Imperial College
London

Accessibility and validity of **smart meter data**

Low Carbon London Learning Lab

Report C5

ukpowernetworks.co.uk/innovation

Low carbon LONDON Energising change

UK Power Networks Delivering your electricity

Authors

Mark Bilton, Richard Carmichael, Alex Whitney, Jelena Dragovic,
James Schofield, Matt Woolf, Goran Strbac

Imperial College London

Report Citation

M. Bilton, R. Carmichael, A. Whitney, J. Dragovic, J. Schofield, M. Woolf, G. Strbac,
"Accessiblity and validity of smart meter data",
Report C5 for the "Low Carbon London" LCNF project: Imperial College London, 2014.

SDRC compliance

This report is a contracted deliverable from the Low Carbon London project as set out in the Successful Delivery Reward Criteria (SDRC) section "Using Smart Meters and Substation Sensors to Facilitate Smart Grids".

Report C5
September 2014

Contents

Executive Summary

This document reports on the quality of smart meter data available for research in the Low Carbon London (LCL) Learning Lab.

During the period between December 2011 and November 2012, nearly 6000 Landis and Gyr (L+G) E470 electricity meters where installed in residential homes across the UK Power Networks LPN area of the London distribution network. The installation of these meters, the communication of load profiles, and data transit to the Operational Data Store (ODS) through to the Learning Lab was validated using a suite of software tools and visualisation.

First, the meter installation program is described and visualised in terms of the increasing numbers of meters reporting in 2012. Whilst this visualisation highlighted the progress of the installation campaign it also revealed intermittent gaps in the data. These data gaps are described in terms of frequency and duration and appear to be divided into two categories; the first is gaps of data longer than a day, and those comprising gaps in the diurnal profile data. It appears that the former issue is related to communication failures that result in data not being uploaded into the CGI ‘head end’, and the later are thought to be associated with the L+G meter annulling profile data when supply failures occur.

Despite dropouts affecting nearly all meters at some point during 2012, the frequency of dropouts is relatively low and did not significantly distort the findings of Learning Lab analysis of demand profiles or flexibility under the EDF Energy ‘Economy Alert’ tariff.

Once the basic availability of data was established, it was then visualised in combination with data from the trial participant database which contains the details of demography and appliance ownership. The distribution of smart meters is represented geographically and in relation to social demographics.

Using a top down classification of household size and income bracket groupings, profile class one is divided into 9 sub-classes of consumer. This is the first time that such a large sample of consumers has been banded like this and it reveals stark differences in winter energy use for the higher social group families. In winter the high income family groups’ demand deviated from other groups quite dramatically, with an average peak of 1.6kW, versus just 0.4kW for the single-occupancy low income group.

The report finally concludes that the data yielded from the smart meter trial is fit for application in the later LCL reports, namely: ‘Residential consumer attitudes to time varying pricing’ and ‘Residential consumer responsiveness to time varying pricing’.

Glossary

ACORN	A Classification Of Residential Neighbourhoods (CACI Ltd)	Geodemographic segmentation system similar to MOSAIC and commonly used for planning and marketing.
3G	Third generation	Common term used to describe the forthcoming smart meter technology.
DCC	Data and Communications Company	Organisation responsible for transfer of data between smart meter and other organisations.
DNO	Distribution Network Operator	
dTOU	dynamic Time-of-Use	Distinct from traditional time of use tariffs which typically have a fixed daily cost profile.
EDF Energy	Electicite de France Energy	The retail arm of EDF.
L+G	Landis and Gyr	The suppliers of smart meters for the SM trial.
LCL	Low Carbon London	An LCNF funded programme.
LCNF	Low Carbon Network Fund	An Ofgem scheme intended to promote innovation in DNO activities.
LCZ	Low Carbon Zone	An area of London targeted for energy efficiency by the Mayor's office.
LPN	London Power Network	The distribution network License area covering the majority of London's electricity supply.
ODS	Operation Data Store	The central repository for all measurement data in the LCL programme.
PMS	Participant Management System	A database containing information about trial participants.
SAP	Sales and purchasing	
SM	Smart Meter	
SMETS	Smart meter equipment technical specification	

1. Introduction

The Low Carbon London smart meter trial, facilitated by EDF Energy represents the most comprehensive review of residential electricity demand in London ever conducted.

The trial has three essential goals; to characterise London's residential consumer demand; to test demand flexibility in response to time varying pricing; and to quantify the benefits of smart metering for distribution network operators.

To these ends the smart metering trial comprises four key elements:

- The installation and monitoring of nearly 6000 smart meters in homes across the London Power Network (LPN) license area of UK Power Networks;
- A broad questionnaire survey of the households involved;
- The execution of the UK's first residential dynamic Time-of-Use Tariff (dTOU, see below);
- A longitudinal qualitative, interview based, analysis of attitudes to smart meters and time-varying tariffs.

'Time of Use' tariffs typically refer to electricity pricing schemes where the price changes depending on the day of the week and/or time of day. Traditional TOU schemes usually charge more at times of peak demand and vice versa. They fall into two categories – static and dynamic. Static TOU tariffs are fixed in time, e.g. a price reduction every weekday from 10pm to 6am and on weekends. Dynamic ToU change the timing depending on external conditions, e.g. the LCL dTOU is not fixed it is aimed primarily at providing demand response to wind generation and distribution network events.

This report describes the first of the activities listed above in detail, including the selection and recruitment of customers through to the yielded data, the applicably to the GB population and its implication for the distribution network operator.

The household questionnaire is touched upon, since it relates to consumer categorisation, but on the whole the remaining aspects of the smart meter trial are covered in considerably more detail in the Learning Lab reports: C2: 'Impact of energy efficient appliances on network utilisation ' [***1***], A2: 'Residential consumer attitudes to time-varying pricing' [***2***] and A3: 'Residential consumer responsiveness to time-varying pricing' [***3***].

The following section describes the smart meter trial design and this is followed by a description of the trial findings and their implications.

2. Validity through trial design

2.1. Introduction

In order to have the smart meter trial best serve the LCL objectives, the trial design involved considerations of a host of issues. This section aims to highlight the factors that are most relevant to the DNOs going forward, and those that influenced the scope and quality of the Learning Lab research programme. The following sections provide an overview of the actual metrology technology deployed and the households that became part of the LCL SM trial.

2.2. Meter technology deployed

The timeline and technology used in the LCL smart meter trial were significantly influenced by the associated government policy and corresponding responses from industry during the period from 2011 – 2012.

In the original project, as approved by Ofgem, the objective was to use '3rd generation smart meters', as described by the Ofgem 'Smart Meter Prospectus' [***4***]. This was important to the LCL programme because this new generation of meters record information that is valuable to distribution networks, most notably voltage profiles, voltage sag and swell events and outage alerts.

However, at this time the meter requirement specification was not finalised and this impacted expected design and delivery dates for EDF Energy's preferred meter supplier. This was the largest material cause of delay to the LCL smart meter trial. With delay posing the risk of the trial not being possible with new technology the programme steering group determined to conduct an impact assessment.

Following this assessment it was decided that the programme would deploy an existing meter already available in volume namely the Landis and Gyr (L+G) E470, see Figure 1.

Figure 1: the Landis and Gyr E470 with in-home display.

While this choice excluded the possibility to record and hence analyse network voltage ranges and perturbations, it did allow profiling of demand and the trialling of the Time of Use tariff which were fundamental components of the LCL programme.

Figure 2 outlines the main IT infrastructure associated with the smart meter trial. Data is transmitted to and from the smart meter by Global System for Mobile communications (GSM) mobile phone infrastructure, and this activity is marshalled by the CGI Instant Energy 'head end', a product used by the majority of electricity suppliers smart metering systems.

The tariff information and other messages come to the head end from the suppliers sales and purchasing (SAP) systems which in turn also collect settlement data (in some instances this might be managed by a third party aggregator). For the purposes of LCL, tariff and demand data is also directed to a secure server which supplies the input data for both the Operational Data Store (ODS) and Participant Management System (PMS) to which the Learning Laboratory has secure File Transfer Protocol (FTP) access.

Within the home, the smart meter communicates with its associated In Home Display (IHD) via the Zigbee protocol, a low-power wireless communications protocol.

It should be noted that the whole system as described was designed and implemented specifically for the LCL programme.

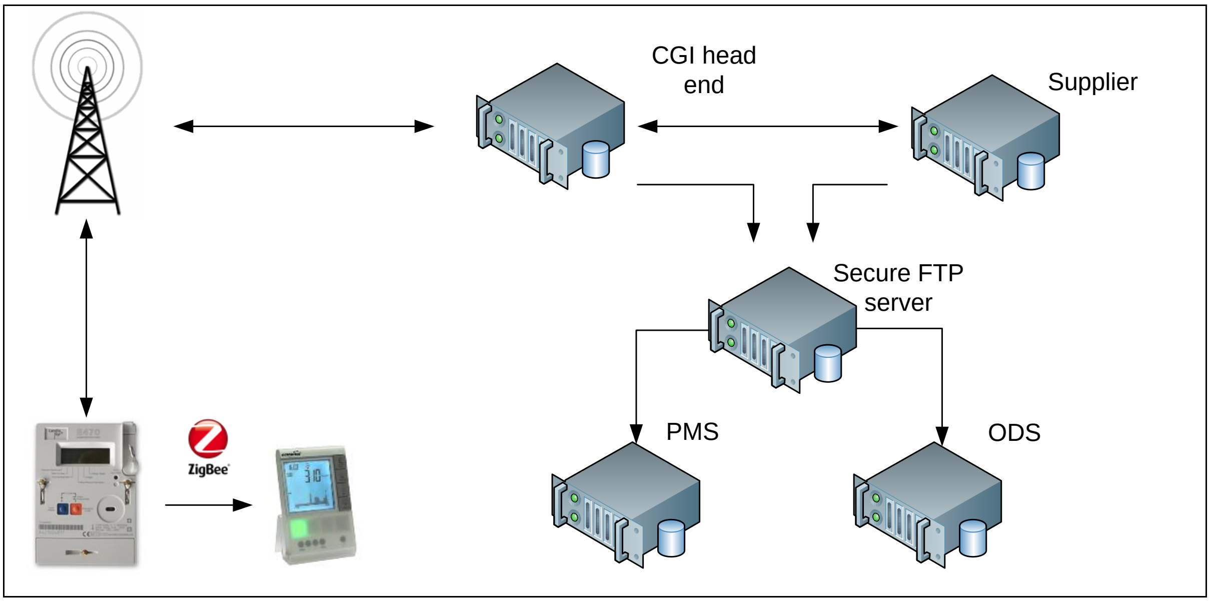


Figure 2: LCL smart meter infrastructure[1]

[1] Note that only survey data came from the suppliers to the PMS.

2.3. Meter installations: approach to sampling and recruitment

In parallel to discussions about what meter technology to deploy on the LPN network, the question of where to locate meters was also being resolved. The following sub-sections identify the key design parameters:

2.3.1. Target sample size

The number of smart meters deployed was determined by a range of factors, including: regulatory constraints; EDF Energy's wider smart metering activities/plans; costs; and a desire for statistically valid results from the planned residential dynamic time-of-use trials. The original project bid had proposed smart meter numbers of 5,000 and this was the preliminary target for recruitment. A later target of 6,500 was set following analysis by EDF Energy of the likely customer churn rates and likely take-up of the dTOU tariff.

2.3.2. Geographic area: from LCZs to LPN-wide

The original objective was to cluster meters within a number of London neighbourhoods identified as 'Low Carbon Zones' (LCZs) by London's mayoral office, partners in LCL.

The purpose of the LCZs was to provide prototypical demonstrator networks in which the various LCL interventions, such as smart meters, could be introduced and analysed in terms of their effects on power flow and power quality. In order to understand if the use of these existing zones would impact the representativeness of the meter sample, demographic data was acquired from Experian[2] and the LCZs were compared to the Greater London population. Unsurprisingly the mayoral LCZs were found to be heavily skewed to lower income groups with a high percentage of homes falling into one or two demographic groupings[3].

This was problematic in that it would not form a representative sample of London households for studying electricity demand, attitudes or responsiveness to tariffs, making extrapolation to wider London impossible. As a consequence, the smart meter trial was divided into a 'London-wide smart meter trial' using the L+G meter, and proposed 'engineering trials' including deployment of meters that could measure voltage where available.

This changed the trial design considerably, but was extremely beneficial for a range of practical reasons.

Firstly the LCZ population size would not have been sufficient to recruit enough smart meter participants, since LCL had committed to an 'opt-in' recruitment policy for both smart meter installation and subsequent recruitment, from within this group, of participants for the dTOU trial for which take-up rates were unknown.

Secondly, the much larger and more varied LPN population allowed a stratified sampling procedure, targeting specific demographic groups until appropriate numbers of each were achieved to attain a sample matching the make-up of Greater London. One of the objectives for the trial was for learnings to be applicable to Greater London.[4] This raised the question of whether EDF Energy customers within LPN (the widest area easily accessible to LCL) offered a population that could produce a sample representative of Greater London. This was checked by: (a) comparing how the geographical boundaries of LPN and Greater London differed; (b) comparing the geo-demographic make-up of households in LPN with those of Greater London; and (c) checking whether EDF customers within LPN were representative of LPN households of any electricity supplier (as we were recruiting from EDF Energy customers only).

---

[2] Experian is a commercial credit rating and demographic data provider.
[3] See Appendix 1, *Demographics of Low Carbon Zones - Mosaic Household Type*
[4] Extrapolating beyond London is a much less certain prospect due to London being very atypical as a UK city – see ESRI analysis (ESRI, 2011)

(a) Geographical boundaries of LPN versus Greater London

The LPN area is largely contiguous with Greater London with some differences – each include some postcode areas that the other does not have, see Figures 3 and 4, below. Notably, LPN includes some Essex and Kent postcodes but excludes some 'SW' and 'N' Greater London postcodes.

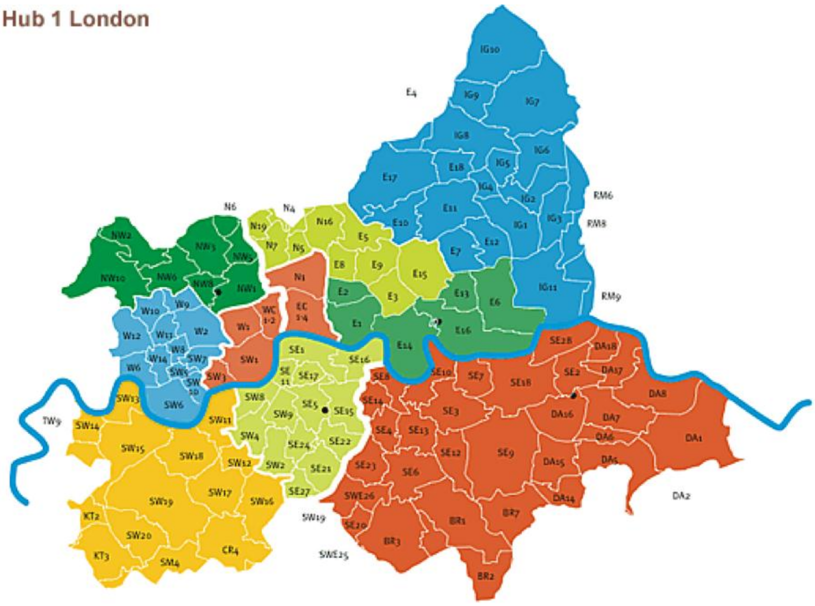


Figure 3: LPN postcode district map (source: UK Power Networks)

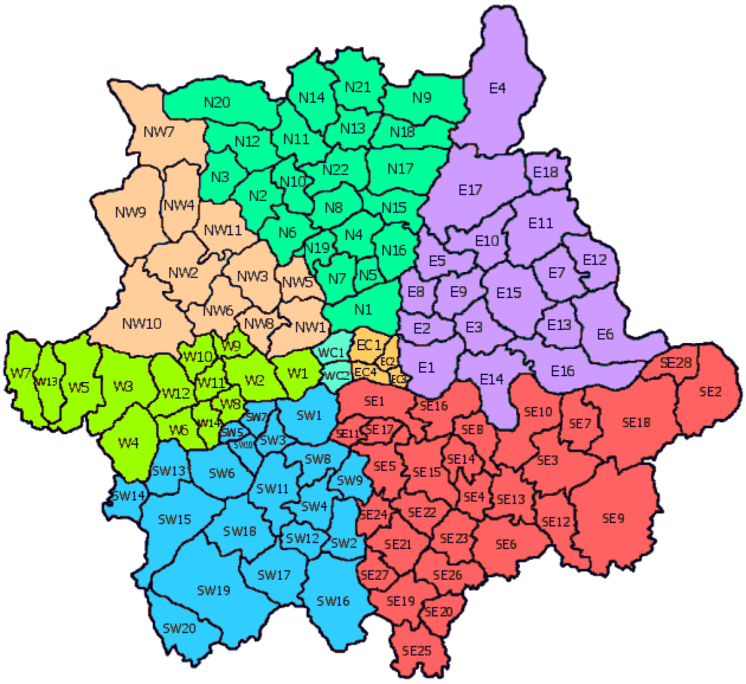


Figure 4: Greater London postcode district map

(b) Geo-demographics of LPN versus Greater London

A profile of Greater London by ACORN Groups (CACI Ltd) was obtained for all households in the LPN area and also for households in LPN supplied by EDF Energy. Comparison revealed that among the households in LPN there were slightly more Educated Urbanites and fewer Secure Families and Asian Communities, than in the Greater London population[5].

(c) EDF Energy LPN customers versus all LPN households

Among the EDF Energy customers in LPN there were relatively more Educated Urbanites and fewer Secure Families and Asian Communities compared to all LPN households and the Greater London population.

2.3.3. Self-selection but stratified sampling

The goal was to get a sample that was representative of Greater London but recruited from within LPN and from only EDF Energy customers. Having a sample which was representative of Greater London was important largely because the households recruited for smart meter installation would be the pool from which households would subsequently be recruited to participate in a residential dynamic Time-of-Use trial. A large and varied sample at the stage of the smart meter installations was a necessary prerequisite for recruiting a representative sample for the dTOU trial. A large and varied sample of households was also necessary to provide a useful control group (or comparison group) for between-groups analyses with the dTOU trial group.

Recruitment of EDF Energy customers for smart meter installation had to be done on a voluntary, opt-in basis and this meant there was the potential for biases in the sample arising from take-up rates being higher or lower for different types of households. A stratified sampling approach was employed in order to achieve the desired sample to overcome any differences between LPN vs London, or between EDF Energy vs. all households, and to attempt to partly mitigate some biases arising from self-selection. Targets were set for each of the 17 ACORN groups (from A– *Wealthy Executives*, to Q– *Inner City Adversity*) and recruitment aimed to hit these individual targets whatever their respective take-up rates were.[6] One other stipulation for the sampling criteria was that the recruitment be spread out over as wide an area of LPN as possible.

The contact methods EDF Energy used for recruiting customers for smart meter installation were: local events held in community centres (LCZs only); a mail-shot to all customers; phone calls made by a call centre.

Although the sample was stratified using ACORN groups, this did not prevent the self-selected sample being biased or skewed according to other criteria associated with accepting or refusing to participate in the trial. For example, households under-represented in the final sample may include: those less interested in technology; those who are difficult to reach by the recruitment methods used (though efforts were made to telephone in early evening as well as daytime); and those who felt too busy to go through the installation process (installation did require an engineer to visit the home). The sample recruited is, to some degree, biased towards ‘early adopters’ of smart meters.

2.3.4. Exclusion criteria

For a variety of reasons there were several types of households/customers excluded from recruitment for smart meter installation. The total number of EDF Energy households in LPN was 911,000. The most notable exclusion criteria are listed below:

- Pre-pay households (196,599 households excluded in LPN)
- Dual-fuel households (49,085 households excluded in LPN)

---

[5] See Appendix for an example LCZ Mosaic distribution.

[6] Initially, it was hoped to have a stratified sampling approach to recruitment that also controlled for electricity consumption (which would be related to household size). Like ACORN groups, consumption levels would be pre-existing data available, in principle, to use to help plan and direct recruitment. It was decided, however, that this would make the recruitment process too complicated in practice and so it was hoped that a good, near-random spread of electricity consumption and household size would be achieved while stratifying by ACORN group only.

- Economy 7
- Vulnerable households
- Micro-generation households

Further exclusions were made when installations were aborted due to poor communications performance with the smart meter (from IHD and or the mobile network).

2.3.5. Meter Installation timeline

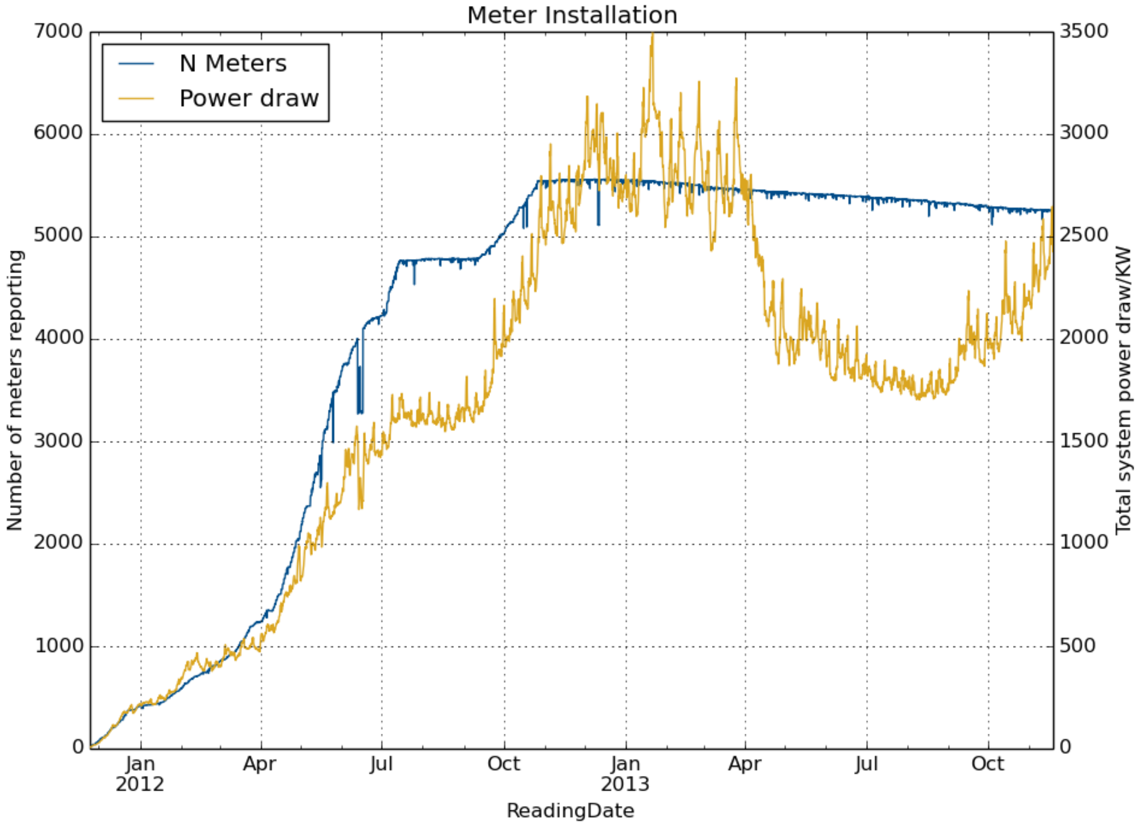


Figure 5: Meter installation progress showing combined power draw.

Figure 5 above shows the numbers of installed meters responding to the head end system, from the first install to the final install, followed by the trial 'attrition' as customers move house and or supplier or leave the trial. The short dips on the blue line are meters that fail to register for a short period of time but reconnect automatically when the communication has been restored.

As this figure indicates, the trajectory of installation in late 2011 was such that if it continued similarly then the target number of installs would not have been achieved by years-end 2012. This was important because both the smart meter and dTOU trial required a whole year of data and 2013 was the final opportunity for this to be collected within the programme timeline. In order to improve installation rates EDF Energy substantially increased their recruitment resources and the effect of this can be seen in the acceleration occurring just after April 2012.

As the pool of potential customers diminished, and filling each demographic bin became increasingly more difficult, installations slowed, and eventually all prospects where exhausted, slightly before the 5,000 meter target had been reached. The hiatus of installations in summer 2012 represents a period when additional potential recruits where identified and the programme negotiated with EDF Energy for further meter installations.

The LCL programme decision to install further meters was based on analysis conducted by both the Learning Laboratory at Imperial College, and EDF Energy. Imperial College had calculated that the programme required 1,521 participants for the dTOU trial, and EDF Energy had conducted a survey which suggested dTOU take-up would be in the region of 20%.

The recruitment of these additional sites in September and October concluded the process and resulted in a population of over 5,500 installations from a pool of ~ 8,000 recruits. All recruits did not result in installation because of technical reasons such as access to meters as well as customers not responding to later communications.

2.4. Installed sample

2.4.1. Number and geographical distribution of installed smart meters

Final number of installed meters: 5,568. Figure 6 presents the geographical distribution of LCL 2G smart meters, with the colour shading representing ACORN geo-demographic group information (see legend).

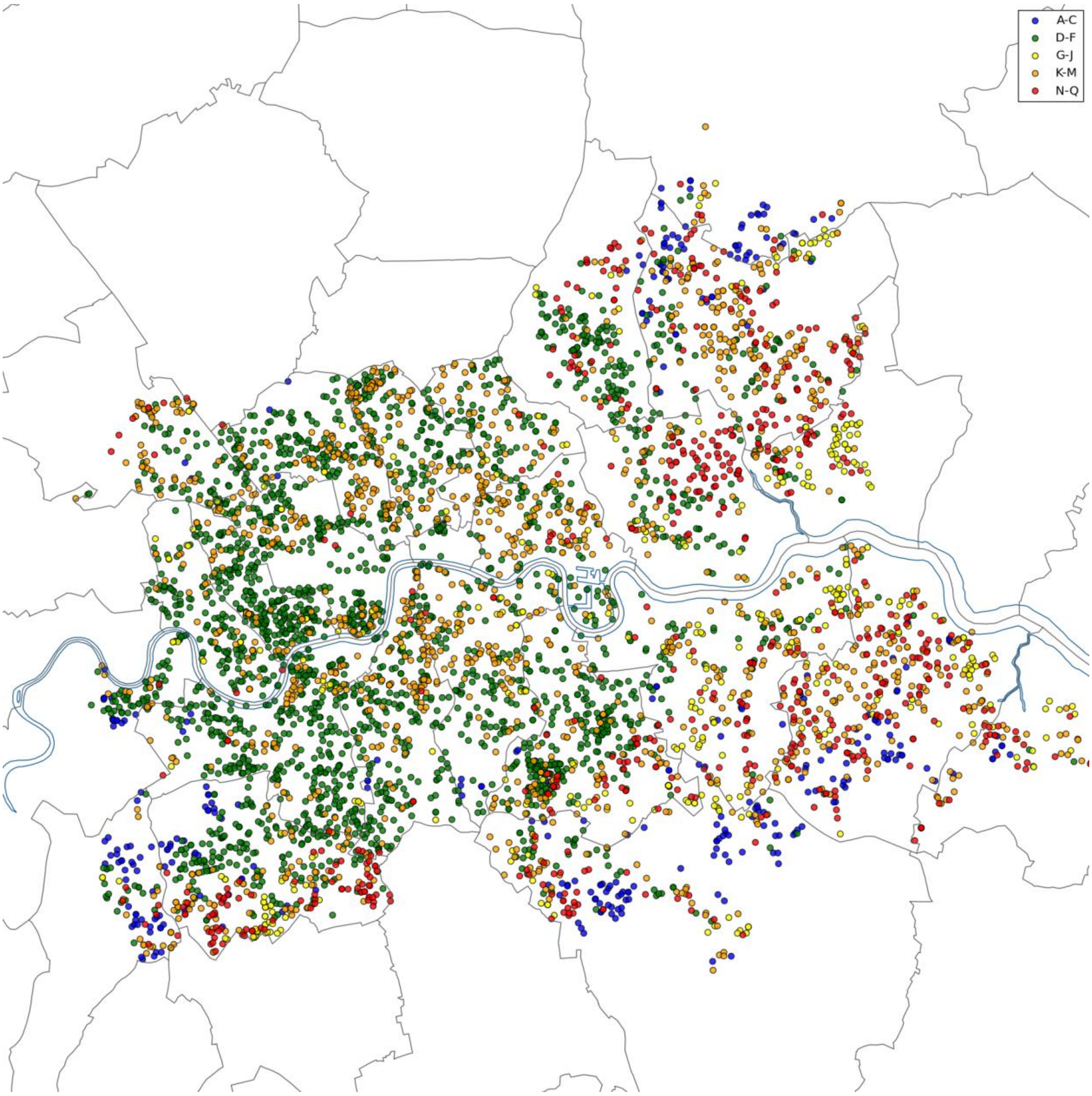


Figure 6: Geographic distribution of L+G E470 smart meters in LCL programme.

2.4.2. Geo-demographics of sample (ACORN)

The success of EDF Energy's targeted recruitment campaign is demonstrated by Figure 7, which shows that the obtained sample is close to the breakdown of ACORN groups for the LPN area.

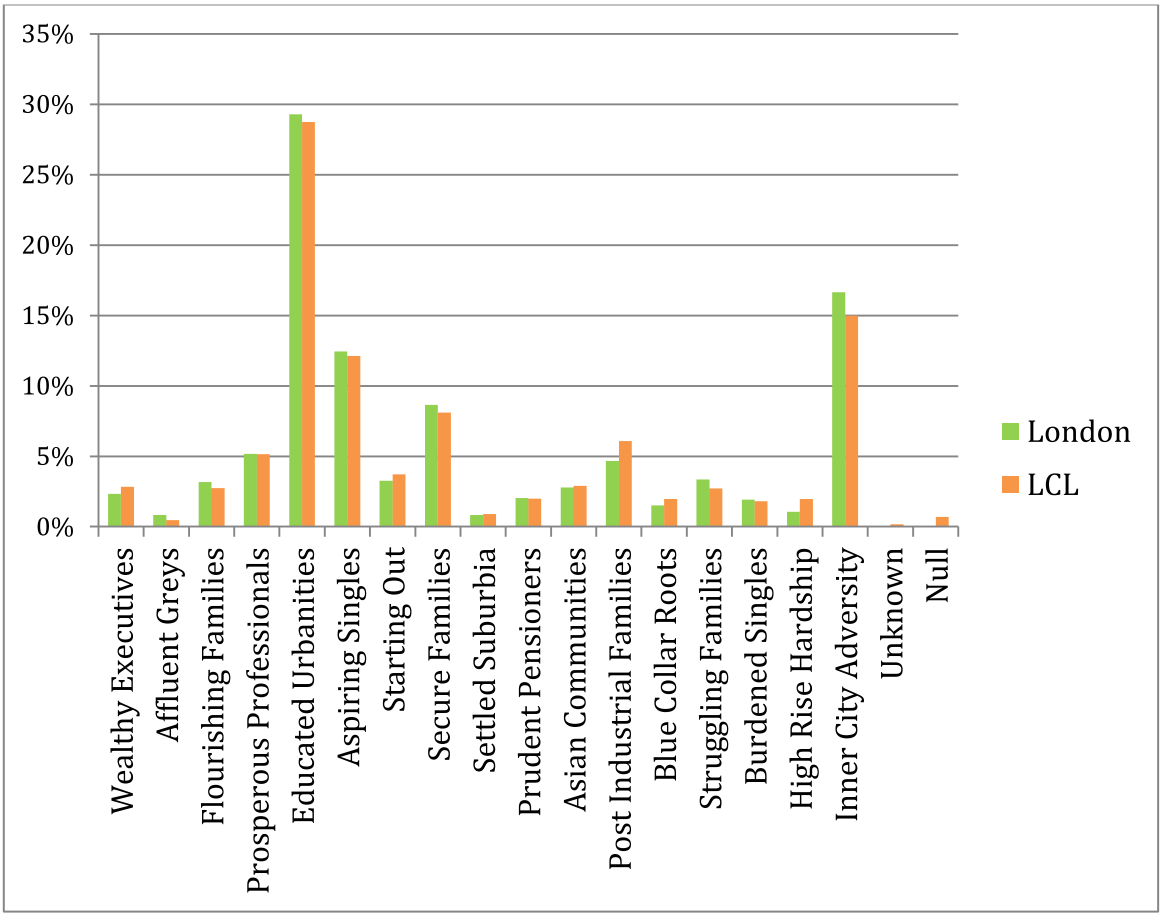


Figure 7: Acorn group distribution of LCL sample versus all households in LPN area

Whilst the demographic mix is close to that of the LPN area some types of residential electricity customers are not represented in the sample. The most obvious example is where customers were filtered from the recruitment 'funnel' process.

2.4.3. Excluded types of households

Besides the need for a representative sample in demographic terms, a range of exclusion criteria influenced the smart meter sample make-up. Two of the most significant exclusions, in size and potential impact on findings, were Pre-pay and Dual Fuel.

Pre-payment customers: No smart meter with a pre-payment facility compatible with existing infra-structure was available at the time of recruitment.

Dual Fuel (DF): The rationale for not including DF customers was that EDF Energy did not want customers to have a customer experience with gas that was different to their experience with electricity; installing smart gas meters, and a more complex refund process, was not feasible within the timescales of the project. If this will be the position of suppliers in the future, then a later roll-out of gas meters might delay offers and take-up of smart tariffs to non-DF customers.

In order to understand the significance of this exclusion we ideally need to understand:
(i) What proportion of LPN households are Dual Fuel?
Of the 911k EDF customers in LPN, there were 49,085 households on Dual Fuel tariffs with EDF Energy in LPN – approximately 5.4% of the EDF customers in LPN.

(ii) How do Dual Fuel customers tend to differ, if at all, from non-DF customers? For example, DF, may be more price consciousness/price-sensitive or more prone to switching; or may have a different make-up by ACORN groups, age, household type, property type, or consumption levels etc.
We do not have sufficient data to evaluate this depth but EDF Energy customers within LPN has a greater proportion of Educated Urbanites than does London and this skew is stronger among EDF Dual Fuel households. This skew is reflected in slightly lower rates for the other ACORN groups, spread across most of the other groups, e.g. there are fewer Secure Families, Post-Industrial Families and Flourishing Families among Dual Fuel households than the London population would predict. However, the make-up of EDF Energy customers who have Dual Fuel may not be representative of DF customers with other suppliers.

2.4.4. Accidental recruits

In some instances customers were recruited that were supposed to be excluded and since they differ from the sample criteria they are excluded from analysis at a data-cleaning stage. One example of this is customers with micro-generation.

Micro-generation: Whilst micro-generation is becoming widespread in some areas, particularly in response to incentives for micro-generation, to include these customers would have required a separate experimental group. This is because micro-generation affects net demand profiles, but also is known to affect energy use behaviour.

2.4.5. Attrition rate

In the UK electricity market, which enables competition between suppliers, customers can change supplier. In the case of homes within the LCL trial, if a householder chose to switch supplier their smart meter data would remain in situ but the data from it would no longer be visible to EDF Energy. Similarly if someone moves house the meter data is no longer valid because the legal right for the project to use the data is connected to the householder’s agreement opt-in. Some loss of trial participants was expected and was factored into to the calculation of the required number of installed meters.

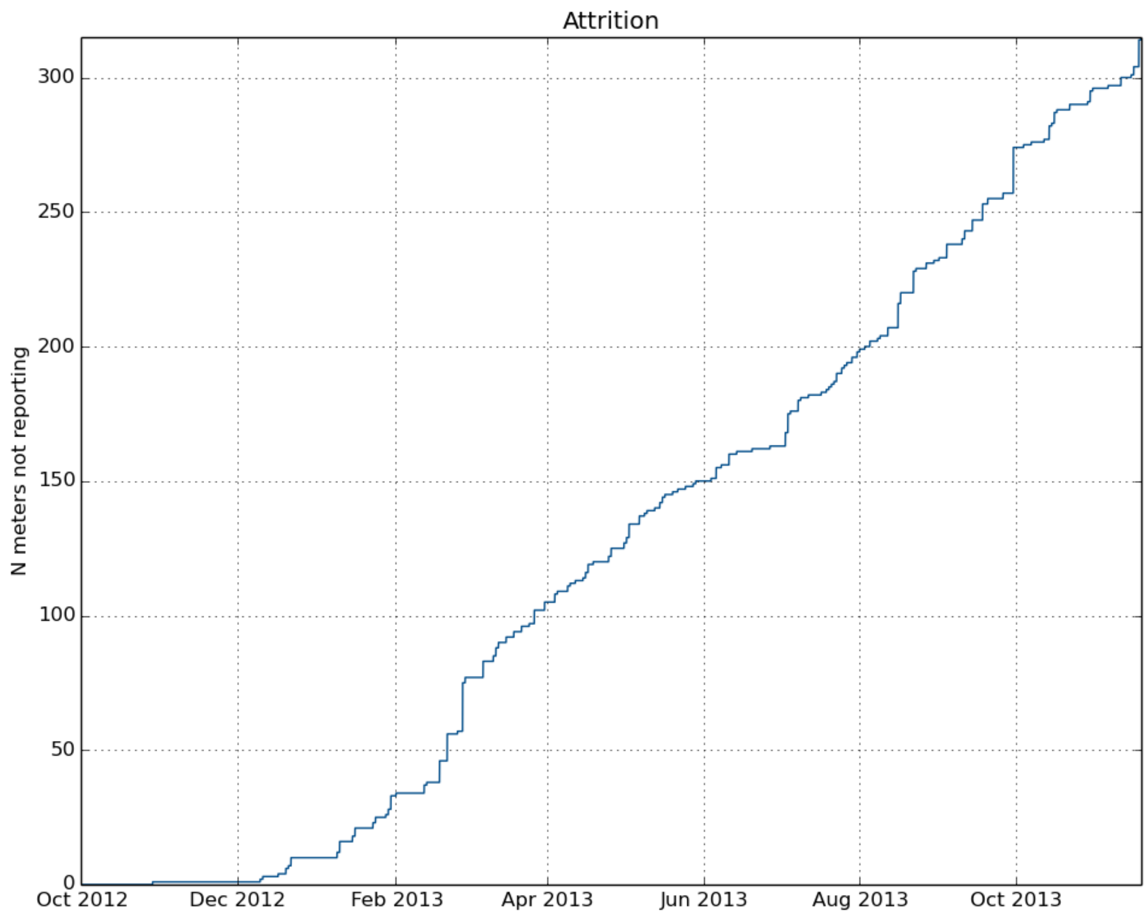


Figure 8: Attrition of responsive smart meters on the LCL trial[7].

Figure 8, above, shows the rate of attrition for the LCL smart meter trial, the trend representing a fairly steady rate of roughly 8% per annum. The final sample size for smart meter trial participants by the close of 2013 is shown in Table 1, below.

		Count at Start 2013	Count at End 2013	Number lost	Percentage lost
Group	All	5510	5095	415	7.5%
	dTOU	1113	1059	54	4.8%
	Non-dTOU	4397	4057	340	7.7%

Table 1, Attrition of trial participants during 2013.

2.4.6. Household Survey

More detailed background data on households in the SM trial was collected via a survey in late 2012. The topics covered in the survey included appliance ownership, household make-up, and some attitudinal questions (e.g. on environmental attitudes). Consent was also requested for the researchers to contact households for interviewing. A

[7] Responsive smart meters refers to any meters that was supplying data to the ODS. Meters may not respond because of technical reasons such as communication failures, i.e. temporarily, or consumers withdrawing permanently from the trial.

paper copy of the survey (with return-paid envelope) was sent to all households with an installed smart meter and the option of completing it online was also available. An incentive of £20 was offered. A total of 2,612 responses were received by post and 218 responses via an online version. This total of 2,830 represents a response rate of approximately 51%. These households who returned the survey represent a more valuable core set of data for analyses.

Notable deviations from the Greater London make-up is that our obtained sample of EDF customers within LPN has fewer Secure Families, Aspiring Singles, Asian Communities, and has more Educated Urbanites than London. This skew is stronger for the sub-set of participating households who returned the Household Survey.

3. Data accessibility

3.1. Data security infrastructure

From the outset, the LCL programme has been clear in regard to the sensitive nature of smart meter data and the need to conform to the Data Protection Acts [***5***].

In essence this applies to any personal information that can be linked to an identified individual. Within that category, some data types are further classified as *sensitive* personal data, and require stronger levels of protection.

Due to the practical nature of the LCL meter trials, the name and address of the customer must be known to install the meter and also to allow customer interviews for the qualitative component of the forthcoming analysis (covered in 'Attitudes to time varying pricing').

Restricting access to such data could be performed in a number of ways, for example database access could be role-based or access-limited by firewalls.

When the LCL Learning Laboratory IT requirements were being developed the situation was such that some of connected systems where yet to be designed, for example the 'participant management system' (PMS). Because of this it was decided to opt for a highly secure configuration at Imperial to allow for the eventuality that the Imperial LCL team would be handling sensitive personal data.

In summary only one ICL server can access the Operational Data Store (ODS) and Participant Management System (PMS) due to the configuration of a hardware firewall (situated next to the server). The ICL server is located in Imperial's secure Data Centre and access rules managed by our security manager under instruction from Imperial's LCL director. The server and associated firewall is itself within the Imperial secure domain and the access to the secure LCL domain is locked to hardware IP addresses.

The Imperial LCL team are under instruction that no information that can identify a participant may leave the secure server.

3.2. Data anomalies

Once regular and stable access to the ODS had been established the Learning Lab team started to investigate the nature of the data being accumulated. On the whole, and as will be described in more detail in the following sections, the kWh profiles extracted from the ODS, when averaged formed profiles very similar to those of Profile class 1 as used by Elexon in market settlement. However during the analysis, a number of anomalies where discovered.

The most commonly of these was what has become labelled 'drop-outs'.

3.2.1. Data drop-outs

Soon after the Learning Lab's analysis had commenced it became apparent that within the smart meter data there were sections of data missing. In practical terms this meant that where a number was expected in a table, there was no data, for example '1.0,2.0,,4.0,'. Figures 9 & 10 represent the number, frequency and duration of data dropouts in the SM trial.

From these charts we can see that the majority of dropouts are short in duration, covering just one or more settlement periods. However we can see two trends on the lower plot, a dense line of short dropout events, and a sparser line of longer 'dropouts'.

At the time of writing it is believe that these two distinct trends are associated with two different phenomena, firstly short term issues causing changes in the meter data and communication failures from the meter to 'head-end'.

The first of these is thought to be associated with supply perturbations causing the L+G meter to overwrite consumption data with event alerts. More specifically the specific half-hourly period is thought to store a 'null' value if the meter has detected a power outage, though this has not been confirmed.

The second category of dropout event is thought to be associated with communications failures where whole packets of data are missing. This is supported by the fact that during the programme's smart meter installation phase mobile phone signal in some locations was not sufficient to commission the meter and was a common cause for aborted meter installs.

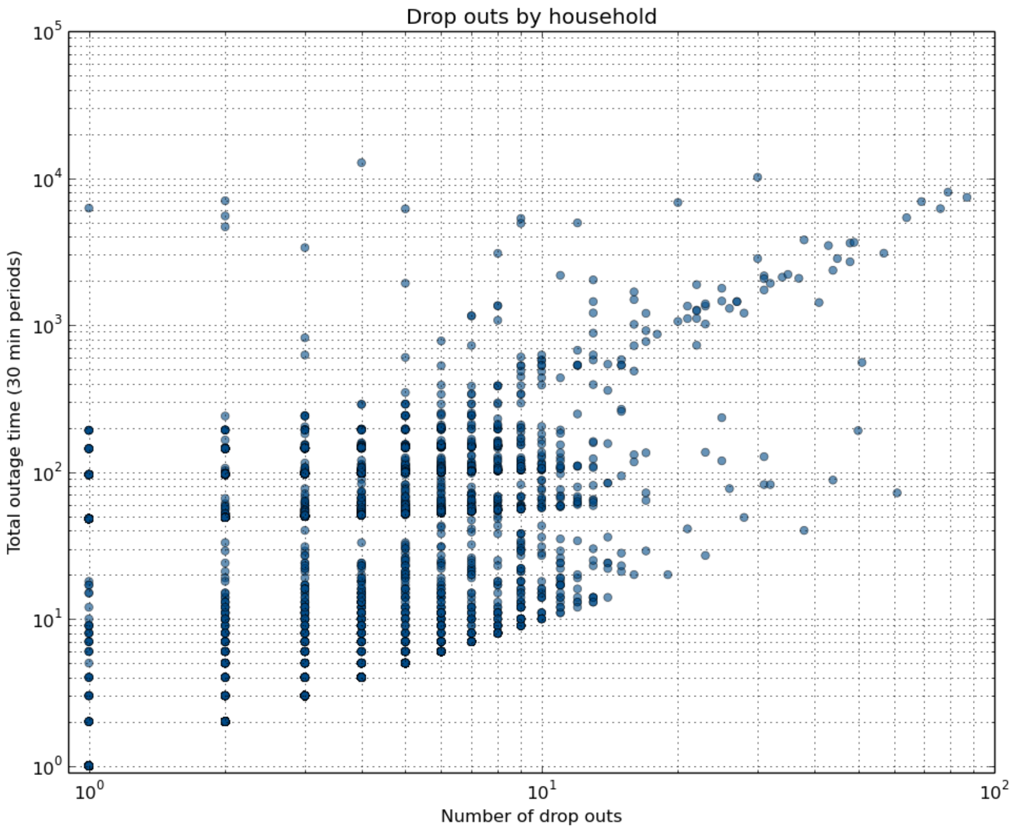


Figure 9: Dropouts by duration and frequency.

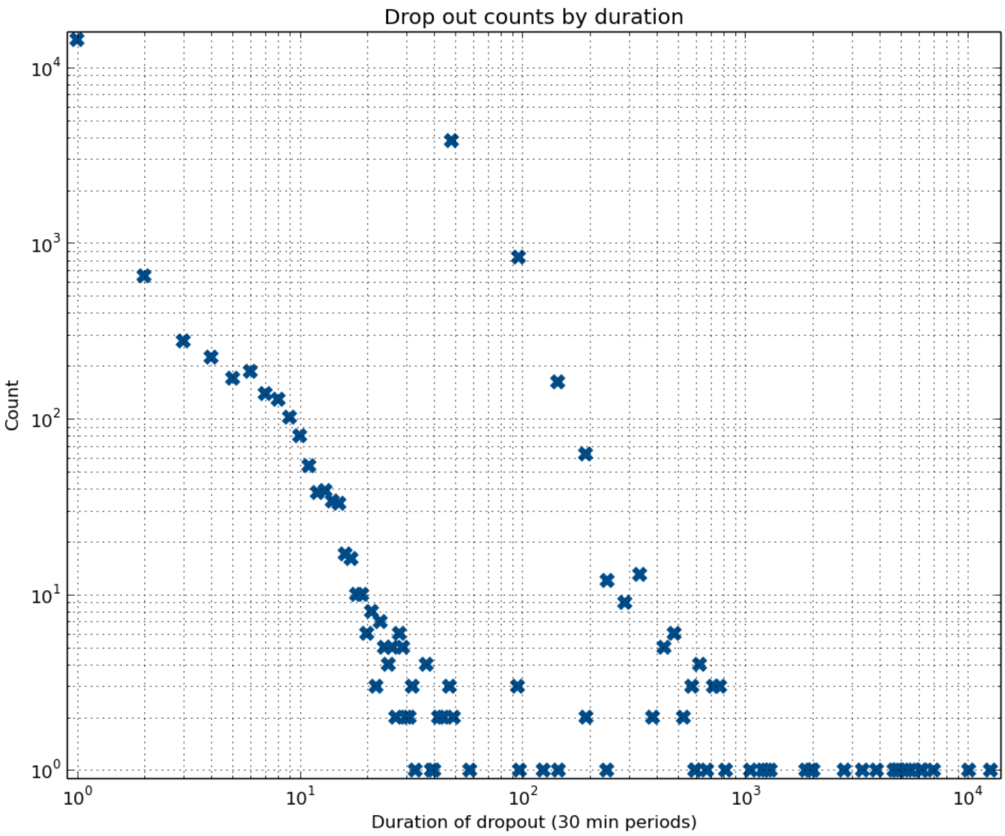


Figure 10: Dropouts by duration and frequency.

The E470 meter would be expected to drop consumption data when:

- A customer disconnects the mains electricity during property maintenance and developments;
- Supply is momentarily lost due to network switching events or faults;

This behaviour was confirmed with Landis and Gyr:

'There isn't a configuration in the meter that affects the recording in the profiles during a power fail or low voltage. The meter will either fill the profile with the energy used during the half-hour period, if it still has power, or will indicate it as power fail filler data once the meter is powered-up following an outage. In the case of power fail data, the profile data will have the upper two bits set to indicate the data as power fail filler data.'

Landis and Gyr E470 SMS Product Manager (2014)

Figures 11 and 12 present the timings of the drop out events by time of day and by day of week respectively. Whilst there appears to be little difference between days of the week, there is a higher occurrence of interrupt events during the day versus the night time.

This is consistent with a mix of the events listed above causing drop-outs, since we might expect intentional disconnections to occur during working hours, when the most dropouts occur, but we also see some dropouts throughout the night.

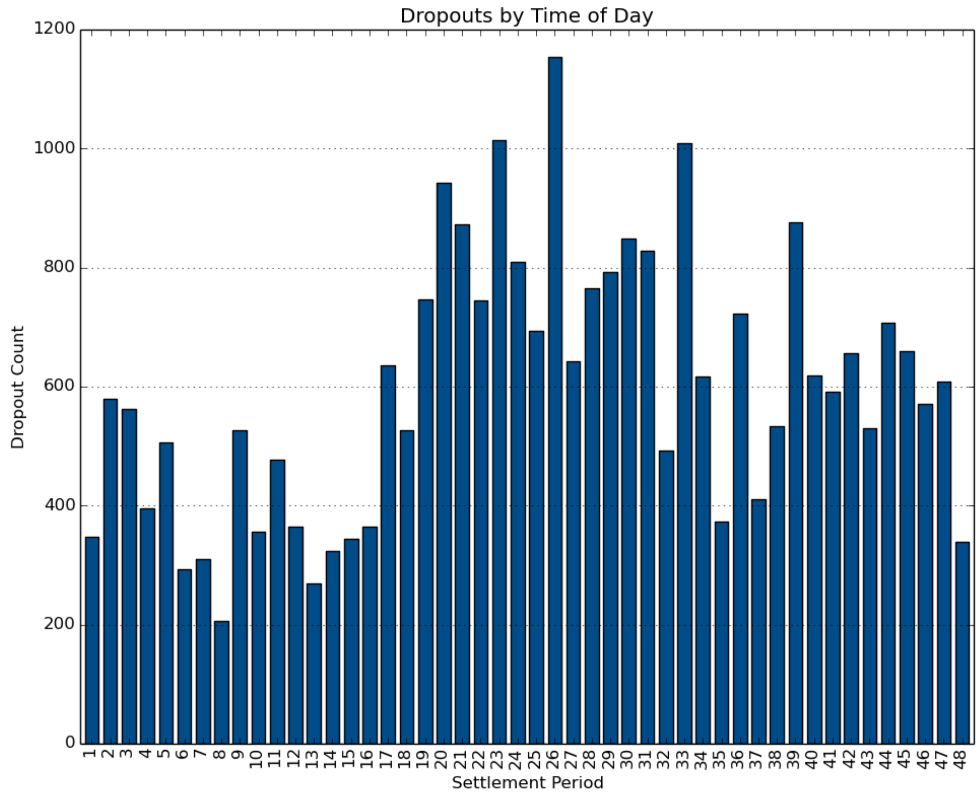


Figure 11: Dropouts by time of day.

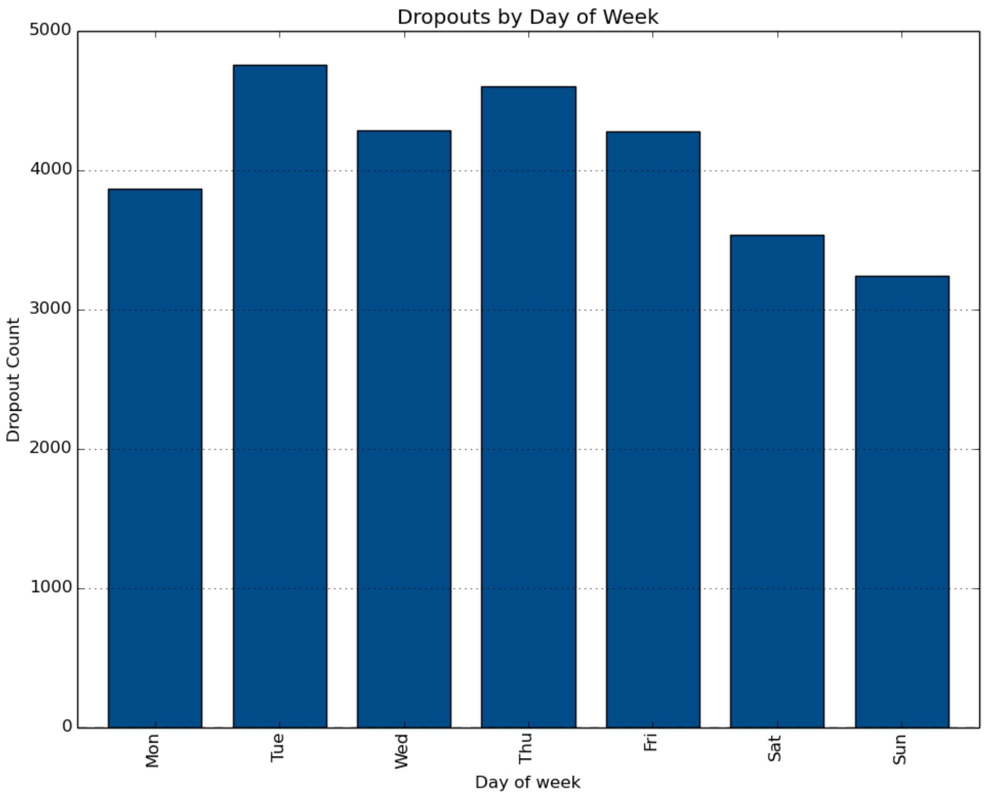


Figure 12: Dropouts by day of week.

4. Data validity

4.1. Data ranges

The LCL smart meter trial comprises some of the first smart meters to be installed across London and, as such, pre-existing datasets for comparison are scarce. However for the purposes of market settlement a sample of ~600 UK residential consumer premises are systematically monitored to provide an estimation of residential demand (K. Spencer, personal communication, January 13, 2014[8]).

The residential electricity market is currently settled based on estimations of customers half hourly usage, derived from the intermittent[9] total kWh usage data supplied through manual meter readings. For any given day, in order to approximate the demand profile of an individual customer a single profile is scaled according to an estimate of their energy use for that day. The profile shape is collected from current sensors situated at the homes of a stratified, randomly selected sample of the UK population. A different profile is used for weekdays, Saturdays and Sundays as well as for different seasons. This collection of profiles is known as a profile class and residential consumers without time-switched electric heating (Economy 7) are classified as 'Profile class 1'.

This UK average profile is adapted for different locations, to account for sunrise/sunset times and local temperature etc. through a set of 7 coefficients and these are dispatched to energy retailers on a daily basis.

Given that Profile class 1 aims to provide an average of all non-Economy 7 UK residential consumers we would expect average London profiles to be distributed both above and below any trend according to factors such as household-size and relative prosperity.

Rather than simply comparing the total average profiles with an average London profile, given the wide ranging survey data associated with each home it is possible to sub-divide the London sample according to various characteristics.

Early analysis of the survey results has shown that the London sample is large enough to allow valid appliance ownership statistics for 9 sub-categories of profile class 1[10].

---

[8] Discussion with Kevin Spencer, market analyst with Elexon, on balancing and settlement of dynamic tariffs; interviewed by Mark Bilton.

[9] Manual meter readings require access to a customer's premise. Full settlement only occurs 14 months later when metered energy use has been verified covering 97% of demand for a given period.

[10] This analysis will be covered in more detail in report 4-1.

Table 2, Sizes of sample sub-groups: demographic and household size

		Household Size (number of occupants)		
		1	**2**	**3+**
Demographic Groupings	**Affluent** (ACORN Groups ABCDE)	406	404	226
	Comfortable (ACORN Groups FGHIJ)	244	312	213
	Adversity (ACORN Groups KLMNOPQ)	325	281	236

Understanding the determinants of energy demand and demand profiles is notoriously difficult in the residential sector with family size, age, and lifestyle affecting both habits and appliance ownership. Demographic groups are valuable metrics because they can be applied to locations for which no other information is available except a postcode and thus could potentially be used by distribution network operators to identify likely patterns in demand.

Figure 13 shows Profile Class 1, winter weekday from Elexon in grey against the LCL meter trial participants who successfully completed the household questionnaire but are not on the dTOU tariff.

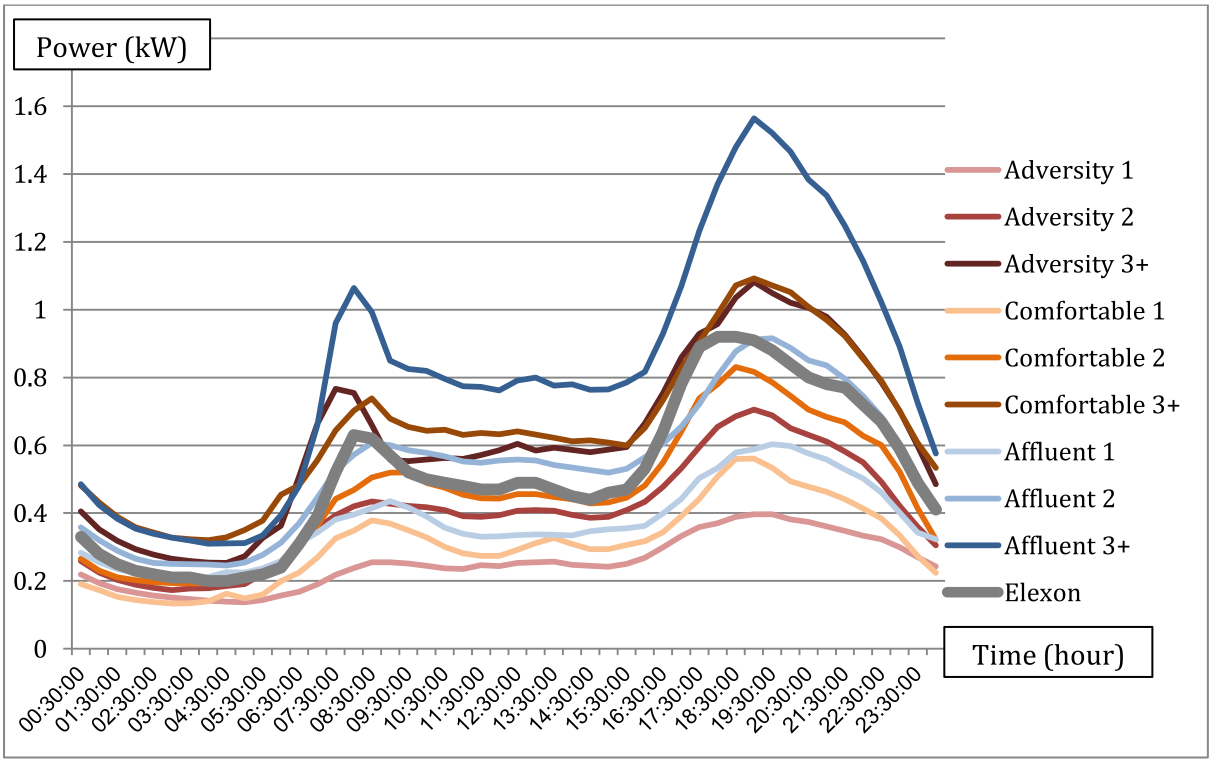


Figure 13: London sub-groups profiles compared to Profile Class 1 (Winter weekday)

The profiles from LCL meters in 2013 are similar to Profile class 1 and we can see that occupancy has a clear effect upon energy demand. The effect of wealth upon demand is less clear except that wealthier families on average consume considerably more energy throughout the day, and at peak, compared to their less wealthy cohort. The steeper start to the national average evening peak is most likely due to the later sunrise times in the North which is included in Profile Class 1 (K. Spencer, personal communication, January 13, 2014[11]).

Figure 14 represents the average demand seen at the LCL trial meters for the whole year, blue representing low demand and red high demand. Here we can see the marked increase in peak demand through the winter period.

Figure 15 shows the strong correlation between temperature and demand. At the chart centre is February 2013, which proved to be one of the coldest periods in London in recent history. This offers a valuable data set because this was an extended period of cold close to 'worst case' weather conditions from an energy demand perspective. However in general it should be noted that the temperature is not the only determinant of demand here since cold weather will often correlate with cloud cover and in some case desire for 'mood' lighting.

[11] Discussion with Kevin Spencer, Market Analyst with Elexon, on balancing and settlement of dynamic tariffs; interviewed by Mark Bilton.

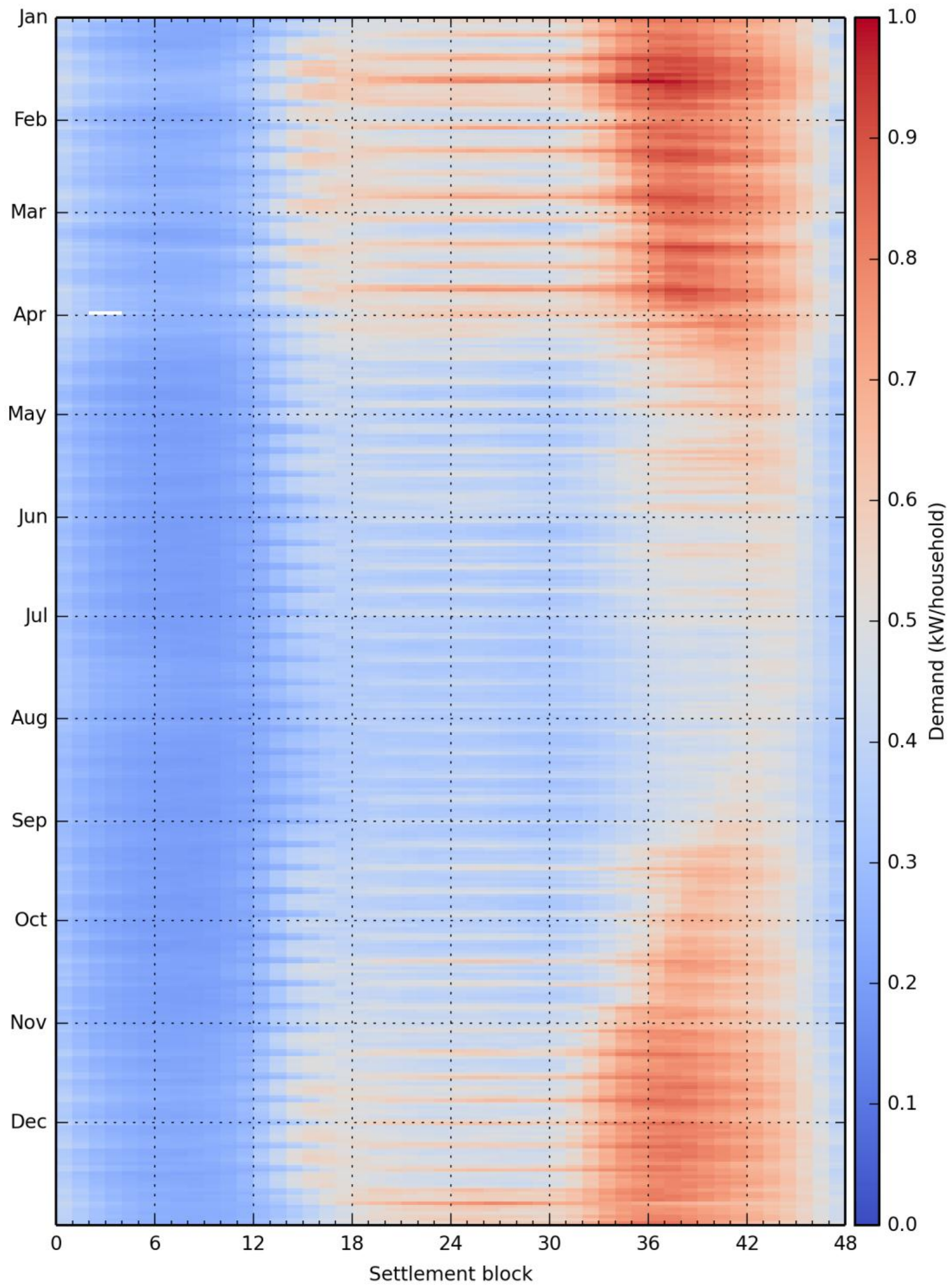


Figure 14: Annual demand trend for the LCL smart meters (non TOU)

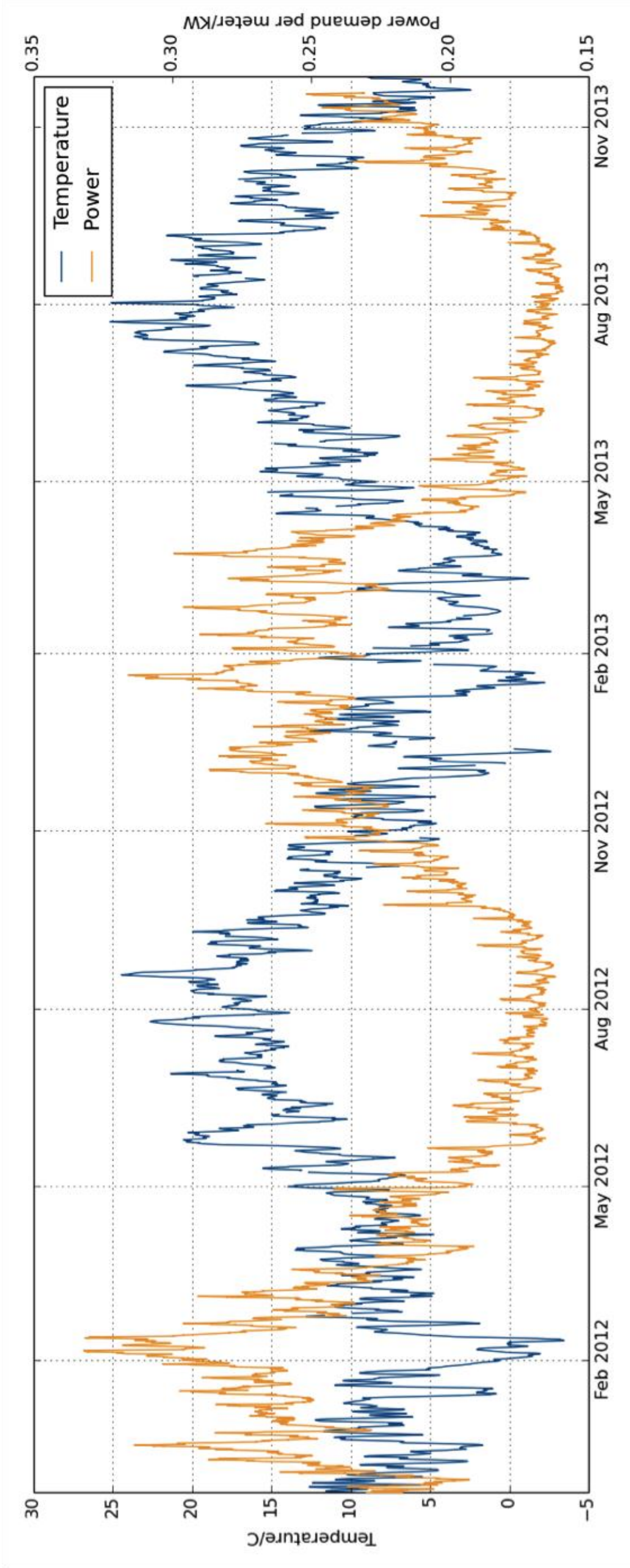


Figure 15: Average power demand and outside temperature

4.2. Valid identification of trial participants

The previous section demonstrated that meter data from the trial was within expected average ranges; however it is important that we understand which customer is associated with which survey data, including details of which tariff customers are on.

Figure 16, below, summarises the demand characteristics of all the smart meter trial participants (in blue), with those on the dTOU trial (coloured orange). This scatter diagram represents the relationship between energy use at different price points. Each dot on the chart represents one consumer's total energy use. The position of each dot represents two ratios, the X axis representing the ratio of energy used in low and mid-price band, the Y axis representing the ratio energy used in High to Mid-price band.

It is clear from this chart that the dTOU trial participants are demonstrating price elasticity both away from high prices and towards low prices.

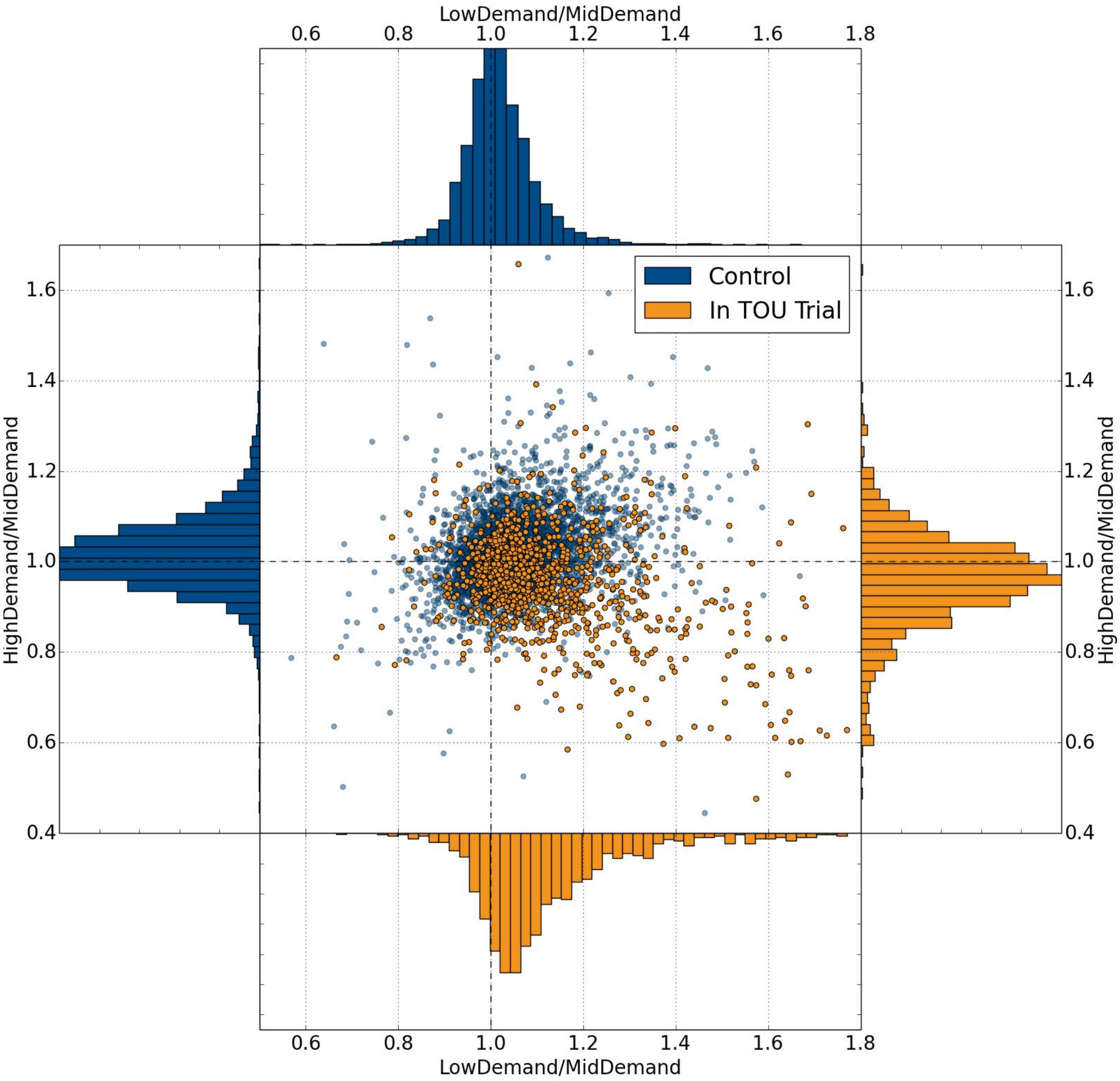


Figure 16: Representation of TOU flexibility.

5. Conclusions and recommendations

The LCL smart meter trial was a considerable undertaking in terms of both design and delivery. It has fulfilled both of the programmes requirements to provide data in order to better understand customer demand and flexibility. Going forward, the yielded data will allow unprecedented insight into the nature of and determinants of electricity use patterns in London.

With hindsight the decision to use a non 3G meter was appropriate since the SMETS 2 specification, for which meter manufacturers have been waiting, was only submitted in draft to the European Commission in January 2013 [***6***].

Whilst the population sample is not entirely random, due to factors such as self-selection and exclusion criteria, it does reflect London demographics well. Moreover, the early indications are that London average customers profiles are very similar to the UK average. However there is a considerable range especially in winter peak depending largely on household occupancy and income, most pointedly with wealthy families.

Because of the limitations of the meter technology it was not possible to access voltage quality in London through smart metering data, other than through to identification of the occasional dropouts indicating a total or very large fall in supply voltage. However, had a SMETS 2 compliant meter been available, for the DNO to fully understand the cause of voltage perturbations would have required knowledge of customer phase information and, perhaps more importantly, the accurate association of meters to specific feeders. To this end, Engineering Instrumentation Zones were established in order to directly measure LV network performance and will be discussed in the Low Carbon London Learning Report ‘The Use of Smart Metering Data in Network Planning and Operation’.

The data collected from the LCL SM trial will feed into a number of forthcoming reports, namely with: ‘The effect of energy efficient appliances on network utilisation’, ‘The Impact of LV connected DERs on network utilisation’, ‘Smart appliances for residential demand response’, ‘Residential attitudes to time-varying pricing’ and ‘Residential consumer responsiveness to time-varying pricing’

The bulk of analysis of the smart meter data will be in the latter two reports, but the smart meter data is essential to the former three reports for establishing baseline profiles. Associated survey data will be presented in the same reports where appropriate. A further report will describe analysis of smart meter data from a DNO planning perspective.

6. References

[1] M. Bilton et al., "C2: Impact of energy efficient applainces on network utilisation," Imperial College, London, 2014.

[2] R. Carmichael, J. Schofield, M. Bilton, R. Ozaki, and G. Strbac, "A2: Residential consumer atitudes to time-varying pricing," Imperial College , London, 2014.

[3] J. Schofield, R., Tindemans,S. Carmichael, M. Woolf, M. Bilton, and G. Strbac, "A3: Residential consumer responsiveness to time-varying pricing.," Imperial College, London, 2014.

[4] Ofgem, "Smart Metering Implementation Programme: Statement of Design Requirements," London, 2010.

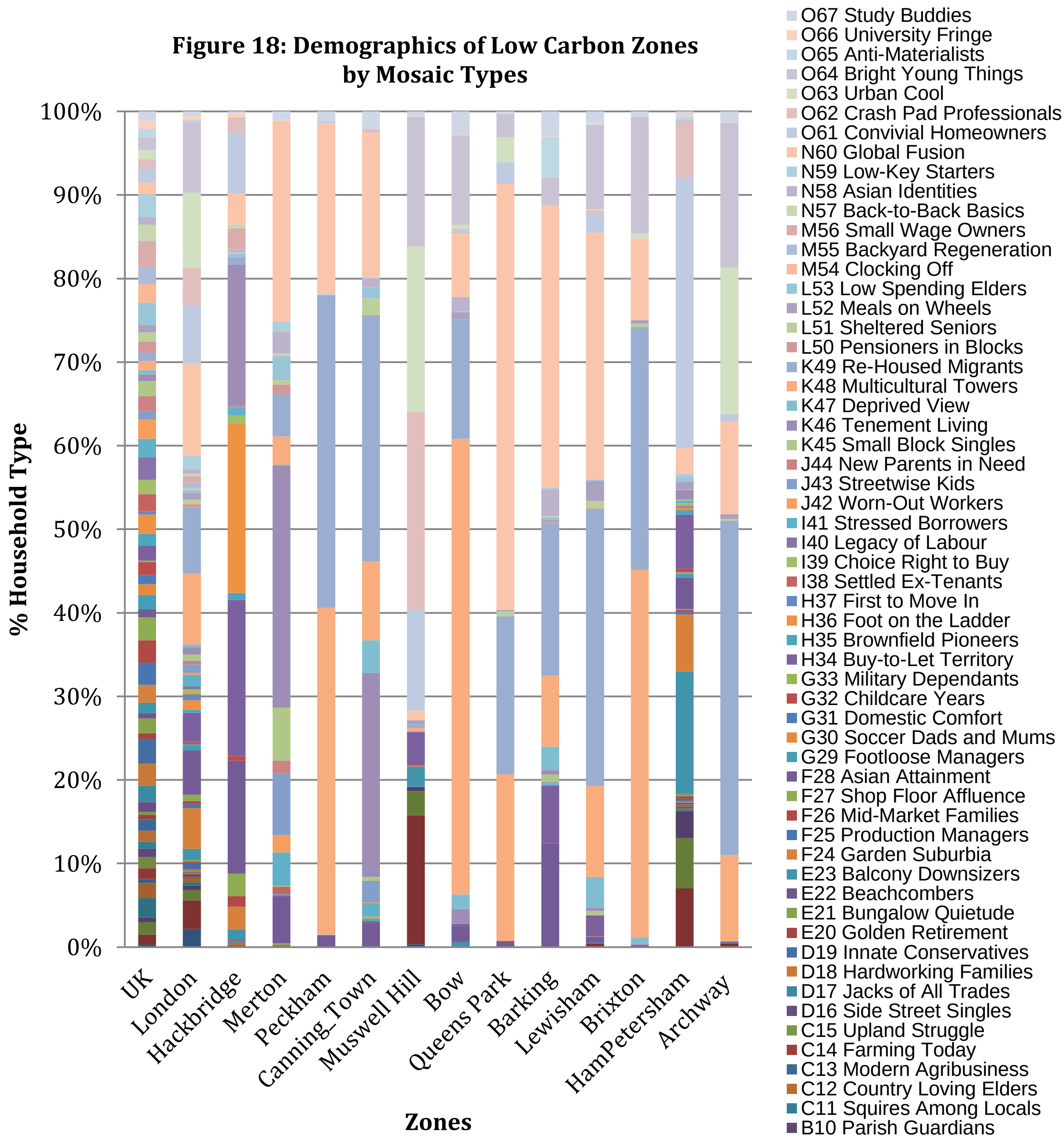
[5] Gov. Data potection act. [Online]. https://www.gov.uk/data-protection/the-data-protection-act

[6] DECC, "Smart Metering Equipment Technical Specifications V2," London, 2013.

[7] ESRI. (2010) http://www.esriuk.com/. [Online]. http://www.esriuk.com/news/releases/2011/smart-meter-cities-will-thrive-midlands-and-trans-pennine-corridor

[8] DECC, "The Smart Metering System," London, 2013.

7. Appendix I



[12]

[12] The LCL programme in no way endorses these characterisations of consumer types.

Project Overview

Low Carbon London, UK Power Networks' pioneering learning programme funded by Ofgem's Low Carbon Networks Fund, has used London as a test bed to develop a smarter electricity network that can manage the demands of a low carbon economy and deliver reliable, sustainable electricity to businesses, residents and communities.

The trials undertaken as part of LCL comprise a set of separate but inter-related activities, approaches and experiments. They have explored how best to deliver and manage a sustainable, cost-effective electricity network as we move towards a low carbon future. The project established a learning laboratory, based at Imperial College London, to analyse the data from the trials which has informed a comprehensive portfolio of learning reports that integrate LCL's findings.

The structure of these learning reports is shown below:

Theme	Code	Report
Summary	SR	DNO Guide to Future Smart Management of Distribution Networks
Distributed Generation and Demand Side Response	A1	Residential Demand Side Response for outage management and as an alternative to network reinforcement
	A2	Residential consumer attitudes to time varying pricing
	A3	Residential consumer responsiveness to time varying pricing
	A4	Industrial and Commercial Demand Side Response for outage management and as an alternative to network reinforcement
	A5	Conflicts and synergies of Demand Side Response
	A6	Network impacts of supply-following Demand Side Response report
	A7	Distributed Generation and Demand Side Response services for smart Distribution Networks
	A8	Distributed Generation addressing security of supply and network reinforcement requirements
	A9	Facilitating Distributed Generation connections
	A10	Smart appliances for residential demand response
Electrification of Heat and Transport	B1	Impact and opportunities for wide-scale Electric Vehicle deployment
	B2	Impact of Electric Vehicles and Heat Pump loads on network demand profiles
	B3	Impact of Low Voltage – connected low carbon technologies on Power Quality
	B4	Impact of Low Voltage – connected low carbon technologies on network utilisation
	B5	Opportunities for smart optimisation of new heat and transport loads
Network Planning and Operation	C1	Use of smart meter information for network planning and operation
	C2	Impact of energy efficient appliances on network utilisation
	C3	Network impacts of energy efficiency at scale
	C4	Network state estimation and optimal sensor placement
	C5	Accessibility and validity of smart meter data
Future Distribution System Operator	D1	Development of new network design and operation practices
	D2	DNO Tools and Systems Learning
	D3	Design and real-time control of smart distribution networks
	D4	Resilience performance of smart distribution networks
	D5	Novel commercial arrangements for smart distribution networks
	D6	Carbon impact of smart distribution networks

Low Carbon London Learning Lab

UK Power Networks Holdings Limited Registered office:
Newington House 237 Southwark Bridge Road London SE1 6NP

Registered in England and Wales Registered number: 7290590

innovation@ukpowernetworks.co.uk
ukpowernetworks.co.uk/innovation