limit threshold (and the duration of permitted demand over the threshold for SMETS2) have to be carefully configured to ensure that consumers are not penalised for short duration high demand. For example, an electric shower can be rated at 8-10kW, which is significantly higher than demand for an average household during peak-time. Assuming 5-10 minutes of showering time, interruption to supply 30 seconds after starting the shower will not be popular.

Access to smart meters
It is already the case that some customers cannot physically or practically access all tariff options. For example, those on restricted meters or those unable to access the internet. Tariffs which require a smart meter are starting to emerge, for example Time of Use Tariffs – at the moment these are mainly static Economy 7 time of use charges. Only one, as far as we know, is a dynamic tariff.[69]

Capacity-based charges would – as a minimum – require a smart meter, but not all customers have or will have a smart meter, by choice or because it cannot be offered. So, capacity-based charging will further widen the gap between those with and without smart meters, leaving those without unable to access potential savings (and inevitably, picking up some residual costs from other's savings).

Inflexible demand peaks
Some consumers may simply not have the ability to flex power requirements and avoid high charges. For example, those with medical equipment in the home. Our work on the existing smart meter data shows that electric heating has a near-doubling effect on core capacity requirements, and many electrically heated homes will be unable to control the size or duration of peak demand. There is a definite case for provision of higher core capacities in this and perhaps other circumstances.

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[69] https://octopus.energy/agile/

5 Conclusions and further work

5.1 Core capacity – domestic consumers

There is some strong evidence here that consumer's circumstances are driving peak capacity. In particular income, and, of course, whether consumers have electric heating. High income consumers are responsible for up to double the peak capacity of low income consumers.

The evidence points to a basic core capacity of around 2-3kW, characteristic of low income consumers. This is based on defining core capacity as a half hourly "average".

Electric heating, traditional or ASP-based, can double this to around 6kW.

An electric car could double this again, if consumers plug in on return from work. Smart charging should be able to avoid this, but peak capacity will still be high, around 6-7kW.

Based on current consumption patterns, some consumers will exceed this core capacity, reaching peaks of up to 20kW. We do not yet know enough about these outliers, what and who is responsible for them.

⇒ **Further analysis of capacity outliers is required.**

We also do not know whether low income consumers are meeting their essential needs at 2-3kW peak demand.

⇒ **Further work is required to understand if a core capacity based on low income-levels of use is sufficient to meet basic needs**

On the basis that heating is an essential need, core capacity should be higher for electrically-heated homes. Exactly how high needs further investigation, looking at the variation in need by technology, heating regime and location.

⇒ **Electric heating is clearly an essential for those that have it, but further research is required on the capacity premium it represents.**

The argument is less clear for EVs, especially where consumers do not have smart charging to avoid coincidence of peaks.

⇒ **The basic or not requirement for EVs and needs further consideration, linked to whether consumers adopt smart charging.**

At a simple level, consumers generally pay more if they consume more electricity, but whether this recoups both the network and energy costs for which they are responsible is impossible to know just yet. There is concern that low income consumers are subsidising network costs driven by high income consumers.

⇒ **Investigate cost reflectivity of the network element of consumer bills**

Setting a core capacity may not solve this potential inequity. Evidence from Italy shows that setting a basic level for everyone still over-charges consumers who consume even less. There is also the potential to over-complicate charging to the extent that consumers do not know how to respond. Capacity-based charging for domestic consumers is in use in other countries, but it would be helpful to understand more about its effectiveness, if the evidence exists.

⇒ **Capacity-based charging should be considered carefully, taking into account unintended consequences**

We found some conflicting evidence on whether structured volume-based charging (Increasing Block Charging) could offer a viable alternative to capacity-based charging. There are good correlations between capacity and energy across all the smart meter datasets, but Elexon's load profile data showed poor correlation when broken down by region.

⇒ **Increasing Block pricing has precedent elsewhere and could offer a useful alternative to capacity-based charging. This should be included as an option in any further consideration of capacity-based charging and investigated as to whether it is a cost reflective alternative for all parts of the UK.**

There are compelling reasons to set core capacity based on half hourly average values: this is what is used for existing capacity-based charging; it is what other countries seem to use (Italy uses 15 minute average); it aligns with smart meter measurements; and, it does not penalise consumers for short bursts of high usage, such as showers.

⇒ **There are strong reasons to set core capacity based on the half hourly average**

However, we do not know if this gives the right incentives in terms of what is driving network costs.

⇒ **DNOs need to consider if half hourly average capacity charging gives the right incentives**

Current small business capacity charges in the UK are based on half hourly average capacity values, which in part may be because this is aligned to smart meter functionality. Smart meters could be configured to record and interrupt supply when capacity limits are exceeded. We assume charging could also reflect exceedance of these values. However, this may prove unpopular unless very carefully designed – for example to allow basic activities such as showering.

⇒ **Instantaneous peak-based charging may be more cost-reflective, but this needs to be balanced against practicality and acceptability.**

5.2 Core capacity – small business

There are no clear conclusions on core capacity of small businesses, mainly due to the lack of data. It seems likely though that it will be difficult to define a core level across multiple businesses and consideration will need to be given to the capacity drivers in businesses. So, where income and heating is a key determinant of capacity requirement in households, what is the equivalent for small businesses?

⇒ **If small / micro businesses were to be deemed to require a level of core capacity, extensive further work would be required on smart meter data for small businesses, considering amongst other things the factors driving capacity requirements.**

5.3 Multi-core capacity

There is scope for setting multiple core capacities by time of day, reflecting typical load profiles for gas-heated and electric-heated households, and for small businesses. However, it is not immediately clear what this would achieve, over-and-above time-differentiated charges and a carefully set single core capacity. For example a core capacity set below the level required for simultaneous evening peak and EV charging would already encourage smart EV charging. Whilst there is precedent for time-of-day charging, there is no precedent that we could find for time-varying hard capacity limits.

Furthermore, there are many unanswered questions both around core and multi-core capacity levels, including on regional variations. For this reason it would be prudent to start with a simpler single core.

⇒ **Multi-core capacity is untested and needs further evidence as to its viability and efficacy.**

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