Customer-Led Network Revolution

Developing the smarter grid: the role of domestic and small and medium enterprise customers

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Abstract

This report covers the aspects of the CLNR project that tested the level of flexibility customers can offer in how they generate and use electricity. It is one of two customer flexibility reports; this report (CLNR-L246) covers residential and small and medium enterprise (SME) customers and the other report (CLNR-L247) covers industrial and commercial (I&C) customers and distributed generators (DG). The key findings in relation to our residential and SME customer research are as follows:

Customer demand profiles - The analysis revealed a relatively consistent average demand profile across the different domestic demographic groups, with much higher variability within groups than between them. This high variability is seen both in total consumption and in peak demand. This variation is seen not only within customer groups, but also within the year for individual customers. Most customers consume on average about 3,500 kWh during the year, with a range of roughly 200 kWh either side of that value. There was even less variance in the mean peak demand (daily peak demand averaged across a year). Of the appliances monitored, washing machines and dishwashers offer the greatest flexibility in terms of time of use and our surveys suggest customers are prepared to be flexible. For EV users, household electricity demand (exclusive of EV charging) was broadly comparable to typical households. The days and precise times on which participants charged their cars varied considerably. Overall, charging tended to peak at around 8pm on weekdays with less charging during the day. Heat pumps had the same impact on load as the rest of household load put together but clusters are likely only in social housing. Of all the LCTs examined, only domestic charging of EVs seems likely to have a major impact on the network, but is not yet a problem for network system design and operation. Encouraging off-peak charging is an important part of the solution.

SME consumption per customer tends to be an order of magnitude higher than domestic consumption, but the demand profiles of individual SMEs vary to a much greater extent than households. Weekday demand is generally characterised by high demand during 9-5pm hours, with no early evening peak. There is some seasonal variation, but this is not as marked as for domestic premises. We found that businesses have some processes that are re-schedulable but none that were interruptible. Some businesses have intermittent demand for high loads that could be flexible. This is an area which has been little studied in the past and where data has been limited.

Static time of use tariffs - Time of use tariffs (ToU) are popular with and easily understood by domestic customers, where the majority saved money (60%) and demand in the 4pm to 8pm peak was up to ca. 10% lower than the control group. Our trial provided a safety net for the 40% that did not save money, and they were guaranteed to pay no more than a standard flat tariff. However we do not know how our results would have changed if customers had not had the safety net provided with the trial.

Compared to the control group, annual electricity consumption was lower amongst our time of use trial participants despite average use increasing in the off-peak period. This difference in overall consumption was however not statistically significant, nor was an overall reduction in evidence on the days of maximum network peak demand. Therefore this, in itself does not facilitate a change in

network planning. However, ToU could be used as part of a solution or would help if introduced by another electricity market player e.g. an energy supplier.

Other interventions - The restricted hours and direct control trials tested customers' willingness to a time-based restriction on the use of a smart heat pump or washing machine. The technology was proven, but the benefit from smart washing machines was limited and whilst the heat pumps successfully reduced peak **load** by 2.5 kW, there were technical issues and problems of customer acceptability. SMEs were reluctant to face restrictions on their electricity usage but the one example where we engaged with a hospitality business to interrupt a chiller unit was successful.   Encouraging customers via an IHD to use their PV generation rather than export made no significant difference. However the qualitative research indicated that solar PV customers without the IHD found other means to monitor and assess the amounts of electricity they imported and exported, which may offer some explanation of this effect.

1. Executive summary

The UK Government's three energy policy objectives (security of supply, affordability and addressing climate change) all impact the electricity system. As electricity generation becomes lower carbon, the Government's energy scenarios suggest that more electricity will be generated from less flexible sources such as nuclear and renewable sources that are intermittent, such as wind. The decarbonisation of transport could lead to an increase in the use of electric vehicles, and reducing the use of fossil fuels for heating may well see an increase in the use of heat-pumps in homes and businesses, both of which could result in load growth on the electricity distribution networks. There will be an increasing number of distributed generators connected to the distribution network including at the domestic level. Customers will be encouraged to participate in demand side response using their own demand, local storage and/or generation.

As a result, distribution networks will have to respond to power flows that are more complex and less predictable. This requires all distribution network operators (DNOs) to find the best deal for customers in the long-term by seeking out and deploying novel solutions when economic, avoiding too much investment ahead of need but being ready for the accelerated uptake of these technologies when it happens in terms of investment and resource planning.

The Customer-Led Network Revolution project, part-funded via the Low Carbon Networks Fund, is a smart grid project that ran from 2011 to 2014 and was led by Northern Powergrid in partnership with British Gas, Durham University, Newcastle University and EA Technology. Learning from the project will help DNOs find cost-effective ways to manage the introduction of low carbon technologies (LCTs) like solar PV, heat pumps and electric vehicles and ensure customers continue to receive a safe, secure and affordable electricity supply now, and in a low-carbon future.

The project explored the flexibility in the ways customers use and generate electricity and how DNOs can find ways to reduce customers' energy costs and carbon footprint in the years to come. It therefore tested demand-side response through a range of customer-side innovations (innovative tariffs and load control incentives) alone and in combination with network-side technology (including voltage control, real time thermal rating and storage). The project was designed to deliver robust learning that would be applicable to a high percentage of GB networks and demographic groups. More than 13,000 domestic, SME and industrial and commercial customers and merchant generators took part in the project.

The project was also designed to investigate future loading patterns as the country moves towards a low-carbon future and to research novel network and commercial tools and techniques and to establish how they can be integrated to accommodate the growth of LCTs in the most efficient manner. The project trialled new network monitoring techniques to measure power flow, voltage and harmonics, trialling alternative smarter solutions that employ active network management and customer engagement to increase network capacity and/or modify load patterns and it developed new planning and design decision support tools for engineers.

This report provides an account of the part of the project that explored the load characteristics and flexibility of domestic and SME customers, and the related findings. Two other reports deal with larger customers[1] and the network-related part of the project[2]. The project was designed to deliver a specific set of five learning outcomes, of which the two relevant to this report are:

- **Learning Outcome 1: understanding of current, emerging and possible future customer (load and generation) characteristics;**
- **Learning Outcome 2: to what extent are customers flexible in their load and generation, and what is the cost of this flexibility?**

In relation to each learning outcome, the aim was to recruit a sufficient number of trial participants to ensure statistical validity into a number of different test cells, relating to the nature of the customer, the customer intervention (if any) and whether they had any form of LCT.

Learning Outcome 1: Understanding of current, emerging and possible future customer (load and generation) characteristics

This part of the trial involved monitoring the electricity consumption and generation profiles of around 13,000 domestic and SME customers, both those with and those without LCTs (heat pumps, photovoltaics, micro-CHP, electric vehicles). For smaller selected sub-groups this also included enhanced monitoring of selected individual appliance usage in addition to half hourly metering. This is the largest sample of customers' electricity usage to have been undertaken in the UK and Ireland to date. The size of the sample, when compared with previous projects monitoring customer electricity use, has generally ensured a statistically robust set of conclusions and greatly improved the rigour and breadth of our understanding.

Domestic smart meter customers without LCTs or interventions

Around 9000 domestic participants from a wide range of socio-demographic backgrounds took part in this baseline trial[3] and provided three important inputs to the project:

- The data created an overall picture of current domestic electrical energy consumption in the UK. This has been used to provide a key input to the updating of ACE49[4], which provides guidance on the design of electricity distribution networks serving domestic areas and is currently based on data last gathered in the 1970s. More details are provided in the Optimal Network Systems report[5].

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[1] CLNR-L247: Developing the smarter grid: the role of industrial & commercial and distributed generation customers

[2] CLNR-L248: Optimal solutions for smarter distribution systems

[3] CLNR-L216: Insight report: Baseline domestic profiles & CLNR-L242 Summary of learning: Domestic smart meter customers

[4] CLNR-L185: Review of the distribution network planning and design standards for the future low carbon electricity system

[5] CLNR-L248: Optimal solutions for smarter distribution systems. The main conclusion was that, after taking account of diversity between customers, average demand declines much more slowly with increasing numbers of customers in the study group than had previously been assumed. For regular domestic customers, this new method gives after-diversity average demands of 2.8 kW for a group of 10 customers; 1.7 kW for 100 customers; and 1.0 kW for 1000 customers.

- The data provided a baseline against which to measure the impact of the installation of low carbon technologies (LCTs) and/or various types of customer intervention, which are described further on in this report.
- Qualitative data from customer surveys and in-depth interviews of trial participants within this cohort provided important understanding of customer behaviours and attitudes in relation to electricity use, electrical appliances, smart meters and customer interventions. This is of importance in relation to the development of effective customer interventions at the commercial scale by both DNOs and suppliers and assist all parts of the industry and policy makers in gaining an understanding of the likely impact of changes in policy, marketing or regulation that impact directly on customers. A list of the associated social science outputs, for further reading, can be found in the table in Appendix 4.

Economy 7 and other specific high electrical loading customers were excluded from this group. The trial participants either already had smart meters installed or smart meters were installed prior to commencement of the trial start date. These smart meters were capable of recording electrical energy consumption to a 30 minute resolution. The trial participants were allocated to 144 different demographic customer groups[6], based on income, house efficiency, tenancy, rurality and whether they have dependents (small children or elderly relatives), to provide a good statistical basis for assessing the typical electrical use of each of these groups.

In order to gain a detailed understanding of customers' electricity usage, some trial participants had monitoring equipment installed on the premises in addition to the British Gas smart meter, or for non-British Gas customers, in addition to their existing meter. The additional monitoring comprised in-line monitoring and/or smart plugs and (in the case of non-British Gas customers) a secondary meter for whole-house monitoring.

In addition to quantitative monitoring of electricity usage, two methodologies were used to help understand the social dimensions of the CLNR trial: surveys and qualitative face-to-face research visits. These methods were used in conjunction with the analysis of energy consumption data to provide insights into how and why energy use takes particular patterns for groups and individuals.

By comparing consumption and load data across demographic groups, it was possible to compare electrical energy consumption patterns. All aspects of the analysis had sufficient customer numbers to satisfy sensible confidence intervals, apart from rural off gas customers.

The dataset displayed some expected behaviour:

- The daily energy use profile is broadly divided into night/early morning (low demand), daytime (mid-level demand) and evening (higher demand).
- In the winter months, overall consumption and average daily peak demand are higher than in other seasons. Also in winter there is a greater variability in energy use between customers.

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[6] The demographic group allocation is described in CLNR-L107 Test cell protocol

- Most households have their peak daily demand during the 4-8pm period. However, there is a significant minority of households across all demographic groups whose peak demand occurs earlier in the day, around midday.

However, the demographic analysis and the large number of detailed monitoring profiles provided a range of important new insights.

There was a surprisingly consistent average demand profile across the different demographic groups, with much higher variability within groups than between them. This high variability is seen both in total consumption and in peak demand. This variation is seen not only within customer groups, but also within the year for individual customers.

The only statistically significant link between customer consumption and demographics was in relation to income, and even there the correlation was weak. Most customer groups consumed on average about 3500 kWh during the year, with a range of roughly 200 kWh either side of that value. Notable exceptions here are the high income group (ca 4100 kWh) and rural off gas (ca 5300 kWh). Further, the low income group (ca 3000 kWh) and renter group (ca 3200 kWh) are outliers to this picture. A similar pattern is also observed in the peak demand for these customer groups. The next major factor appears to be house efficiency. There was even less variance in the mean peak demand (daily peak demand averaged across a year) groups, with the exception of rural off gas group. On the other hand, the maximum peak demand (the demand in the half hour in the year with highest consumption) followed the annual consumption pattern more closely.

In terms of seasonal variation, as might be expected, there was a higher electricity load in winter when it occurs earlier in the evening. On the four days of greatest network stress, the average peak demand was 0.9 kW during the hour 5pm to 6pm. Electricity demand was broadly the same at peak hours whether it is on a weekday or at the weekend.

The qualitative surveys and interviews supported the applicability of the CCRES model of energy use (conventions, capacities, rhythms, economies, structures), in which each element works together to shape how energy is used. This approach, with its emphasis on practices rather than energy behaviour, is still not widely understood by energy practitioners and policy makers, who continue to focus on energy use and thereby miss a crucial link in understanding domestic energy-using behaviour and how to influence it. Conclusions from the surveys and interviews were:

- Customers had varying levels of ability to be flexible, but this was shaped by practices and the 'gearing' of their everyday life, rather than by socio-demographic type.
- The household practices that contributed most significantly to electricity use in the evening peak period were those which had the biggest load and which interviewees said were most commonly undertaken at this time, in particular laundry and dish washing.
- Electronic entertainment and cooking, although often undertaken in the evening peak period either had low electrical intensity (entertainment), and/or were perceived by respondents to be less flexible.

In addition, we carried out enhanced monitoring of individual disaggregated loads at 10-minute intervals for a smaller group of domestic customers[7]. The domestic loads monitored included: lighting, consumer electronics, the cooker, kitchen appliances, washing appliances and refrigeration. The results presented are average results over the cohort. In line with the findings from the baseline cohort, individual consumption profiles varied significantly between households and on different days within a single household.

Average annual consumption among the enhanced monitoring group in the trial was 4,192 kWh. Overall, the data indicates a pronounced early evening peak. The patterns of consumption we observed tend to match those from the Household Electricity Survey (HES) closely. There is, however, a discrepancy in lighting demand, with HES consumption profiles exhibiting a far larger spike in lighting demand in the evening relative to our data. This may be the absence of lamps plugged into sockets in our data. There have also been changes to the efficiency of lighting since the HES survey was undertaken in 2010 as a result of phasing out of incandescent bulbs.

Lighting and **cooking** have a substantial early evening peak, but our qualitative research indicates that customers are reluctant to change behaviour in these areas. Further efficiency improvements in lighting, use of timers and motion sensors could assist in lowering peak demand. **Space** and **water heating** are potentially a highly movable source of demand, through the ability to store heat, in particular if a way can be found to assist those that use electric backup heating (electric storage heating is dealt with below). The potential to substitute between the different energy sources of multiple heating systems or to utilise heat storage capabilities represents a potential source of electrical demand side flexibility within such households. There was however an insufficient sample size of direct electric space heating or electric hot water heaters in our data to carry out a robust analysis, but this area would merit further study. **Refrigeration** is partially switchable. However, our survey analysis indicates that households generally do not see any scope for changes in refrigeration behaviour owing to the perceived risk to food safety. A refrigeration scrappage scheme could however assist through demand reduction from more efficient appliances.

Washing appliance use as seen in the trial varies significantly between weekdays and weekends with average weekday early evening peak demand rarely exceeding 100 W. Weekend demand is significantly larger, reaching ca. 180 W in spring and winter and is more evenly spread across waking hours. Washing appliances are potentially among the most flexible of sources of demand. Our survey research indicated that households tended either to programme laundry at specific times (either weekends or evenings) or as and when required. This suggests the possibility of some flexibility as to the precise timing of use.

Consumption from **consumer electronics** shows an evening peak and falls away sharply in the late evening. This evening peak is pronounced on weekdays, but is also clearly visible on weekends, when the peak builds more gradually throughout the day. These findings suggest that consumer electronics will become an increasingly important component of household electricity consumption. If these new devices are designed to be portable, and so have in-built batteries, they may also bring new options for households to shift their load.

[7] CLNR-L094 Insight report Enhanced domestic monitoring

About half of the overall consumption within the disaggregated load monitoring was unaccounted for, i.e. not attributable to the devices that were monitored, and so could have included portable devices plugged into sockets, such as direct electric heating. The 'unaccounted' group was larger during the colder winter months and exhibits strong seasonal variation. We understand from surveys of these customers that many use portable electric heaters in the winter that were not monitored, and this could account for this pattern. This area would merit further investigation.

We also carried out enhanced monitoring of a limited number of customers (17 in total) with electrical immersion hot water heating or with immersion hot water heating and storage heaters and an existing Economy 7/10 tariff. Although specific data is not held on which tariff each specific customer was on, the average power consumption profiles broadly matched the profile of an E7 or E10 tariff. This is consistent with customers on these tariffs responding to the price incentives they provide. However, there were two exceptions. The average data for immersion heaters alone showed a peak at 8am, both during weekdays and at weekends. This may reflect a customer routine or an appliance setting. Second, both the hot water and storage heater profiles for properties that had both showed some power usage immediately after the morning off-peak periods have finished. It may be that this is the result of misconfigured appliances. Storage heater use on all days was confined to the off-peak periods, probably reflecting appliance and meter settings. It is clear that storage heaters combined with Economy7/10 tariffs continues to be an effective means of reducing demand at peak times.

Enhanced profiling of domestic customers with air source heat pumps[8]

Because of the delay in the launch of the Government's Renewable Heat Incentive and the related uncertainty about the support to be provided to air source heat pumps, the number of customers with ASHP installations was much lower than anticipated at the start of the project. The team sourced additional money from DECC for heat pump installations, including innovative heat pumps with energy storage capability. There was very limited demand from the 'able to buy' market for heat pumps and we had to recruit largely from social housing providers.

Heat pump consumption, at an annual average electricity consumption of 2880 kWh, represented a significant additional electrical load compared to the rest of the house. (Total average annual consumption in the baseline customer group was 3498 kWh). Average daily heat pump electricity consumption in January was 13.96 kWh compared with average baseline household consumption of 11.46 kWh per day. For the January evening peak period, average heat pump electricity consumption was 3.17 kWh per day, compared to 3.11 kWh for average baseline household consumption. Hence the overall effect of the heat pump is to roughly double electricity demand at the times when the electricity network is already likely to be experiencing high levels of demand.

The heating season half-hourly heat pump consumption profiles, averaged across customers and across each month, showed distinct morning (6am – 9am) and evening (4pm – 8pm) peak demands.

[8] CLNR-L091: Insight report: Domestic heat pumps and CLNR-L245: Report on interviews with domestic customers with ASHPs

In addition to the morning and evening peak period, the heat pumps in this trial show a distinct peak in consumption around 3am. This was due to default timer settings for hot water heating.

As a heat pump load represents a near doubling of total household consumption, widespread rollout of the technology would present significant challenges to electricity networks, especially where clustered. Steps may need to be taken to introduce diversity into the set-up of heat pump operations, in particular the morning pick-up in demand. However, at present, widespread use of heat pumps seems likely to be confined to the social housing sector.

Enhanced profiling of domestic customers with Micro-CHP[9]

These participants had a micro-CHP with a Baxi Ecogen Stirling engine (maximum heat output 6 kW, maximum electrical output 1 kW, an overall efficiency of 90%) installed. The micro-CHP generation profile had a high morning peak, and a lower, but longer evening peak, with the summer peaks being lower than the winter ones. The main effect of the use of the micro-CHP units was to reduce the evening electricity demand peak by a few hundred watts in winter. The micro-CHP also generated electricity for export in the winter mornings, as heat demand drives micro-CHP export before morning electricity demand starts to rise. The group was small in number, but exhibited a wide variation in electricity demand at peak from import of 2.5 kW to some trial participants exporting throughout the day. If micro-CHP plants become popular, the reduction in household load at peak could be significant for both network planning and electricity generation costs. There would be benefit in a wider trial to establish more robust conclusions.

Enhanced profiling of domestic customers with solar photovoltaic (PV)[10]

On the day of peak export, participants in this trial group on average exported 1.3 kW at 12 noon. Export occurred in the six months April to September 2013, with July being the month of peak export. Comparing these trial participants with those with a smart meter but no PV, the following findings were statistically significant:

- Average annual gross electricity consumption was 700 kWh higher (4216 kWh as against 3507 kWh) and was significantly higher in nearly every month (but less so at weekends)
- Electricity consumption during the day was higher (at 30% compared with 27%)
- Average and maximum peak demand was higher (1.5 kW and 4.9 kW as against 1.2 kW and 4.2 kW, respectively) with the difference focused more in the summer months

Enhanced profiling of domestic customers with Electric Vehicles (EV)[11]

Electric vehicle sales have been much lower than had been anticipated at the time of the bid. A small number were recruited from British Gas' existing customer base and the team also worked with Charge your Car (North) Ltd (CYC) to recruit more EV users. The partnership between CLNR and

[9] CLNR-L086: Report on enhanced profiling on domestic customers with Micro-CHP

[10] CLNR-L090: Insight report: Domestic solar PV and CLNR-L244: Summary of learning: Domestic solar PV customers

[11] CLNR-L092: Insight report: Electric vehicles and CLNR-L254: Summary of learning: Electric vehicle users

CYC meant that a total of 159 EV-driving customers' household and electric vehicle charging demand were monitored). CYC operate residential and public charging infrastructure provision in the North East of England, and recruited some of its residential charger customers to take part in the monitoring programme.

The limited availability of EV charging data relative to household demand data constrained most of the analysis to the period January-June 2014, and this limitation must be taken into account in understanding the findings. 108 participants were drawn from employees, or friends and family of employees, of Nissan in Sunderland. These participants drive a Nissan Leaf as part of a company car scheme and this sample bias should be borne in mind. However, these customers (generally working families, singles or couples) have been assumed for the purposes of the trial to be fairly representative of likely current and future EV owners.

The household metering included all household demand except for the EV charger. The chargers were all 3.8 kW. Amongst these participants, household electricity demand (exclusive of EV charging) was broadly comparable to typical households, perhaps with a rather higher proportion of peak to off-peak usage. The levels of average EV charger load (i.e. for each time period averaged across the data from the available participants) show that at-home charging diversifies rapidly: i.e. the days and precise times on which participants charged their cars varied considerably (supported by the size of the standard deviations of the results). Overall, charging tended to peak at around 8pm on weekdays with less charging during the day. Average peak charger demand on a weekday was around 0.9 kW in January compared with less than 0.4 kW in June (probably reflecting the extra charging associated with car heating and lighting). Charging at weekends was lower in total and less concentrated in the evening. The average daily energy consumption for an EV was 7.9 kWh in January 2014, which was the peak month. This steadily reduced down to 5.2 kWh by June 2014.

These results show that domestic charging of EVs has raised the level of domestic peak demand but that this is not yet a problem for network system design and operation. But with greater concentration, or if there were 2 EVs at a household, this would no longer be true. However, EV users are already establishing habits to charge their car when it suits them and this may be difficult to break even with appropriate ToU tariffs. There is therefore a strong case for taking appropriate action to encourage off-peak EV charging behaviour at an early stage. Further work is needed, which was beyond the scope of this project, to investigate ways of doing this.

In addition to the conclusions from the monitoring results above, the partnership with Charge Your Car led to a unique collaboration involving Newcastle University[12] and EV charging data from the Switch EV project, which explored domestic charging habits in rural and urban locations and their different impacts on the distribution network, which suggested that the impact on the network would be felt first in rural locations.

[12] CLNR-L038: Integrating Smart Meter and Electric Vehicle Charging Data to Predict Distribution Network Impacts

Small and medium sized enterprise (SME) customers[13]

SME consumption per customer tends to be an order of magnitude higher than domestic consumption, making these energy users of particular importance for understanding both current and future demand. The demand profiles of individual SMEs also vary to a much greater extent than households. They are heterogeneous in terms of their business activities, and hence also in terms of their overall demand for power and the timing of that demand during the day. This heterogeneity presents particular problems when trying to extrapolate conclusions from the trials to the wider SME market.

For SMEs, the daily demand profile tends to be shaped differently to domestic consumers. Weekday demand is characterised by high demand during 9-5pm hours, with no early evening peak. The peak demand generally is spread across the standard working day of 8am to 5pm. Power demand is driven by the firm’s specific business activity, which for many activities may be relatively more constant throughout the working day. Weekend demand has a peak until early afternoon.

Many businesses consume less electricity per hour during the early evening peak than during the day or night. Smaller businesses tend to consume a higher proportion of their total electricity in the early evening peak. Larger businesses consume more evenly across the 24-hour period.

There is some seasonal variation, but this is not as marked as for domestic premises. Seasonally electricity demand for SMEs is highest in January and February, whereas the peak for domestic occurs in December. It is highest for Commercial and Office Enterprises and lowest for those in the Public Sector & Other Industry classification. This means that the kind of businesses with the highest electricity demand could be those involved in the wholesale and retail trade, hotels and restaurants, transport, storage and communication, financial intermediation, real estate, renting and business activities, while the lowest consuming group included education, health and social work, other community, social and personal service activities.

The largest firms do not necessarily have the highest power demand per employee. In terms of business size, organisations with 10-49 employees had proportionately the highest demand (more than those with 50-249), suggesting that the relationship between number of employees and electricity demand is not linear.

Key practices associated with electricity use in SMEs are lighting, heating and cooling, refrigeration and ICT. Some processes were found to be re-schedulable but none interruptible. Some businesses have intermittent demand for high loads that could be flexible. Because of the considerable variability in the SME community, the results themselves do not have immediate implications for network planning or operation, but provide an important baseline.

In addition, we conducted enhanced monitoring with a further 80 SME British Gas customers all with smart meters. The participants remained on their existing tariff.

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[13] CLNR-L099 Insight report: Small and Medium Enterprises

Our findings about SMEs are important because this is an area which has been little studied in the past and where data is limited. The results provided valuable new information about detailed SME activities. Some activities, such as lighting, are less susceptible to demand side management, although lighting load could be reduced significantly through timers, motion sensors and energy efficient lighting such as LEDs. Others, such as chillers, have the capability of being moved from peak time if business priorities permit. There is also scope for better energy management, for instance setting timers to begin operation after the peak period. Whilst these interventions would reduce electricity consumption in peak periods, there is no evidence yet that they would contribute to reducing peak load and so therefore we cannot make an assessment of potential network benefits.

Learning Outcome 2: To what extent are customers flexible in their load and generation, and what is the cost of this flexibility?

This part of the trial aimed to assess the effectiveness of different kinds of demand-side intervention in encouraging those taking part to change the pattern of their electricity usage. These interventions included combinations of electricity tariffs, in-home displays and automation. The type of ToU tariff had not previously been trialled in the UK. The smart washing machine and smart heat pump trials were a first in the UK, as were the automatic and manual within-premises balancing of PV load. Despite the difficulties arising from the technology tested and the data collection, the smart technology trials have provided valuable case study findings and indicated areas for further research.

Time of use tariffs[14]

Static time of use tariffs, with over 600 domestic and 40 SME customers were used to test customers' ability and willingness to move their discretionary load to low-rate price periods. The Time of Use and Restricted Hours propositions were both designed specifically for our trials. The tariff aimed to reflect the costs of supplying electricity at each point in the day in 2020, and the likelihood that shifting demand in response to tariffs would change the profile of these costs. For domestic customers, the peak ToU rate was 99% higher, the day rate 4% lower and the off-peak rate 31% lower than British Gas's standard (flat) rate tariff at that time. In addition, there was a 16p standing charge. The tariffs were designed to ensure that overall the bills for an average customer remained similar. Customers on this trial were however guaranteed that they would not incur higher bills as a result of taking part[15]. There was no feedback to these participants on whether they were saving or losing money under the ToU tariff until the end of the trial.

The domestic and SME tariffs differed in that the domestic tariff did not include an 'evening shoulder'. Instead it reverted back to the lower night rate directly after the peak evening period. This domestic tariff provided new learning as a tariff of this shape had not been included in previous

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[14] CLNR-L093 Insight report: Domestic time of use tariff & CLNR-L243 Summary of learning: Domestic smart meter customers on time of use tariffs

[15] As part of the Terms & Conditions of the trial, British Gas made a commitment to customers that if they paid more on the trial tariff than they would have paid on British Gas' Standard tariff over the period, then British Gas would refund the difference via a credit to their account. This was calculated on a customer by customer basis at the end of the trial by British Gas via a 'shadow billing' exercise.

major trials in the UK and Ireland. It allowed testing of the assumption that an evening shoulder is required to avoid a new peak occurring once the lower night rate commenced in mid-evening.

Comparing domestic participants on the ToU trial with trial participants with smart meters alone, statistically significant results were as follows. Average peak power demand during the 4-8 pm period (i.e. the average across the year for each customer of the highest half-hour demand each day within this time period) was lower on average, by 96 W (1.123 kW compared with 1.219 kW for baseline smart meter participants). When analysed by month, the difference in average peak power demand was statistically significant from November 2012 to March 2013 but not for other months. Annual maximum peak during the 4-8pm period (i.e. the highest half-hour recorded on any day of the year for each customer) was lower on average by 261 W (3.927 kW compared with 4.188 kW for baseline smart meter participants). Again, the difference is focused more on weekdays and in the winter months.

There was no statistically significant new peak in demand in either the period preceding or the period following the peak period on an annual basis, although there is scope for further analysis of the monthly data for the 2-4 pm period[16].

Average annual energy consumption during the peak period was lower by 55 kWh (806.6 kWh compared with 861.7 kWh for baseline smart meter participants), with the difference focused on weekdays. However, there was no statistically significant difference in total annual electricity consumption (on average, annual consumption is about 3500 kWh) between the two groups. The survey found that three quarters of those ToU participants responding considered that they had made a slight or significant reduction[17].

There was no statistically significant difference between the two groups in average peak demand at the half hour of highest network aggregate demand.

The only statistically significant demographic correlation to the ToU tariff was housing tenure (renter/home owner) and the presence of dependents in the household. Home owners and households without dependents were more likely to respond to the ToU tariff than renters and those with dependents.

Some 40% of participants would have incurred higher electricity bills than under a flat-rate (had they not been safeguarded against this). From the tariff design, an average customer making no changes to their behaviour should have neither gained nor lost from the ToU tariff. Those who would have paid more may have been customers whose monitored usage had a higher than average proportion at peak times. Therefore they may or may not have changed their behaviour in response to the trial.

The majority of those on a ToU who were surveyed said they changed the timing of appliance use in response to the ToU tariff, and most considered that they used less energy overall while on the ToU

[16] The previously announced discovery of a reduction in load during the peak period accompanied by a new peak after 8pm came from a small initial sample comparing behaviour before and after introduction of the ToU tariff.

[17] This compared smart meter users with a ToU tariff with those with a smart meter alone. It could not therefore take account of any change caused by the installation of a smart meter itself.

tariff. Laundry was identified by most respondents as an activity that had been displaced to a different time, followed by washing dishes and cooking.

The lower level of peak demand seen in this trial was small. Whether it could assist in network planning would depend on its impact on maximum demand after diversity had been taken into account. However, static ToU could be used as part of a solution or would help if introduced by another player e.g. an energy supplier.

We also trialled a ToU tariff with SME customers. Although few conclusions on the impact of ToU tariffs on SMEs can be drawn from this, there is clearly interest from SMEs in ToU tariffs and so further work would be useful. However, it demonstrates the need, because of the heterogeneity of the SME community, to conduct monitoring both before and after applying the ToU tariff for the same SME.

Restricted hours tariff

The restricted hours trial tested customers' willingness to accept a default time-based restriction on the use of a specific appliance, and also the degree to which they exercised the over-ride that we provided. This combined the ToU tariff with an automated service that used smart-enabled, automatic interactive scheduling for smart washing machines and automatic turn down/cycling with smart heat pumps with technology provided to allow customers to override this automated service when they wished[18].

Overall, the level of engagement on weekdays was low at 10%. However, customers that were classified as engaging showed near zero consumption at peak times. Customers whose appliance was in an engaged mode over the weekday saw an increase in load at the end of the peak period as washing machines started. Customers who engaged reduced their weekday consumption of the device by 28% compared to those customers that disengaged.

For those who had engaged the 'energy control', the trial successfully reduced load during the peak period. The peak that occurred following the end of the peak period could be reduced by the manufacturers including a randomisation element. The level of engagement was low and the reasons for this need further examination. If energy control buttons on washing machines become more prevalent, finding ways to encourage engagement could prove valuable in reducing peak load.

For participants in this part of the trial with smart heat pumps, the electricity supply to the heat pump was automatically switched into a low output mode for periods of between 30 minutes and two hours in the peak hours during the trial period, in order to optimise the operation of the smart heat pump in line with the time of use tariff. The heat pump was set to build up a store of heat for up to two hours prior to an interruption to ensure the customer always had a supply of hot water through the tariff's peak hours. Should the customer want to override the low output more of their heat pump, they could easily do this by using the control provided with the heat pump.

[18] This override functionality was explained in the trial equipment user guides

Direct control[19]

The direct control trial, with approximately 100 domestic trial participants, tested customers' willingness to have the time of use of a specific appliance directly controlled by the customer's electricity supplier, in response to a distributor's need. Trial participants either received a smart washing machine or smart heat pump (part subsidised). The terms of the trial allowed the operation of these appliances to be delayed or turned down through external dynamic signals. These signals were initiated from Northern Powergrid's network control centre (both by control engineers and by our smart grid control system) and passed on to the smart device via British Gas' demand management platform. Certain limitations were placed on the frequency and timing of when interventions could be called:

- A maximum of 15 interventions
- Only 1 intervention per day
- Interventions could occur on up to 10 consecutive weekdays
- Each intervention could last up to four hours
- Interventions would only be called in the peak periods of 4pm to 8pm
- The trial participant could override without penalty
- Excludes weekends and public holidays

When enabled, the **washing machine**'s energy control mode allowed the appliance to receive load control signals. These signals enabled the washing machine to automatically schedule a wash cycle to avoid the times specified for the load control or if currently in use, it would send a message via the machine's display asking the customer to pause the cycle to be resumed after the load control event. Trial participants were encouraged to keep this mode enabled throughout the trial, but could operate an override at any time by disabling the energy control mode.

An average of 4% of customers who received the signal delayed the washing machine cycle, while a further 12% ran their machines during the DSR period. This is consistent with DSR having an effect on behaviour: on almost a third of occasions when the user attempted to start a cycle on the machine during a received DSR event, they delayed it. These results show that some consumers clearly do respond to events, although a small number of households interviewed asserted that there had been no change to their previous washing regimes. This discrepancy may reflect the fact that washing routines vary by household: households which (for example) routinely carried out washing on weekends would be unaffected by the weekday only DSR events.

Given the small numbers of smart washing machines that were active during the direct control windows during the trial, any conclusions must be treated with caution. Nevertheless, this trial was unique and ground-breaking. It has demonstrated the end-to-end process of a DNO successfully calling a response from a DSR supplier automatically using smart grid systems and that direct control of appliances can reduce peak load, albeit not by much at present. This is partially due the relative

[19] CLNR-L096 Insight report: Domestic direct control trials

infrequency with which most households use a washing machine compared to other appliances such as heating. The technology is new and will improve.

On receiving a signal from British Gas's demand management platform, the electricity supply to the trial participant's **heat pump** was automatically switched into a low output mode for between 15 minutes and two hours. As the heat pump was set to build up a store of heat for up to two hours prior to an interruption, the trial participant always had a supply of hot water to see them through the peak interruption.

Data collected in this trial suggests that smart heat pump electricity consumption had two distinct peaks – one of around 2 kW in the morning, and then a smaller one (1.5 kW) in the evening. This profile is different to the sample profiles published in DECC's heat pump trials, and may reflect a particular characteristic of the operation of these heat pumps with storage (for example, these may be the times when priority is given to charging the heat store).

The equipment used for this trial would cancel the interruption if the customer adjusted their thermostat during (or immediately before) the interruption. Customers may have therefore inadvertently cancelled interruptions, and further research into the user interface for thermostats could be helpful to determine whether this was the case. Nevertheless, interruptions were successfully carried out the majority (67%) of the time. For those customers that did not cancel the interruption (during three interruptions occurring between 6pm and 7pm), electricity consumption fell close to zero during the time of the intervention (compared to around 1.5 kW on days without DSR events). However, there was a strong peak immediately at the end of the intervention, which is indicative of a rapid "payback" for this form of DSR.

The existence of peak loads in the morning and early evening on non-intervention days and the peak immediately following an intervention suggests a particular characteristic of the type of ASHP with thermal storage used, or of the settings applied. This characteristic, together with the mixed attitude of customers towards the technology and the additional space requirement for the thermal store, limits the potential benefit of this intervention at present. Nevertheless, the trial has been ground-breaking, using innovative equipment, and clearly demonstrates the technical potential for this intervention. The size of the peak reduction makes it of interest to a DNO, but the utility of the intervention will depend on what cost the DNO would have to bear.

SME customers; restricted hours and direct control

The technologies held by SME trial participants were much more diverse. However, the main problem with the SME trials was the difficulty in recruiting participants. Over 20,000 SMEs were approached and we recruited and undertook time consuming technical site surveys with a significant number. Whilst we found a high level of interest in the concept of demand side management, there were a number of factors with SME customers that meant that only ca. 50 customers were able to take part in the flexibility trials of the restricted hours tariff and the direct control proposition. Survey results indicated that broadly the needs of the business meant that the uncertainty introduced by potential interruptions was unacceptable. Of the two customers that signed up to the restricted hours trial, data from one was inadequate to process. The trial with the one remaining customer, with a cellar chiller, was entirely successful.

This demonstrated that the restricted hours DSR can be successful in reducing load during the peak window. This potentially is of use to both suppliers and DNOs. The difficulty remains in recruiting suitable SMEs and meeting their concerns about being able to continue operating their mainstream business despite the intervention, but a targeted approach to SME customers with suitable loads could be successful.

Within–premises balancing

For domestic solar PV, over 300 customers participated in studies of within-premises balancing (i.e. seeking to avoid the export of surplus electricity by increasing electricity consumption within the premises by, for example, heating water) where customers attempted a degree of balancing by manual or automatic means.

Some trial participants were supplied with a real-time solar meter display to show the trial participant when they were generating more electricity than they were using. These participants were encouraged to turn on their appliances manually at these times in order to reduce the amount of electricity they imported from the grid when they were not generating. Other trial participants had equipment installed to automatically use any excess PV generation that would otherwise have been exported to heat hot water electrically in the home. Unfortunately challenges with data quality could not be resolved and reliable outputs could not be generated with the automatic balancing trial, at this time.

For domestic solar PV customers with in-home displays for manual in-premises balancing, compared with trial participants with a smart meter but no PV, the following were statistically significant:

- Average annual gross electricity consumption was 1170 kWh higher (4674 kWh as against 3507 kWh) and was significantly higher in nearly every month (but less so at weekends)
- Electricity consumption during the day was higher (at 30% compared with 27%)
- Average and maximum peak demand was higher (1.6 kW and 4.9 kW as against 1.2 kW and 4.2 kW, respectively) with the difference focused more in the summer months

There was, however, no significant difference in any of these variables between trial participants with PV and manual in-premises balancing and those with PV alone. When surveyed, participants said that they had made shifts in laundry and dishwashing. This suggests that participants thought they were making larger changes to behaviour than was evidenced by the data. The qualitative research indicated that solar PV customers without the IHD found other means to monitor and assess the amounts of electricity they imported and exported, which may offer some explanation as to the absence of observed difference between the two groups. There is scope for further study here. However, on the basis of the quantitative findings alone, manual in-premises balancing would make no significant contribution to DSR.

Turning to the implications of the learning gained from these trials, the basic and enhanced monitoring of customers with smart meters has provided valuable up-to-date information about domestic consumer load profiles and their make-up. Washing machines and dishwashers offer the greatest flexibility in terms of time of use and our surveys suggest customers are prepared to be flexible. However, there is limited use of these appliances during weekday peak times, and so customers without LCTs may have limited ability to move load out of the peak period.

Enhanced monitoring of LCTs provided important new information that will assist system planning as increased numbers of LCTs are introduced. Only domestic charging of EVs could have a major impact on the network, but this will depend on the speed and extent to which EVs are introduced. Whilst this is not yet a problem for network system design and operation, there is a strong case for taking appropriate action to encourage off-peak charging behaviour from the outset.

For a DNO, what is needed in terms of customer flexibility is a reduction in peak load at times of particular network stress, for example at network peak or after an interruption. All of the domestic interventions tested were successfully demonstrated, but, on the basis of our findings and with the tariffs and costs we used, none of them appear likely, in isolation, to be cost effective if they were to be used only as a means of meeting DNO needs to avoid reinforcement. On the other hand, by reducing the amount of electricity consumed during the peak period, ToU tariffs could be of benefit to a supplier. ToU tariffs could therefore be useful to DNOs as part of a solution or would help if introduced by another player e.g. an energy supplier[20]. Alternatively, more sophisticated tariffs might have a direct impact, but this would need further testing. Smart washing machines are effective technically, but the level of engagement and the low amount of peak activity mean that the impact on the peak is low. Smart heat pumps can reduce peak load, but have technical issues, limited feasibility to fit into existing properties and problems of customer acceptability. In the future these smart devices may be more effective as part of a smart connected home, where multiple appliances run on a common platform, configured to respond to either a tariff or control signal. Refrigeration scrappage schemes could also help by improving the overall efficiency of home refrigeration. We have insufficient evidence to indicate whether PV with in-house balancing, whether manual or automatic, has the potential to make a significant contribution to DSR.

Electricity suppliers have different needs in relation to demand side response from DNOs. They might be interested in reducing electricity consumption at times when generating costs are high and they can aggregate the responses achieved over a wide geographical area. By reducing the amount of electricity consumed during the peak period, the ToU trial has the potential to reduce generation costs. An enhanced level of response might be expected in a trial without a 'safety net'. The project has shown that some smart appliances clearly work from a technical point of view and can deliver reductions in consumption at peak times. The technology will continue to improve. There remain problems with noise and space availability for smart ASHPs with thermal store.

[20] Further insight into future commercial arrangements can be found in report, CLNR-L145: Commercial Arrangements report

2. Introduction

2.1. Purpose and scope of this report

The purpose of this report is to disseminate the learning from the Customer-Led Network Revolution (CLNR) project with respect to domestic and SME customers, and specifically to the questions:

- What are the current, emerging and possible future customer (load and generation) characteristics?
- To what extent are customers flexible in their load and generation, and what is the cost of this flexibility?

The CLNR project, funded via the Low Carbon Networks Fund, was a smart grid project led by Northern Powergrid in partnership with British Gas, Durham University, Newcastle University and EA Technology. This is one of three reports providing an overview of the project and its findings. The other two deal with larger customers[21] and network-related[22] aspects of the project.

2.2. Background information; the issues, legislation / initiatives, LCNF

The UK Government has set some ambitious goals for reducing the amount of greenhouse gases that we as a country emit into the atmosphere. The achievement of these goals will require a dramatic change in how electricity is produced and used, which will have a profound effect on the way that electricity distribution networks are operated in the future.

In summary there are three broad UK government policy objectives[23] that will impact the electricity system:

- ***Carbon reduction targets:*** The achievement of 2020 and 2050 carbon reduction targets[24] is likely to require the almost complete decarbonisation of the electricity sector.
- ***Energy security:*** There is a need to ensure secure and sustainable energy supplies as the power system decarbonises and electricity demand changes.
- ***Affordability:*** This will have to be achieved while ensuring that networks continue to deliver long term value to existing and future customers.

The impact of these policy objectives upon the electricity system will be:

- ***Integration of inflexible and intermittent generation***: As the GB national generation infrastructure is renewed, more electricity will be generated from less flexible sources such as nuclear and renewable sources that are intermittent e.g. wind.

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[21] CLNR-L247: Developing the smarter grid: the role of industrial & commercial and distributed generation customers

[22] CLNR-L248: Optimal solutions for smarter distribution systems

[23] ENSG "A smart grid routemap" 2010

[24] Climate Change Act 2008 stipulates that the UK must reduce its CO_2 emissions to 34% lower than the 1990 levels by 2020 and 80% lower by 2050

- ***Electrification of transport and heating:*** The decarbonisation of transport will lead to an increase in the use of electric vehicles and reducing the use of fossil fuels for heating will see an increase in the use of heat-pumps in homes and businesses, both of which will result in load growth on the electricity distribution networks.
- ***Integration and optimisation of Distributed Energy Resources:*** There will be an increasing number of distributed generators connected to the distribution network as opposed to the transmission network, including at the domestic level. In some cases this generation will be dispatchable by the transmission system operator whilst the remainder will be of a size that the customer will decide when they operate. Customers will be encouraged to participate in demand side response using their own demand, local storage and/or generation.

Although a lot of these changes to the electricity system will be at the demand and generation ends, the network that connects these together will have to be strong yet flexible. Distribution networks will have to be operated to respond to power flows that are more complex and less predictable.

This will involve making effective and efficient decisions in how the network is designed and operated so as to minimise the impact on customers' bills while maintaining high levels of network reliability. This requires all distribution network operators (DNOs) to find the best deal for customers in the long-term by seeking out and deploying novel solutions when economic, avoiding too much investment ahead of need but being ready for the accelerated uptake of these technologies when it happens in terms of investment and resource planning.

The Customer-Led Network Revolution project

The Customer-Led Network Revolution project, funded via the Low Carbon Networks Fund, was a smart grid project led by Northern Powergrid in partnership with British Gas, Durham University, Newcastle University and EA Technology designed to test a range of customer-side innovations (innovative tariffs and load control incentives) alone and in combination with network-side technology (including voltage control, real time thermal rating and storage). The project was designed to deliver robust learning that would be applicable to a high percentage of GB networks and demographic groups.

More than 13,000 domestic, SME, industrial and commercial and merchant generator customers took part in the project, which involved the trialling of innovative smart grid solutions on the Northern Powergrid electricity network and the trialling of novel commercial arrangements to encourage customer flexibility.

Learning from the project will help DNOs find cost-effective ways to manage the introduction of low carbon technologies (LCTs) like solar PV, heat pumps and electric vehicles and ensure customers continue to receive a safe, secure and affordable electricity supply now, and in a low-carbon future. The project tested the flexibility in the ways customers generate and use electricity and how DNOs can find ways to reduce customers' energy costs and carbon footprint in the years to come.

The project was designed to predict future loading patterns as the country moves towards a low-carbon future and to research novel network and commercial tools and techniques and to establish how they can be integrated to accommodate the growth of low carbon technologies (LCTs) in the most efficient manner. The project trialled new network monitoring techniques to measure power flow, voltage and harmonics, trialling alternative smarter solutions that employ active network management and customer engagement to increase network capacity and/or modify load patterns and it developed new planning and design decision support tools for engineers.

To understand existing and future customer generation/demand profiles and the potential flexibility of different customer types we established customer trials, divided between a number of test cells, each designed to deliver a specific set of five learning outcomes, as follows:

Learning Outcome 1: understanding of current, emerging and possible future customer (load and generation) characteristics;

- The project analysed the basic demand profiles of typical business and domestic customers and those with heat pumps, electric vehicles, micro-CHP and solar photo-voltaic panels using smart meter data and the more detailed disaggregation of some customer load profiles down to individual appliances using additional metering. This was done with the aim of updating the statistical analysis of the existing design standard for the design of low voltage radial networks (ACE49) to improve the planning of future LV networks and to provide a baseline against which to measure the impact of demand-side response interventions.
- Research was also carried out into the profile of various types of generation with the aim of updating the Engineering Technical Report ETR130 to better understand the network security contribution from generation.

Learning Outcome 2: to what extent are customers flexible in their load and generation, and what is the cost of this flexibility?

- We researched the development of various tariffs and other interventions for domestic and business customers with and without LCTs to test their willingness to provide a demand-side response (DSR) to help reduce peak loading and prevent thermal and/or voltage issues on the electricity distribution network. The types of intervention tested were time of use and restricted hours tariffs and within premises balancing and direct control of smart appliances.
- We also tested demand side response (DSR) for industrial and commercial customers, contracting both via aggregators and directly with customers. The aim is to test whether such commercial propositions are attractive to customers and what level of confidence we can place on their response.
- We also trialled working with distributed generation to provide free voltage support for the network to which it is connected via the controlled import/export of reactive power.

Learning Outcome 3: to what extent is the network flexible and what is the cost of this flexibility?

- Learning outcome 3 sought to understand to what extent the network is flexible and the likely cost of this flexibility. It involved trialling network technologies and an active network management (ANM) control system called the grand unified scheme (GUS) control system in a series of large-scale field trials. This control system is given control objectives, for instance to manage voltage or power flow and it then monitors relevant network parameters in real-time, runs network analysis to estimate states where measurements are not possible, determines the location of network issues and dispatches the optimum response based upon the types and location of the smart technologies available.

- Although the technologies trialled had previously been deployed individually at high voltages, this project delivered new learning on the deployment of technologies in combination, in conjunction with demand-side response and at lower voltage levels.

Learning Outcome 4: what is the optimum solution to resolve network constraints driven by the transition to a low carbon economy?

- Learning outcome 4 sought to develop the overall optimum solutions to resolve future network constraints which could result from the transition to a low carbon economy. We considered optimum solutions for representative customer groupings and networks, and these solutions informed network design and were encapsulated in the prototype tool for network designers, Network Planning and Design Decision Support (NPADDS) tool.
- We combined data and analysis from learning outcomes 1, 2 and 3, with desktop modelling, simulation and emulation. This approach allowed us to model combinations and future scenarios and those which were unfeasible or not economically viable to pilot in the field.
- From this, we have established a merit order of solutions to network constraints, taking academic learning and placing it firmly in an industrial context. Non-CLNR solutions were also considered, to create a comprehensive merit order of solutions and forge a coherent, wide-ranging view of how to design future networks. We considered opportunities and solutions and explained why, in practice, DNOs might take a certain policy stance. The conclusions are structured for easy incorporation into relevant policy documents, and they also inform the coding of the NPADDS design tool to ensure consistency with policy.

Learning Outcome 5: what are the most effective means to deliver optimal solutions between customer, supplier and distributor?

- The objective of learning outcome 5 was to provide a framework for transition of the technologies and interventions trialled by CLNR into business as usual (BAU). For the outputs for DNOs, include:
    - the provision of a prototype software tool for network designers (NPADDS);
    - material for training courses;
    - new operational procedures to define safe working practices for new technologies;
    - design policy guidance;
    - equipment specifications and equipment application documents; and
    - recommendations to update national design standards.
- For the wider industry, this includes possible new commercial models and policy recommendations as well as an assessment of the value of these solutions to the customer. One key output is a tool for the toolkit, to guide network planners in selecting non-network, novel network and conventional network solutions. This will be built upon a better cost/benefit analysis tool, which we shall develop as part of this Project (having identified the

volume and cost of new solutions for releasing network headroom) and which can be used in itself to guide further work.

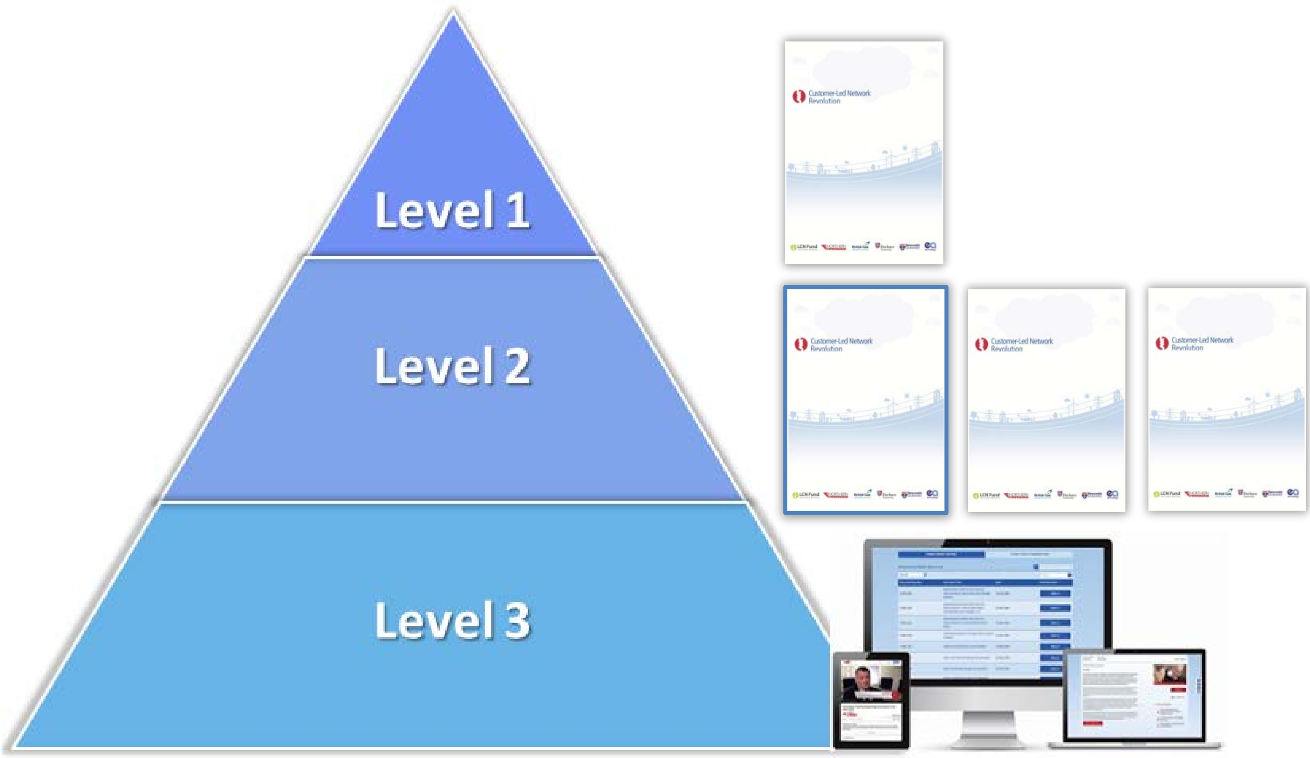
2.3. Structure of this paper

Part 1 covers delivery of the trials. Section 3 focuses on the trial design: gathering of baseline data, testing of different interventions, and issues relating to customer payment, consent and use of data. Section 4 considers customer selection and recruitment: demographic modelling, methods of communication and engagement, customer response and types of intervention.

Part 2 covers the findings from the trials. Section 5 describes the findings from the on-line survey and interviews. Section 6 explains what data was captured and the analysis that has been carried out. Sections 7 and 8 set out the findings from the basic and enhanced profiling of domestic customers without demand-side interventions. All of these had smart meters fitted and some had LCTs installed. Section 9 describes the findings from demand-side interventions on domestic customers. Section 10 deals with SMEs. Section 11 summarises the key findings and draws lessons for network companies, suppliers and future innovation projects.

2.4 How this paper fits within the full CLNR output suite

The diagram below provides an overview of the structure of the CLNR project output documents. This report resides at Level 2, as shown in blue.



All published documents are available at:
http://www.networkrevolution.co.uk/resources/project-library/

Part 1 Delivering the trials

3. Trial design

3.1. General approach

3.1.1. Monitoring customers' existing load and generation patterns – Learning Outcome 1

This part of the project involved monitoring the electricity consumption and generation profiles of around 13,000 domestic and SME customers, both those with and those without LCTs (heat pumps, photovoltaics, micro-CHP, electric vehicles). This is the largest sample of electricity customers' usage to have been undertaken in the UK and Ireland to date. The size of the sample, when compared with previous projects monitoring customer electricity use, has generally ensured a statistically robust set of conclusions and greatly improved the rigour and breadth of our understanding.

Almost 9000 domestic trial participants from a wide range of socio-demographic backgrounds provided three important inputs to the project:

- The data created an overall picture of current domestic electrical energy consumption in the UK. This has been used to provide a key input to the proposed updating of ACE49, which provides guidance on the design of electricity distribution networks serving domestic areas and is currently based on data last gathered in the 1970s. More details are provided in the Optimal Network Systems report[25].
- The data provided a baseline against which to measure the impact of the installation of low carbon technologies (LCTs) and/or various types of customer intervention, which are described further on in this report.
- Findings from customer surveys and in-depth interviews of trial participants within this cohort provided important understanding of customer behaviours and attitudes in relation to electricity use, electrical appliances, smart meters and customer interventions. This is of importance in relation to the development of effective customer interventions at the commercial scale by both DNOs and suppliers and assist all parts of the industry and policy makers in gaining an understanding of the likely impact of changes in policy, marketing or regulation that impact directly on customers.

For monitoring and analysis purposes, the trial participants were divided into a number of test cells.

The base test cell excluded economy 7 and other specific high electrical loading customers. These trial participants either already had smart meters installed or smart meters were installed prior to commencement of the trial start date. (Note that the purpose of the trial was to compare smart meter customers with LCTs and/or interventions against those with smart meters alone, rather than a comparison of before and after behaviour.) These smart meters were capable of recording electrical energy consumption to a 30 minute resolution. The trial participants were allocated to 144

[25] CLNR-L248: Optimal solutions for smarter distribution systems

different demographic customer groups, to provide a good statistical basis for assessing the typical electrical use of each of these groups.

The other test cells in this learning outcome involved customers with LCTs and customers without LCTs who had agreed to accept more detailed monitoring of the various appliances comprising the electricity usage within the premises. The original intention was to use only British Gas customers who had smart meters and/or low-carbon technologies in their homes, of which a sufficient number seemed likely to be available. However, it became necessary to extend the means of recruitment. (See section 4.5 below for changes that were necessary because of recruitment issues.)

3.1.2. Trialling customers' flexibility in load and generation – Learning Outcome 2

This part of the trial aimed to assess the effectiveness of different kinds of intervention in encouraging those taking part to change the pattern of their electricity usage. These interventions included combinations of electricity tariffs, in-home displays and automation:

- Time of use tariffs to test customers' ability and propensity to move their discretionary load to low-rate price periods.
- Restricted hours tariffs, akin to Economy 7, to test customers' willingness to accept a default time-based restriction on the use of a specific appliance, and also the degree to which they exercised the over-ride that we provided.
- Direct control of appliances to test customers' willingness to have the time of use of a specific appliance directly controlled by the customer's electricity supplier (sometimes in response to distributor need).
- For domestic PV, studies of within-premises balancing (ie seeking to avoid the export of surplus electricity by increasing electricity consumption within the premises by, for example, heating water) where customers attempted a degree of balancing by manual or automatic means.

In order to gain a deeper and broader understanding of demand side management as a whole and to provide for independent expert challenge of our propositions and findings, we part-funded and contributed to Sustainability First's three year GB Electricity Demand Project[26] .

The interventions are described in more detail in section 3.2.

3.1.3. Installation of equipment

In order to gain a detailed understanding of customers' electricity usage, some trial participants had monitoring equipment installed on the premises in addition to the British Gas smart meter (which recorded electricity consumption at 30 minute intervals), or for non-British Gas customers, in addition to their existing meter. The additional monitoring comprised "in-line" monitoring and/or smart plugs (which provided consumption data at 10 minute intervals) and (in the case of non-British Gas customers) a secondary meter for "whole-house" monitoring. This was required for trial

[26] http://www.sustainabilityfirst.org.uk/gbelec.html

participants other than British Gas customers with plain single tariffs, i.e. for non-British Gas customers and for customers on a tariff such as prepayment or economy 7.

In all instances where monitoring equipment was installed, trial participants were provided with details of this equipment installation (including an indicative timescale for it to remain in situ) before they consented to take part in the trial. Additional monitoring equipment was installed by the equipment supplier under contract with British Gas and, where appropriate and wherever possible, was combined with the installation of either a low-carbon technology (where installed) and/or a British Gas smart meter to minimise disruption to the trial participant. The equipment was left installed in the customer's premises for the duration of the trial, after which the installer made arrangements with the trial participant for its decommissioning and removal.

A description of the monitoring equipment installed, including smart meters, secondary meters, smart plugs and LCTs is given in Appendix 1. A number of issues arose in relation to the installation of equipment. These are referred to in Section 11.

3.2. Tariffs and other interventions

3.2.1. Time of Use tariffs

A set of tariff propositions was developed that aimed to maximise the relevant learning from the trials, given practical constraints faced in their implementation. A full report on our approach to the development of the commercial propositions has been published on the project website[27].

The Time of Use and Restricted Hours propositions were both based on an underlying time of use tariff. For a time of use tariff to be commercially viable and valuable in 2020, it should reflect the costs of supplying electricity at each point in the day in 2020, and the likelihood that shifting demand in response to tariffs will change the profile of these costs. Time of use tariffs were developed for SME and domestic customers based on estimated future costs and demand patterns. These tariffs are presented in Figures 1 and 2. For domestic customers, the peak ToU rate (from 4pm - 8pm) was 99% higher, the day rate (from 7am - 4pm) 4% lower and the off-peak rate (from 8pm - 7am) 31% lower than the flat rate tariff. In addition, there was a 16p standing charge. The tariffs were designed to ensure that overall the bills for an average customer remained similar. Trial participants were told that if in the trial they would have ended up paying more as a result of the ToU tariff, they would only be charged the flat tariff rate.

[27] CLNR-L006: Domestic and SME tariff development for the Customer-Led Network Revolution

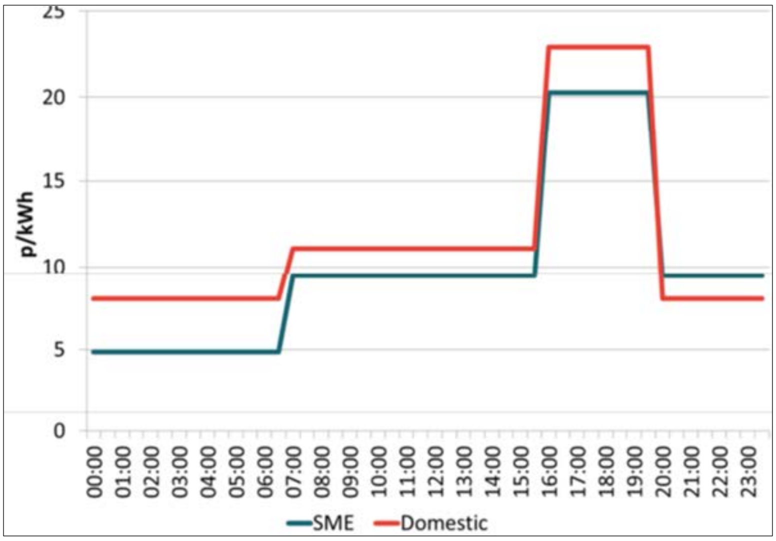


Figure 1: Time of Use tariffs – weekdays

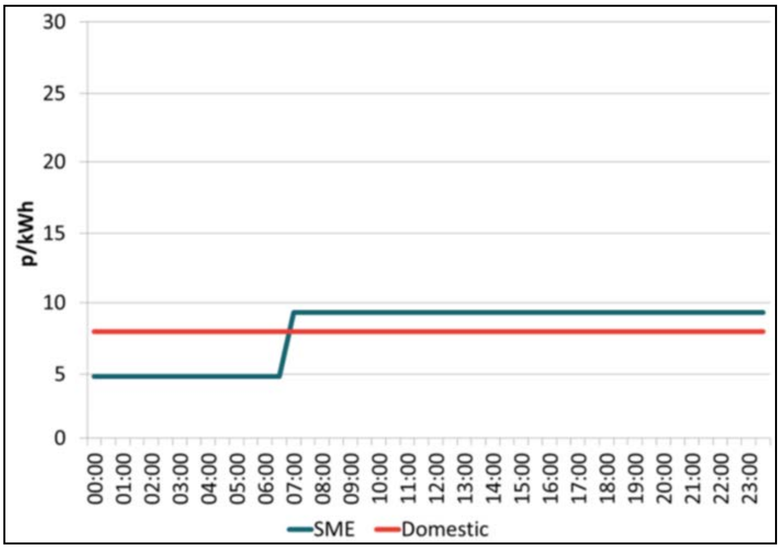


Figure 2: Time of Use tariffs –weekend

The domestic and SME tariffs differed in that the domestic tariff did not include an 'evening shoulder'. Instead it reverted back to the lower night rate directly after the peak evening period. While ideally an evening shoulder would have been included for the time of use tariffs, British Gas's systems were unable to accommodate this for domestic customers. Nevertheless, this domestic tariff provided new learning as a tariff of this shape had not been included in recent major trials in the UK and Ireland. It allowed testing of the assumption that an evening shoulder is required to avoid a new peak occurring once the lower night rate commenced in mid-evening.

3.2.2. Restricted hours tariff

The Restricted Hours tariff aimed to test customers' behaviour with the above ToU tariff combined with an automated service that switched certain appliances (smart washing machines or smart heat pumps) off during the four hour peak period from 4pm to 8pm on weekdays, with technology provided to allow customers to override this automated service when they wished. By combining this automation with the same time of use tariff being used elsewhere in the CLNR, we could assess the incremental impact of the automation.

Trial participants in this trial received a smart washing machine, which they could set to turn off automatically as peak time began, turn on automatically at the most economical time, or choose the most convenient time themselves. If they opted for their machine to automatically select the cheapest time to do their washing, they needed to turn on the energy control mode before beginning their wash cycle. The machine would display the energy used by the appliance as well as the cost. The trial participant could chose to pause the cycle or disable the energy control mode at any time without penalty.

In order to optimise the operation of the smart heat pump in line with the time of use tariff, the electricity supply to the heat pump would be automatically switched into a low output mode for periods of between 30 minutes and two hours in the peak hours during the trial period. The heat pump would be set to build up a store of heat for up to two hours prior to an interruption to ensure the customer always has a supply of hot water through the tariffs peak hours. Should the customer want to override the low output more of their heat pump, they can easily do this by using the control provided with the heat pump.

3.2.3. Direct control

The aim of the Direct Control proposition was to test customers' behaviour in response to the occasional direct control of the load of specific appliances.

To calculate the value associated with moving customer demand, we used a methodology based on the Common Distribution Network Charging Methodology (CDCM). This suggested a value of £30/kW per year for occasional direct control of loads, assuming this intervention would be focused on the heavily-loaded parts of the network where the value of implementing it is at the higher end. For this cost saving to be realised by networks, customers would have to allow their load to be interrupted as many times as was required to defer HV network reinforcement. We estimated these interruptions would need to last for the four hours of peak, for around 10-15 consecutive working days, once every three years.

The value to networks of a customer of accepting a Direct Control proposition would depend on the size of load associated with the appliances that they had available for interruption. The results of the analysis of the value of interrupting domestic loads of different types are set out in Table 1. Based on these values, it was decided to exclude cold appliances from this test cell.

		Annual value of interrupting load at peak
Cold appliances	Fridge Fridge-freezer Freezer	<£0.20/year
Wet appliances	Washing machine Dishwasher Dryer	£2/year £2/year £4/year
Hot water heating		£15/year
Heat pumps		£10-15/year

Table 1: Time of Use tariffs –weekend

Trial participants participating in this part of the trial received either a Smart Washing Machine or Smart heat pump.

The terms of the trial allowed the supply to these appliances to be occasionally interrupted through external dynamic signals, in this case from Northern Powergrid via British Gas's demand management platform. Certain limitations were placed on the frequency and timing with which interventions could be called:

- A maximum of 15 interventions per year
- Only 1 intervention per day
- Interventions could occur on up to 10 consecutive days
- Each intervention could last up to four hours
- Interventions would be called in the peak periods of 4pm to 8pm only
- The trial participant could override without penalty
- Excludes weekends and public holidays

On receiving a signal from British Gas's demand management platform, the electricity supply to the trial participant's **heat pump** was automatically switched into a low output mode between 15 minutes and two hours. As the heat pump was set to build up a store of heat for up to two hours prior to an intervention, the trial participant always had a supply of hot water to see them through the peak intervention.

When enabled, the **washing machine's** energy control mode allowed the appliance to receive load control signals. These signals enabled the washing machine to automatically schedule a wash cycle to avoid the times specified for the load control or if currently in use, it would send a message via SMS, the machine's display or smart meter IHD asking the customer to pause the cycle to be resumed after the load control event. Trial participants were encouraged to keep this mode enabled throughout the trial, but could operate an override at any time by disabling the energy control mode.

The technologies held by SME trial participants were much more diverse. British Gas developed a pragmatic approach to assessing the value of interrupting their loads. This was based on the assumption that interrupting the load of SME customers will allow a portion of their distribution network costs associated with supplying electricity to them to be saved. Applying this methodology results in a discount of 2% in bills to Direct Control SME trial participants, who could allow 20% of their load to be interrupted. A proportionately smaller discount would be given where trial participants can reduce a smaller amount of load.

3.2.4. Solar PV within-premises balancing

The implementation of within premises balancing aimed to incentivise behaviour change through increasing energy consumption during periods of excess on-site generation from solar PV installed at the home. Trial participants were supplied with the Passiv Controller with a real-time solar meter display to show the trial participant when they were generating more electricity than they were using. Trial participants were encouraged to turn on their appliances manually at these times in order to reduce the amount of electricity they imported from the grid when they were not generating. Alternatively, we deployed Coolpower's EMMA system to automatically use any excess PV generation that would otherwise have been exported to heat hot water electrically in the home. This aimed to help trial participants use their solar panel generation in the most efficient way.

3.3. Payments to customers

We made payments to trial participants, other than those in the Learning Outcome 1 base test cell, for joining, completion and project extension (in the form of £50 Marks and Spencer vouchers), to provide compensation for allowing installations, such as electricity usage monitors, into their premises. These fees were also intended to provide an incentive to trial participants to sign up and to continue to participate for the duration of the trial, although anecdotal evidence indicates that trial participants often agreed to participate before being informed about the payments.

SMEs were given a £100 joining payment and a £100 completion payment, applied as an ex-VAT credit to the customer's account shortly after joining and completion.

3.4. Customer engagement and consent

Customer engagement was carried out in line with a customer engagement plan[28] agreed with Ofgem. We understood that to deliver a successful project we needed to build and maintain the trust of customers who agreed to take part in our trials. The management of engagement and consent played a key part in creating this positive relationship with trial participants.

The monitoring of trial participants in the base test cell required no explicit customer engagement since the data was already collected via the smart meter. Moreover, consent was effectively already in place for these trial participants. Where electricity consumption data could be obtained on a business-as-usual basis from British Gas's smart metering customers, the Privacy Notice (contained in customers' supply terms and conditions) allowed personal information held about trial

[28] CLNR-G010: CLNR Customer Engagement Plan

participants to be used for, amongst other things, analysis and research purposes. Therefore, there was already a basis for using this customer data (including where such analysis is undertaken by third parties under contract with British Gas). Nevertheless, we still required and obtained consent to the use of smart customers' data via an opt-out letter. There was a less than 1% drop out rate.

In the other test cells, where we needed to work with trial participants either to install additional monitoring equipment or ask them for more information on their energy use or production, the trial participants were recruited through an opt-in process. Working through established supplier/customer interfaces, British Gas used their existing customer communication, sales, installation and support infrastructure to ensure the engagement of their customers in the trials.

Non-British Gas customers were also recruited to the trials in order to increase the number of trial participants; these trial participants were also recruited via an opt-in process. We only contacted non-British Gas customers who had given their consent via other routes. For example, if as a tenant of a registered social landlord (RSL), they had been put forward for potential heat pump installation or retrospective monitoring, in which case the RSL managed and took responsibility for obtaining consent).

Consequently, the project needed to seek additional consent to use customer data from trial participants in the following categories:

- Non-British Gas customers participating in any trial;
- Trial participants providing additional qualitative information on their energy use or production;
- Trial participants accommodating additional monitoring equipment; and
- Trial participants who enrolled in the CLNR intervention tariffs such as Time of Use, Restricted Hours, Direct Control

Prior to formal enrolment in the trial, we provided trial participants with all relevant information about the project including its background, objectives, timelines and an overview of the consortium members involved in its delivery. The need for generation and consumption data and a high-level overview of the analysis that will be done was explained. In enrolling in the project, trial participants gave consent for the use of their data in the ways detailed in that documentation.

3.5. Treatment of customer data

A data protection strategy was agreed with Ofgem to ensure customer privacy and to comply with the law. All customer data was anonymised during the project data management process.

The key information extracted from the British Gas systems was electricity consumption data associated with a particular Meter Point Administration Number (MPAN). No name or address data was extracted. The MPAN was then removed and replaced with a randomly generated unique identifier created by British Gas, which was recorded against that trial participant and used for the duration of the project. All meter read data was also supplied against the unique identifier.

The process was broadly similar for non-British Gas customers. They were given a unique identifier number as with British Gas customers for use during the duration of the trial. No name or address data was passed on to Durham University for the purposes of studying consumption (but this was clearly needed to invite customers on to the trial in the first instance, and was used by British Gas and Durham University for the purposes of running surveys and providing trial participants support, and to arrange in-depth social interviews respectively).

In terms of linking this to the monitoring data (which comes from a different system but which all needs to be linked together), the same unique identifier was loaded in and associated with the corresponding trial participant. As such, whenever extracts of monitoring data were taken they linked through the common unique identifier. No sensitive customer data is ever shared and British Gas staff not involved in the project did not have access to consumption data from non- British Gas customers.

4. Customer selection and recruitment

4.1. Introduction

The CLNR project benefited hugely from the active participation of a major energy supplier. Indeed, much of the customer-facing aspects of the project would have been impossible without this. However, all those involved in the project have been mindful of the need to avoid the project itself or Northern Powergrid as the project leader appearing to recommend or give marketing support to British Gas as an energy supplier.

4.2. Demographic modelling

The demographics of customers participating in the study were developed collectively between Durham University and British Gas. The project sought to achieve a broad representation of different customer demographics. The extent to which different customer groups actively participated in the study and changed their behaviours, and what factors influenced this were researched by Durham University and British Gas collectively. Durham University research included holding discussions with trial participants, including visits to their premises.

4.3. Non-British Gas customers

The vast majority of trial participants actively involved in the project were sourced from British Gas's customer base. Therefore the majority of engagement and interaction with trial participants for project purposes was carried out by British Gas. In a limited number of instances, it was necessary to engage directly with customers who were not those of British Gas. Material and call centre advice was branded with the project brand, and so was the same for non-British Gas customers as for British Gas customers.

Interaction with these trial participants was the responsibility of British Gas on behalf of the project. Care was taken to avoid any appearance of attempting to recruit these trial participants to be supplied with electricity by British Gas, and no different tariff offerings were made to them. To protect against this appearance, staff involved in non-British Gas customer recruitment were given extensive training in the importance of recruiting trial participants to the project only and to ensure that electricity supply by British Gas is not discussed in any conversations. The risk of this occurrence, however, was considered low as the recruitment of non-British Gas supply customers was only required for test cells where they are not required to be supplied by British Gas so there is no incentive or need to encourage or transfer them to a British Gas electricity supply. Also, in the majority of cases, the staff involved in non-British Gas customer recruitment did not have access to the main British Gas account creation/management systems.

4.4. Channels and approach

Customer engagement included all aspects of trial participants' involvement with the programme:

- Establishing which customers need to be engaged;
- Planning customer selection and approach;
- Developing and implementing initial engagement plans;

- Bringing customers into the programme;
- Keeping trial participants engaged in the programme;
- Managing customer issues and questions; and
- Managing trial participants who are leaving the programme.

A generic welcome pack was issued, with common themes to the approach to each customer group, with a specific trial insert and set of Terms & Conditions tailored to each trial. For each of the customer groups involved, British Gas provided trial participants with printed and electronic materials and access to agents from British Gas's customer contact centres. In addition, in more complex cases where the implications of the technology / tariff combination were likely to be greater (for example where a direct control tariff is being implemented) British Gas's field staff visited the trial participant if necessary in person to ensure the trial participant understood the situation fully and knew what to do if further support is required. Where trial participants were happy to share and allow the project to communicate with them electronically, the project used email communications where possible. This allowed more frequent and timely communication as well as links to the project website.

Communication with trial participants during the trial consisted mainly of customer support: proactively contacting customers on a weekly basis to restore connectivity where required, service visits, courtesy calls, and a trial of a version of our Smart Energy report for ToU customers. Participating trial participants could also access the project website and associated social media (Twitter, YouTube) to find out more about the project, to sign up to project updates by email and to contact the project team.

4.5. Customer recruitment

For a variety of reasons explained below, customer recruitment was more difficult and slower than anticipated at the outset of the project. We considered that it was important to capture the learning from the experience of addressing these challenges and so, as part of the project Sustainability First was commissioned to report on these experiences and their paper29 has been published on the project website. This section summarises the findings. Where appropriate, the findings have been updated in this document, in the light of more up-to-date information. Appendix 2 of this paper gives a detailed breakdown by test cell of the numbers recruited and the reasons for any drop out.

The project bid assumed an ambitious timetable for recruitment of customers to the trial. Challenges (both foreseen and unforeseen) were found with the recruitment and installation into many of the customer groups. As a result the recruitment timescale was revised in October 2011 and new recruitment targets set in October 2012 to be more achievable, given the constraints encountered. We had a gross target of a number of customers we aimed to recruit to each test cell on the assumption that there would be a 1/3 dropout rate during the trial. Accordingly, the net target was 1/3 lower than the gross target. In reality the dropout rate during the trials was very low.

[29] CLNR-L036 Lessons learned from trial recruitment

Initial recruitment to domestic test cells (getting customers to initially agree over the phone to be on the trial) was broadly successful. Recruitment proved most straight-forward into the 'simplest' household test-cells (i.e. monitoring, enhanced monitoring, ToU tariff). The household test cells where recruitment fell short most against targets at the initial stage were those where it proved most challenging to find suitable customers with the right technologies, install new technologies, and/or to find customers willing to take the new technologies.

The vast majority of customers involved in the project fell within two smart-meter related groups. In terms of customer volumes and the project timescales, recruitment into these two core groups was successful:

- For to the baseline domestic customer group we had 8,909 trial participants, very close to the gross target of 9,000 customers). Although the demographic was representative of British Gas's smart-meter population at the time, it was not representative of the population as a whole.
- The ToU domestic customer group also met the gross target of 600. This has been a particular success for trial recruitment, as unlike the far larger baseline test-cell, this group of 628 household trial participants were required to opt-in.

Recruitment to the other domestic monitoring test cells was strong enough for us to comfortably meet our gross targets for enhanced monitoring (420 customers[30)], for PV (160 customers), for EV (159 customers) and to be close to our net targets for heat pumps (344 customers or 86% of target) and for CHP (14 customers or 70% of gross target).

For the flexibility trials, recruitment was strong for the PV balancing trials with 307 customers (77% of the net target), some with auto balancing and some with manual balancing. For the other domestic flexibility trials, numbers of trial participants was low due to the challenges mentioned above.

For the baseline monitoring of SME customers, we achieved 1,800 customers, 80% of the gross target or 120% of the net target. Whilst recruitment to the SME opt-in trials was initially successful (with over 560 initially recruited to the enhanced monitoring and the three flexibility trials), once site technical surveys for installation were carried out almost all customers dropped out of the restricted hours or direct control trials, because of concerns about the possible impact on their business. Enhanced monitoring had the greatest rate of proceeding to full participation with 81 customers (representing 81% of the net target). For the ToU trial, 44 customers (44% of the net target) proceeded to the trials.

4.6. Availability of low carbon technologies

The original intention at the time of the bid had been to access British Gas customers who were installing LCTs, and to fit smart meters where these had not already been installed and other

[30] Customers in all the '2a' test cells; i.e. domestic customers with no LCT, and customers with immersion hot water heating, or immersion hot water heating and storage.

monitoring equipment at the time of the installation of the LCT. Outside of the project, British Gas had been engaged in commercial sales of low-carbon technologies, and it was intended to use this sales channel as a route to identify customers who wish to participate in the Customer-Led Network Revolution. The commercial sales activities were not funded or subsidised by the project. However, for various reasons, recruitment was severely hampered by the lack of penetration of the various technologies:

- For the PV test cells, it was difficult to find sufficient properties where either the property owner or the 'rent a roof' provider was prepared to agree to the householder's participation. The principal provider of 'rent a roof' installations in the area was unwilling to take part in the project. This was solved by working with housing associations.
- Delay in the launch of the Government's Renewable Heat Incentive and uncertainty about the support to be provided to air source heat pumps reduced significantly the number of ASHP installations. The team sourced additional money from DECC for heat pump installations, including innovative heat pumps with energy storage capability.
- Electric vehicle sales were much lower than had been anticipated at the time of the bid. The team worked with Charge your Car (North) to recruit scarce EV users.

Further challenges arose as a result of the need to develop technical solutions given the lack of availability of these solutions in the market. Ideal technical solutions were not necessarily available, and some products and equipment were larger or more cumbersome than a fully-developed market-ready product. Nevertheless, and despite initial low expectations from the project team, trial participants seemed relatively open to accepting trial equipment in their homes, despite some inconvenience. Installing monitoring equipment caused particular problems as it required an isolation switch in the trial participant's home, located between the meter and the consumer unit, to allow equipment to be safely installed, but many houses did not have such a switch. Without an isolation switch, only the supplier's appointed meter operator is authorised under industry guidelines to temporarily disconnect the power supply at the mains fuse instead (i.e. on the DNO side of the meter). Without an isolation switch, liaison was therefore required with the relevant meter operator and/or energy supplier and hence delayed installation of the monitoring equipment.

The majority of residential trials required the installation of home area network hubs to communicate with the installed monitoring technology. This required broadband and a phone line, which many homes did not have and therefore needed installing first. This also required homeowners not to move the hub once in place, which sometimes happened for household convenience or aesthetics. As the trial progressed, British Gas developed a GSM (mobile phone-based) solution as an alternative.

Part 2 Findings

5. Customer attitudes and behaviour

5.1. Method

The social science team at Durham University developed two methodologies to help understand the social dimensions of the CLNR trial: surveys (two approaches, one deployed with SMEs one with domestic trial participants) and qualitative semi-structured face-to-face interviews and research visits. These methods were used in conjunction with the analysis of energy consumption data to provide insights into how and why energy use takes particular patterns for groups and individuals within the population included in the CLNR trial. The social science team drew on the existing literature to design research instruments and methodology which, as well as making a contribution to the existing academic knowledge base, could produce a sufficient dataset and deliver the learning outcomes required by project partners. A number of socio-technical reports have been published to provide detailed findings. Associated social science outputs can be found in Appendix 4.

The face-to-face interviews focused on building rapport with the participant while discussing their energy use in general terms. These conversations included gathering information about occupancy, major electrical loads, heating regimes, washing and cooking practices, thoughts and feelings about electricity use, seasonality and other temporal factors as well as experiences of and attitudes to new and existing tariffs and technologies.

During the tour of the premises led by the participant, they were prompted by the researcher to talk about all aspects of their electricity use using electrical equipment as a catalyst for conversation. Furthermore, multimedia data was collected by the researcher, with permission, to further enrich analysis. The participant-led approach was reflected in the instrument design which did not constrain the respondent or presuppose the factors which are most relevant to the participant. The third part of the visit enabled a discussion of the principal issues with which the project is concerned as they related to the participant's context and focused on the topics of flexibility, peak consumption, key practices with potential for demand-side participation and engagement. Some participants were involved in a follow-up visit, and in this case a fourth part of the research instrument was used to interview participants about their experience of the particular interventions they had engaged with through the CLNR project.

The online surveys were developed following consultation with several sources. National Energy Action's (NEA) experience of conducting different types of household surveys informed the initial set of questions, while feedback from DEI's external advisory group was instrumental for revising the attitudinal questions in the domestic survey. Reviewing examples of energy-focused surveys from different research projects helped in the preliminary selection of questions. The final set of questions for both the domestic and SME surveys was agreed in consultation with British Gas and Northern Powergrid.

The surveys were designed to produce quantitative data that directly addressed the two overarching learning outcomes of the project. To that end, the questions included in the survey addressed issues of current and future energy use and flexibility of energy use in both domestic and small to medium enterprise contexts. There were a total of 152 responses to the SME survey and 1285 responses to the domestic survey.

The survey and interviews included trial participants who had installed LCTs and trial participants subject to trial interventions, as well as trial participants that had only smart meters installed. The results are therefore summarised below, with specific findings relevant to particular groups included within the appropriate groups in Section 6 below.

5.2. The CCRES model

The surveys and interviews confirmed the benefit of the socio-technical approach to understanding the provision and use of energy services adopted by DEI, in which energy systems involve the continual interaction of social and technical factors, and where demand for energy is driven by the workings of different practices in homes and businesses. Energy use as shaped through the interaction of five different core elements, which determine energy-related social practices and the ways they are organised:

- Conventions: what is considered to be normal energy use, resulting from, for example, standards, cultural expectations, design of appliances
- Capacities: the ability and potential for appliances and practices to use energy
- Rhythms: the daily, weekly, monthly, annual patterns through which activities are organised
- Economies: management of social, natural and financial resources and investments
- Structures: enduring features e.g. structures of employment, school hours, building structures, layouts and materials, systems of energy provision, family structures, household life-stages, social class.

This is known as the CCRES model of energy use, in which each element is a cog or gear which work together in different ways in different contexts to shape how energy is used. This approach, with its emphasis on practices rather than energy behaviour, while gathering momentum in academic circles, is not widely understood by energy practitioners and policy makers, who still focus on energy use being shaped by attitudes and socio-demographic attributes that condition people's consumption choices, and thereby miss a crucial link in understanding domestic energy-using behaviour and how to influence it.

5.3. Survey results

5.3.1. Domestic general

Key results from the surveys were:

- Most participants were owner-occupiers, over 50 years old, slightly more male than female, mostly married/two occupants in home, half with someone Not in Education, Employment or Training (NEET), a quarter with someone with a disability.

Information and engagement

- TV, internet and newspapers were the most common sources of information regarding energy. Power companies and local government were a second tier of information sources. As the number of NEET people increased in a household, the use of the common information sources fell. The youngest age group (16-25) is much less likely to use the common sources of information.
- Common community activities included charity fundraising and membership of a group or association. There was a relationship between community activity and housing tenure, with those in social housing more likely to engage.
- Family members were the most common source of decision support.
- Those who are disabled more consistently expressed a lack of confidence and knowledge about energy use, as did those aged 25-34 and over 65.
- Most householders were in favour of government intervention to manage energy use with the exception of banning inefficient technologies.

Paying Energy Bills

- 41% found it easy to pay energy bills but 20% found it difficult. 51% did not have problems affording their energy bills but 10% did. 43% never or rarely went without to pay energy bills but 17% occasionally or often did.

Appliances and energy behaviours

- Popular energy saving practices included: switching off unused lights, waiting for a full load before doing laundry, and reducing the heat in some rooms.
- Men reported doing energy saving activities more consistently and strongly than women, and also scored higher on low carbon technology and especially PV ownership.
- Those in newer houses tended to be more engaged with energy efficiency and with LCT ownership.
- Households with more occupants owned more appliances. Technology ownership increased with age until middle age when it began to fall.

In-Home Display (IHD) devices

- 54% agreed/strongly agreed that IHDs had caused them to change the time they use some electrical appliances.
- IHDs are felt to have led to a small decrease in energy use.

- 90% found IHDs quite or very easy to understand. Younger people seemed to find it easier to understand.
- Laundry was most often shifted, but there was also a response in lighting, showering and heating.
- Those more likely to increase total energy use as a result of the installation of an IHD had a lower age profile.

Social Trends

- Mobile and internet devices appeared to be growing in importance. We discovered a significant move from fixed line broadband to mobile internet use, particularly in the fuel poor. This will have implications for the widespread use of "smart" homes.
- Households were frequently changing their composition with a greater fragmentation of living styles, and often several generations in the same household.
- The wish to manage energy use to reduce costs was growing.

Customer Engagement

- Customers had relevant knowledge and skill sets: energy is a key resource in the household economy.
- Customers wanted to play their part in 'keeping the lights on'/maintaining the grid.
- Little evidence was indicated of concerns about security and privacy. (Survey did not cover safety issues, such as use of appliances when house is empty or at night).
- The installation of technologies (by who, how, and what they replaced) was critical to customer experience.
- Limitations: our understanding of customer experience over time/at the end of the trial.

Implications

- Customers had varying levels of ability to be flexible, but this was shaped by practices and the 'gearing' of their everyday life, rather than by socio-demographic type.
- Higher income groups consumed more electricity, had higher levels of peak demand, and an extended peak period. This suggests that focusing interventions on this group could be the most valuable.
- The household practices that contributed most significantly to electricity use in the evening peak period were those which had the biggest load and which were most commonly undertaken at this time, in particular laundry and dish washing.

- Electronic entertainment and cooking, although often undertaken in the evening peak period either had low electrical intensity (entertainment), and/or were perceived by respondents to be less flexible.

5.3.2. SMEs

The key results from the survey of SMEs were:

- 72% agreed that they needed to reduce the amount of energy.
- Majority of the SMEs had no environmental policy in place.
- Electricity use was related to within-day (e.g. opening hours), weekly (e.g. shift schedules) or seasonal patterns of activities in pursuit of business goals.
- Connectedness was seen as a vital service that energy use provides.
- Servers and mobile devices were often reported as being among the most critical appliances to business continuity.
- Connectivity between employees and data, and between staff and customers was an important feature of communications surrounding DSR surveys show why it is hard to engage.
- Energy was a lifeline; making changes would put business at risk.

6. Consumption monitoring and analysis – method

6.1. Data sets used

For the purposes of understanding a customer's electricity consumption patterns, there are two key variables that can be measured. The first is the amount of electricity consumed in a particular period, measured in kilowatt hours (kWh). The second is the rate of use (or generation) of electricity at a particular time, called load and measured in kilowatts (kW). The peak power occurs when this load is at a maximum. For a particular electricity user, the load can vary minute by minute, and for a domestic user can reach 10-15 kW (for instance, when a power shower is being used). However, because there is usually diversity between neighbouring customers as to the timing of their peak power, what is of interest for network planning purposes is the average load over a longer period, say 10-30 minutes. And because electricity suppliers' customers form an even larger and more diverse group, half hourly averages are sufficient to meet suppliers' needs (and is the basis for wholesale electricity payment settlement).

In the CLNR project, we used smart meters to provide half-hourly consumption readings. From these readings, we could calculate electricity consumed over various periods and the average load for any half hour. For the avoidance of doubt, where we refer to peak power demand in this report, we mean the average peak power in the half hour with the highest overall consumption (measured in kW and numerically equal to twice the consumption measured in kWh in that half hour).

The total span of the data capture period for the whole range of trials was from 1 May 2011 to 30 June 2014. Over that period customer numbers fluctuated due to circumstances such as customers dropping out of trials over time. Certain test cells started earlier than others, dependant on the complexity of recruitment and installation. The test cells monitored also finished in four distinct tranches: end of December 2013, end of March 2014, end of May 2014 and end of June 2014. In order to align sensibly the data for research purposes and to maintain statistical robustness we selected for each test cell the data that provides the optimum mix of customer numbers and trial duration.

For the majority of the trials, monitoring comprised whole house net consumption half-hourly meter reads throughout 24 hours for every day. For the enhanced profiling trials, ten minute whole house meter reads were taken throughout 24 hours for every day. In addition, ten minute meter reads throughout 24 hours for every day of the consumption/output of the specific LCT or smart appliance.

6.2. Statistical analysis carried out

To generate results from the raw meter data, a small number of variables were used, which measure various characteristics that are relevant to network operators and generators:

- Absolute energy consumption: how much energy has been consumed over a given period of time (measured in kWh);
- Peak power demand: the maximum power that was demanded by a customer or group of customers within a specified time frame (measured in kW and reported with the period and

time this peak occurred). Note that this figure is derived from half-hourly or ten-minute meter readings and so is not the instantaneous peak power demand. Rather it relates to the half-hour/ten minute period within the specified time frame when consumption/output is highest and constitutes an average of the power demand over that half-hour/ ten minute period).

- Variation in energy consumption: this measures the variability of customers' consumption patterns between the different socio demographic subgroups and within the same subgroup. The results describe how homogenous a group is in terms of its energy consumption.
- Variation in peak power demand: this measures how varied the peak demand is from a group of customers (and how much diversity or correlation there is between the timing or amount of peak demand from a group of customers). This supports network planning purposes in order to compute the overall peak demand from a set of customers and therefore how much network capacity is required.

These measurements were made against varying time frames, namely annual consumption, monthly demands by weekday and weekend for various demographics. In addition, in relation to peak demand, a number of averages were derived: average individual consumption over the peak period, average peak power demand over a period such as a week or a month. These averages are important because the monitoring has demonstrated that individual peak power demand varies by time within a day and between days and different measurements are relevant to the needs of different electricity industry sectors.

The project also explored the correlation between peak demand and annual consumption and carried out clustering analysis of trial participants according to demand profiles, which enables studying groups of customers that exhibit similar behaviour.

7. Basic profiling of domestic smart meter customers (no LCTs, no interventions)

This trial used consumption data from around 9,000 British Gas domestic customers with smart meters, from both within and outside of the Northern Powergrid region. The split is approximately 50% within Northern Powergrid's region (broadly the area from the Scottish border to Sheffield, between the Pennines and the North Sea) and 50% national. All smart meter data was collected as half-hourly electrical energy consumption in kWh and then converted to average half-hourly power in kW for analysis. The monitoring period was over two full years from 1 May 2011 to 30 April 2013.

The statistical approaches considered the CLNR socio-demographic groups and the Mosaic socio-demographic groups separately. The basic analysis involved applying the four key statistics (see section 6.2) to each of the demographic groups. By comparing these statistics across groups, it was possible to compare electrical energy consumption patterns. All aspects of the analysis had sufficient customer numbers to satisfy sensible confidence intervals, apart from rural off gas customers in the CLNR demographics.

The summary statistics used throughout the report were means and standard deviations for the annual and monthly electrical energy consumption as well as peak daily and peak annual demands. Overall, the analysis revealed a relatively consistent average demand profile across the different demographic groups, with much higher variability within groups than between them. This high variability is seen both in total consumption and in peak demand. The standard deviation across all groupings (both internally defined and the Mosaic social groupings) is roughly half the mean value for each group. This variation is seen not only within customer groups, but also within the year for individual customers.

The dataset displayed some expected behaviour:

- The daily energy use profile is broadly divided into night/early morning (low demand), daytime (mid-level demand) and evening (higher demand).
- In the winter months, overall consumption and average daily peak demand are higher than in other seasons. Also in winter there is a greater variability in energy use between customers.
- Most households have their peak daily demand during the 4-8pm period. However, there is a significant minority of households across all demographic groups whose peak demand occurs earlier in the day, around midday.

However, the demographic analysis and the large number of detailed monitoring profiles provided a range of important new insights.

The link between customer consumption and demographics is primarily, but then only weakly, driven by income. Most customer groups consume on average about 3500 kWh during the year, with a range of roughly 200 kWh either side of that value. Notable exceptions here are the high income group (ca 4100 kWh) and rural off gas (ca 5300 kWh). Further, the low income group (ca 3000 kWh) and renter group (ca 3200 kWh) are outliers to this picture.

A similar pattern is also observed in the peak demand for these customer groups. The next major factor appears to be house energy efficiency. There is even less variance in the mean peak demand across groups, with the exception of rural off gas group. On the other hand, the maximum peak demand follows the annual consumption pattern more closely.

In terms of seasonal variation, as might be expected, there is higher electricity demand in winter when it occurs earlier in the evening. On the four days of greatest network stress, the average peak demand was 0.9 kW over the hour 5pm to 6pm. Electricity demand was broadly the same at peak hours whether it is on a weekday or at the weekend. However, 'rural off-gas' and 'high income' customer sub-groups' average peak demand could exceed 1 kW at network peak in winter.

Network implications

DNOs need reliable information about domestic consumer load profiles for system planning. The current ACE49 standards are based on data which is over 30 years old. These findings have been used to propose possible revisions to ACE49. This is covered in the optimal solutions for smarter distribution systems report[31].

The link between electricity use and income merits further investigation, as does the link with house energy efficiency. It could have implications for network planning if it implied a need for a higher ADMD in more prosperous geographical areas.

Since maximum peak demand is well correlated with annual consumption, applying network charges on a per unit basis (as at present) is a good proxy for the burden placed on the network by a domestic customer.

The support the research has provided to the need to concentrate on energy practices rather than attitudes or demographics should help DNOs frame the way they should invite customers to participate in demand side measures.

[31] CLNR-L248: Optimal solutions for smarter distribution systems

8. Enhanced profiling

8.1. Enhanced profiling of domestic smart meter customers (No LCTs, no interventions)

This trial provided enhanced monitoring of individual disaggregated loads at 10-minute intervals, for a group of domestic customers. The dataset covers a monitoring period of 17 months from December 2012 to April 2014 with a total of around 81 customers[32]. The domestic loads monitored included: lighting, consumer electronics, the cooker, kitchen appliances, washing appliances and refrigeration.

Because of the intrusive nature of the monitoring, participants were recruited from among the staff of the trial partners and friends, and the participants may therefore not be representative of the wider population as a result of their relationship to the energy industry and the trials. However, there is no obvious incentive for the households that we observed to alter their consumption behaviour, so while these households may be different from the UK average, the data should be a reasonably accurate reflection of their typical consumption patterns.

In order to gather the data required, circuit monitoring was installed for all circuits at the consumer unit, as well as for the household as a whole. This was supplemented by the use of up to seven smart plugs on specified appliances. No change was made to customers' existing tariffs.

It is worth noting that the results presented below are average results over the cohort. Individual consumption profiles can and do vary significantly between households and, even within a single household, consumption may not observe a constant pattern. Indeed, the analysis from our surveys has already shown that a household's consumption between 4-8pm can, on any one day, differ from its annual average by up to 50%.

Average annual consumption among the group in the trial was 4,192 kWh, between Ofgem's representative medium (3,200 kWh) and high (4,900 kWh) consumption figures. Figure 3 below shows the average daily profile from this data, disaggregated by appliance type for the peak weekday in 2014 for which sufficient data on the appliance types is available. This indicates a pronounced early evening peak. About half of this consumption was not attributable to the devices that were monitored. The unattributable consumption was larger during the colder winter months and exhibits strong seasonal variation. We understand from surveys of these customers that some used portable electric heaters in the winter that were not monitored, and this could account in part for this pattern. More work is needed to explore this consumption and the reasons for its seasonal variation.

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[32] The sample size varies by time and by monitored appliance – this figure relates to the maximum number of usable observations for a day within the whole house dataset.

	Annual consumption	Share of household demand	
	kWh	peak	baseload
Lighting	225	7.6%	5.4%
Cooker	317	13.8%	7.6%
Kitchen appliances	161	2.9%	3.8%
Refrigeration	427	4.9%	10.2%
Washing appliances	423	12.3%	10.1%
Consumer electronics	470	7.2%	11.2%
General	2,170	-	-
Total household	4,192	100%	100%

Table 2: Electricity consumption by appliance type on a peak weekday

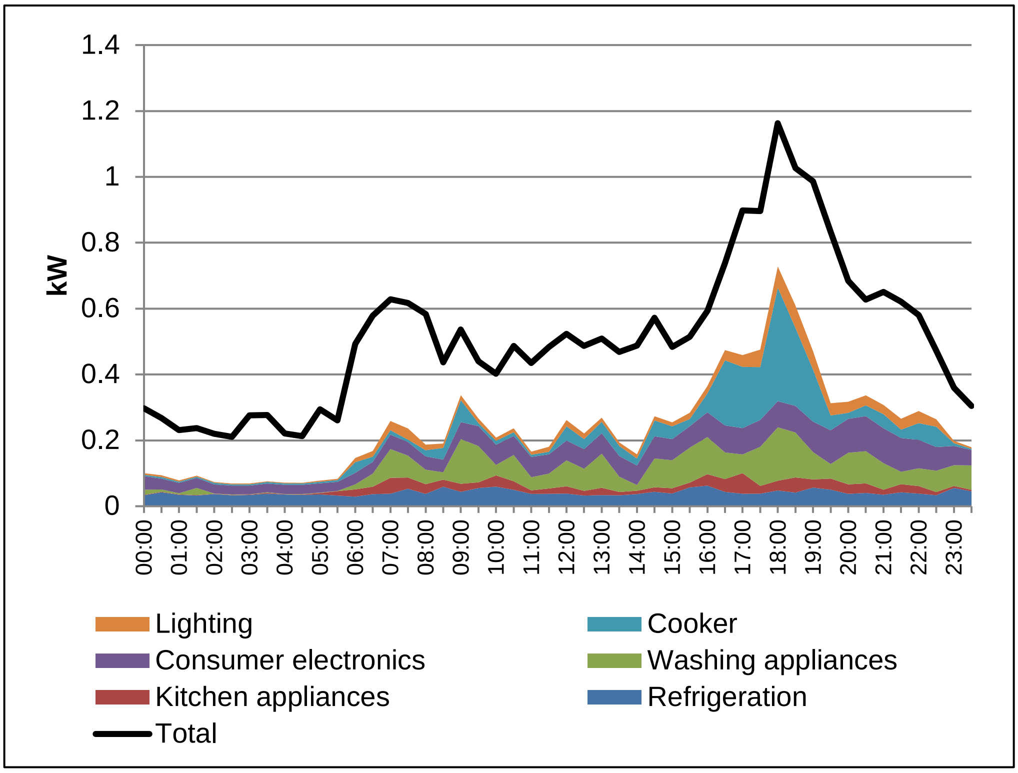

Figure 3: Electricity consumption by appliance type on a peak weekday

Where analogous consumption groupings exist in both sets of data, we have compared the data from this trial with equivalent summary data from the Household Electricity Survey (HES). HES monitored appliance level consumption data in 250 owner-occupied households across England from 2010 to 2011[33] and, at the time, was the most detailed monitoring of electricity use conducted in the UK. As such, it represents an appropriate point of comparison for the appliance level monitoring conducted as part of this test cell.

[33] Note that most households within the study were only monitored for a month, after which monitoring equipment was moved to another household

The patterns of consumption we observed for monitored appliances tend broadly to match those from HES. There is, however, a discrepancy in lighting demand, with HES consumption profiles exhibiting a far larger spike in lighting demand in the evening relative to our data. This may reflect the absence of lamps plugged into sockets in our data. There have also been changes to the efficiency of lighting since the HES survey was undertaken in 2010 as a result of phasing out of incandescent bulbs. Moreover, HES had only around 20% of consumption unattributed.

For **lighting,** we found that consumption is significantly larger in winter and autumn than during the summer; however this increase in demand seems only to affect the peaks (intuitively, when it is dark). Winter demand also ramps up earlier in the day as it gets dark earlier. The morning peak during winter is markedly different between workdays and weekends. Whereas half-hourly average demand exceeds 60 W on weekday mornings, it barely gets above 30 W on the weekend. This may be the result of people opting to start their days later on the weekends during the dark winter months, and more variation in the timing of morning routines across households. Lighting has limited scope for use in DSR, and further efficiency improvements are likely to prove far more effective in lowering peak demand, although motion sensors and timers could assist.

The load profiles for **cooking** display a significant variation between weekdays and weekends. On weekdays, there is a substantial evening peak at approximately 6pm, with comparatively little activity throughout the rest of the day – this is consistent with a large proportion of the sampled households being at work during the day, and preparing dinner during the evening. Load profiles on Saturday have a similar evening peak, but also exhibit a lunchtime peak (just over half the size of the evening peak). The lunchtime peak is higher on a Sunday, while the evening peak moves back closer to 5pm. This may reflect cultural traditions, such as the preparation of a roast dinner. There is also a seasonal trend: in general, cooker loads are lower during warmer seasons. There is limited seasonal variation across the use of kitchen appliances, although high summer use is notably lower. Since cooking amounts for about 20% of peak load, even a modest demand side response would be useful.

Space heating is potentially a highly movable source of demand. Use of storage heaters is dealt with in sections 8.2 and 8.3 below, but evidence from the HES survey (albeit on a small sample size) was that, on the coldest day in 2010, the 24 homes within the HES study that supplemented their gas or oil main heating system with electric heating used an average of 570 W for back-up heating during the peak hour, making up 84% of their electricity consumption at the time. The potential to substitute between multiple heating systems represents a potential source of demand side flexibility within such households. There is however an insufficient sample size of electric space heating in our data to carry out a robust analysis of load profiles for houses with electric space heating on standard tariffs, but this area could merit further study.

Refrigeration demand is extremely stable over the time frames measured. The frequent cycle of individual units results in a steady average base load demand for power. There is a slight, but noticeable increase in the evening, probably associated with opening of the unit's door for dinner. Although there is little variation among days, there is pronounced seasonal change, almost certainly driven by changes in the ambient temperature. As a result, refrigeration demand is consistently higher in the summer than in the winter or spring. Although refrigeration loads are not especially high during peak hours, the potential for time-shifting the load means that that could be 'partially switchable'. However, our survey analysis indicates that households generally do not envisige any scope for changes in refrigeration behaviour owing to the perceived risk to food safety. As a result, any demand side response from refrigeration appliances would be especially reliant on automation to provide households with confidence that any changes in consumption are kept within safe bounds. There are also a number of technical challenges that limit refrigeration's ability to play a more significant role in demand response. The need to maintain a reasonably tight temperature range makes it unlikely that demand could be safely deferred for a whole hour. The scope for delay is similarly restricted by opening of the door, which often occurs during the evening peak owing to the timing of meals. And, given the relatively short time spans over which it is possible to safely defer demand, it will also be more challenging to stagger the return of refrigeration demand such that it does not result in sudden demand changes at the end of the formal peak.

Water heating is among the most switchable of consumption categories where households have hot-water cylinders, as opposed to on-demand heating, particularly where water is heated electrically. The cylinders provide an existing thermal heat store and, provided the cylinder is suitably large and well insulated, allow hot water use to be separated from the associated electrical load. However, there has been a trend decline in the number of hot water tanks as older gas boilers have been replaced by more efficient combination boilers. Between 1995 and 2009, the number of dwellings in England with hot water cylinders fell from 16.7m to 12.5m[34]. If electric heating of hot water becomes more prevalent in future, the stock of cylinders might grow. However, space constraints may mean that the cylinders are too small to fully separate the timing of hot water use and demand for electricity, resulting in more peaky hot water profiles. There is an insufficient sample size of hot water heaters in our data to carry out a robust analysis of load profiles for houses with electric water heating on standard tariffs.

Washing appliance use varies significantly between weekdays and weekends, as well as across seasons. Weekday demand rarely exceeds an average of 100 W, but exhibits a post-work peak, presumably as people activate washing machines after having returned home. Weekend demand is significantly larger reaching 180 W in spring and winter and is more evenly spread across waking hours. Night-time demand is very low on all days, suggesting that few if any households use a time delay to run these appliances during the night. High summer demand is markedly lower than demand during the colder months. Washing appliances are potentially among the most flexible of sources of demand. Our own surveys and interviews indicated that households exhibited some flexibility as to the precise timing of use. This willingness to be flexible is not helped by equipment design. Only 31% of UK households have a start delay function on their washing machine, and about 32% of dishwashers have a similar feature. These figures are low relative to some other European countries, for example France, where the equivalent figures are around 40% and more than 50% respectively[35]. A more significant barrier is likely to be safety concerns associated with running these appliances unattended. In particular, public safety organisations like the Chief Fire Officers Association advise against running these appliances while asleep or absent, given the risk of fire.

[34] Sustainability First, What demand side services could household customers offer?, p.20

[35] Sustainability First, What demand side services could household customers offer?, pp.26-27

Consumption from **consumer electronics** shows an evening peak, which builds through the afternoon and falls away sharply in the late evening. This evening peak is pronounced on weekdays, presumably because work patterns prevent earlier use, but is also clearly visible on weekends, when the peak builds more gradually throughout the day. The profiles also exhibit some seasonal variation, with markedly lower peak consumption in the high summer, and to a lesser extent the summer. Our survey findings show that the number of consumer electronics used in the home is growing, but that many of these new devices, such as laptops, smartphones, and tablets, are inherently flexible. These findings suggest that consumer electronics will become an increasingly important component of household electricity consumption. If these new devices are designed to be portable, and so have in-built batteries, they may also bring new options for households to shift their load.

Network implications

Of the appliances monitored, washing machines and dishwashers offer the greatest flexibility in terms of time of use and our surveys suggest customers are prepared to be flexible. We had limited data on direct electrical heating and electrical water heating but these would merit further investigation into their potential for demand side response as would the half of electricity consumption that was unattributed. It is worth noting that we looked for but could not find homes with on-peak electrical heating to take part in the trials. The findings suggest that other options worth exploring include efficiency of primary and secondary lighting, and upgrading gas boilers to reduce the need for direct electrical heating.

The conclusion from the social science research that energy practices are important in understanding energy behaviour emphasises the need to gain a good understanding of their use of particular appliances if customers' behaviour is to be influenced. This will need closer interactions between DNOs, suppliers and appliance manufacturers.

8.2. Enhanced profiling of domestic smart meter customers (electrically heated hot water and/or storage heaters on a restricted hours tariff)

This trial involved enhanced monitoring of customers with electrical immersion hot water heating or with immersion hot water heating and storage heaters and an existing Economy 7/10 tariff. To gather the data required, in-line monitors were installed on both the immersion heater and the boost facility. Consumption data was recorded every ten minutes. A hot water sensor and temperature strings (5 sensors) were also installed to provide constant data on tank temperatures. Data was only available for 4 properties with immersion heaters alone and 13 properties with storage heaters (of which only 8 had immersion heaters). As a result, the average profiles presented here will not be representative of the UK E7/E10 population as a whole. Instead, they should be interpreted as case studies, which can provide insights into the types of behaviour that individual consumers may exhibit.

Although specific data is not held on which tariff each specific customer was on, the average power consumption profiles broadly matched the profile of an E7 or E10 tariff. This is consistent with customers on these tariffs responding to the price incentives they provide. However, there were two exceptions. The average data for immersion heaters alone showed a peak at 8am, both during weekdays and at weekends. This may reflect a customer routine or an appliance setting. Second, both the hot water and storage heater profiles for properties that had both showed some power usage immediately after the morning off-peak periods have finished. It may be that this is the result of misconfigured appliances or meters. Storage heater use on all days was confined to the off-peak periods, probably reflecting appliance and/or meter settings.

Network implications

Storage heaters combined with Economy7/10 tariffs continues to be an effective means of reducing demand at peak times.

8.3. Enhanced profiling of domestic customers with air source heat pumps

This trial comprised 344 domestic customers with air source heat pumps. Out of these, 89 customers had sufficient quality heat pump data readings available over the one year period to be included in the analysis. There were a number of challenges recruiting customers for this test cell, but despite these challenges, this trial represented the largest UK trial with air source heat pumps to date.

Heat pump consumption represented a significant additional electrical load compared to the rest of the house. The annual heat pump electricity consumption, averaged across all customers was 82% of the average annual household consumption in the baseline group with smart meters but not heat pumps (2880 kWh for the heat pump alone compared with 3,498 kWh). This corresponded to an average annual load factor on the heat pump of approximately 9%-11%.

In the winter season, when household electricity demands were already high, the heat pump consumption was also the highest (both absolute and relative to the house consumption) due to the higher space heating demand. The trial results show that the average heat pump electricity consumption across customers in January was equivalent to 122% of the average baseline household consumption in January (13.96 kWh per day for the heat pump alone compared with 11.46 kWh per day).

Both household demand and heat pump demand are often highest in the winter evening peak period (4pm-8pm). For the evening peak period, averaged across customers for the month of January, the heat pump average electricity consumption is 102% of the average baseline household electricity consumption (3.17 kWh per day in the peak period for heat pumps compared to 3.11 kWh per day). Hence the overall effect of the heat pump is to roughly double electricity demand at the times when the electricity network is already likely to be experiencing high levels of demand.

The heating season half-hourly heat pump consumption profiles, averaged across customers and across each month, showed distinct morning (6am – 9am) and evening (4pm – 8pm) peak demands. These periods broadly coincided with the peak periods in house electricity consumption, as both are driven either by an increase in heating demand or appliance usage as people get up in the morning and arrive back home in the evening. For high or clustered uptake of heat pumps, this has implications especially for winter evening peak periods, when electricity demand is already highest. This impact could be reduced by using hybridised (gas and electricity fuelled) heat pumps or heat storage (which would have the effect of reducing the peaks).

In addition to the morning and evening peak period, the heat pumps in this trial showed a distinct peak in consumption around 3am. This is due to default timer settings for hot water heating. This is not inherent to heat pump operation and can be resolved by diversifying hot water charging times in the default settings of each heat pump.

The trial results show that the heat pump demand, averaged across customers, increases much more quickly in the morning peak period compared to the evening peak period. With large or clustered uptake of heat pumps, this impact network operation. It is often the case that load diversity is lower for appliances that are controlled by timers. Addressing this requires introducing other means of diversity (such as thermal storage, or automated randomisation).

The monitoring in this trial also included household electricity consumption. Although the consumption patterns were relatively similar to typical house profiles, the overall consumption level was significantly lower than the baseline average. This difference is to date unexplained, and hence caution should be taken with interpreting results from this data set.

The social science research indicates that participants may not always have made the best possible use of the heat pumps, and the research identified three key reasons for this:

- Customers found it difficult to understand the technology and how to operate it, both from a technical and an energy efficiency perspective.
- There were no clear incentives to operate the heat pump in a specific way.
- Customers were reluctant to “interfere” with the heat pump operation.

Take up of these new technologies could be supported by user friendly interfaces and a single point of contact for any issues with the appliance.

Despite recruitment incentives– shopping vouchers, free broadband and subsidy of the heat pump to make the cost comparable to a boiler - recruitment for this trial was particularly challenging. The changing regulatory framework (such as delays to the residential Renewable Heat Incentive) meant that market uptake of heat pumps has been lower than anticipated. The social housing sector constituted a substantial proportion of participants due to additional funding available for social housing providers.

Of the population surveyed in this group, most were RSL tenants (51%) or council tenants (42%). 88% had a member of the household not in employment, education or training (NEET), half were over 66 years old, and just over half were female. Half have one occupant and 27% have two occupants in the house.

The thermostat for the heat pump system was most commonly set to 20-21 °C, but some people have their system set to very high or very low temperatures. Younger participants used higher set-points. 20% did not know their set-point. 33% said they kept their set-point the same as their previous heating system; 32% changed to a lower set-point. Participants with someone NEET were more likely to change to a higher set-point. Half of respondents have heated more rooms since installing the heat pump. People over 65 years old and/or NEET were more likely to heat more rooms. Most felt that the heating was on less after the heat pump installation (44%).

Most participants were satisfied or very satisfied (76%) with the heat pumps, but some were dissatisfied or very dissatisfied (15%). Participants were mostly (66%) positive about the appearance of the pumps. 38% understood the new system as well as the old one, although 36 % did not understand it as well or at all. Most people were confident using the control panel.

The experience of changing system was broadly positive (63 %). 12.5% were dissatisfied.

The findings indicated that the history and installation of the heat pumps were critical to success. Heat pumps had a potential to improve heat services while reducing bills. Trial participants appreciated the quality of the heat and hot water provided and its use as a source of drying clothes as well as providing comfort. Concerns included whether running the system all day was most cost efficient and the perceived complexity of the technology (fearing their interventions would cause the system to break down).

Network implications

As a heat pump load represent a near doubling of total household consumption, widespread rollout of the technology would present significant challenges to electricity systems. Technology solutions such as hybrid heat pumps or heat storage could reduce the impact, but future research is needed to understand technical feasibility, environmental performance and consumer acceptance. In the case of widespread heat pump deployment, steps may need to be taken to introduce diversity into heat pump operation, in particular the morning pick-up in demand.

The 3am spike is an important learning point. This is clearly a product-specific occurrence with heat pumps programmed to come on at that time (perhaps as part of a defrost cycle). The message for manufacturers, regulators and legislators is that it would be better to build diversity into the appliances e.g. by a random defrost time between 2am and 4am.

8.4. Enhanced profiling of domestic customers with micro-CHP

The micro-CHP trial[36] investigated the enhanced profiling of domestic customers with a Baxi Ecogen Stirling engine (maximum heat output 6 kW, maximum electrical output 1 kW, an overall efficiency of 90%) installed. In each location, we monitored the electrical demand from and generation produced by the micro-CHP engine and the amount of electricity imported (or exported) from the grid by the house as a whole. Both were measured in average watts per measured interval, with measurements taken every minute. Trial monitoring began in December 2012 and ended in March 2014.

The micro-CHP generation profile has a high morning peak, and a lower, but longer evening peak, with the summer peaks being lower than the winter ones. The main effect of the use of the micro-CHP units was to reduce the average evening electricity demand peak by a few hundred watts in winter. The micro-CHP also generated electricity for export in the winter mornings, as heat demand drives micro-CHP export before morning electricity demand starts to rise.

This group was small in number, but exhibited a wide variation in electricity demand at peak from import of 2.5 kW to some trial participants exporting throughout the day.

Network implications

If micro-CHP plants become popular, the reduction in household load at peak could be significant for both network planning and electricity generation costs. The morning export peak could also impact on voltage levels. There would be benefit in a wider trial to establish more robust conclusions.

[36] CLNR-L086: Report on enhanced profiling of domestic customers with Micro-CHP

8.5. Enhanced profiling of domestic customers with solar photovoltaic (PV)

Within this trial the maximum monitored customers was 145, recorded in January 2013. The window of monitoring within the dataset was the full 12 months of 2013. During the year, customer numbers reduced marginally to 133 monitored customers by December 2013.

On the day of peak export, participants in this trial group on average exported 1.3 kW at 12 noon. Export occurred in the six months April to September 2013, with July being the month of peak export. Compared with trial participants with a smart meter but no PV, the following differences were statistically significant:

- Average annual gross electricity consumption was 700 kWh higher (4216 kWh as against 3507 kWh) and was significantly higher in nearly every month (but less so at weekends)
- Electricity consumption during the day was higher (at 30% compared with 27%)
- Average and maximum peak demand was higher (1.5 kW and 4.9 kW as against 1.2 kW and 4.2 kW, respectively) with the difference focused more in the summer months

In the absence of demographic comparisons, it is not clear whether the cause of higher consumption is the presence of PV or the presence of a higher income.

The results from the surveys and interviews indicated that, in general, PV ownership seemed to lead customers to more active ways of relating to energy. Individuals involved engage in the calculation of their own energy use and production, as well as in monitoring and managing their use. For early adopters, the uptake and use of PV is being shaped by a new convention focused on investment and the potential financial returns from the feed-in tariff. On-site use of power was not widely recognised as a way to maximise financial benefits for PV owners.

Interviews conducted with 10 participants suggested that the introduction of the in-home display created a shift in focus from export to using power when it is being generated. This creates an opportunity for network operators to engage with consumers to identify the potential and value of using PV power on site and attenuate the flow of PV generated power into low voltage networks.

Network implications

Despite the keenness of participants to use their domestically generated electricity, substantial exports of electricity took place with a peak around midday and therefore the potential to create voltage issues for networks. A technical paper has been produced on the diversity impact of PV, which concluded that the output of solar photovoltaic installations does diversify, because the panels point in different directions, and therefore produce their peak output at different times of day[37].

The monitoring results suggest that the existence of PV panels is associated with higher peak electricity demand and this may be relevant for network planning.

[37] CLNR- L095: Technical note: solar PV Installations

8.6. Enhanced profiling of domestic customers with electric vehicles (EV)

159 EV-driving customers' household and electric vehicle charging demand were monitored in a joint partnership between CLNR and Charge Your Car (North) Ltd (CYC) as well as via direct recruitment by British Gas. CYC operates residential and public charging infrastructure provision in the North East of England, and recruited some of its residential charger customers to take part in the monitoring programme. The number of monitoring records was reduced somewhat because of metering failure, withdrawal from the trial and during analysis.

Household monitoring started on 06/12/2013, with significant numbers of customers (100+) being monitored from June 2013 onwards. Data collection from residential chargers started on 30/11/2012, with significant (100+) availability of charging data from late January 2014. Data analysed in this report ran up to early July 2014 for both EV charger and household demand data. The limited availability of EV charging data relative to household demand data constrains most of the analysis to the period January-June 2014, and this limitation must be taken into account in understanding the findings. 108 participants were drawn from employees, or friends and family of employees, of Nissan Motor Manufacturing (UK) Ltd, in Sunderland. These drivers drove a Nissan Leaf as part of a company car scheme, and were able to charge at work. This sample bias must be borne in mind. However, these customers (generally working families, singles or couples) are assumed to be fairly representative of likely current and future EV owners.

Data from the trials were received as half-hourly kWh measurements from EV chargers, and as half-hourly average kW measurements from household metering. The household metering included all household demand except for the EV charger. The chargers were all 3.8 kW.

Amongst these participants, household electricity demand (exclusive of EV charging) was broadly comparable to typical households, perhaps with a rather higher proportion of peak to off-peak usage. The levels of average EV charger load (i.e. for each time period averaged across the data from the available participants) shows that at-home charging diversifies rapidly: i.e. the days and precise times on which participants charged their cars were fairly random (supported by the size of the standard deviations of the results). Overall, charging tended to peak at around 8pm on weekdays with less charging during the day. Average peak charger demand on a weekday was around 0.9 kW in January compared with less than 0.4 kW in June (probably reflecting the extra charging associated with a car heater). Charging at weekends was less in total and less concentrated in the evening.

- The average daily energy consumption for an EV was 7.9 kWh in January 2014, which was the peak month. This steadily reduced down to 5.2 kWh by June 2014.
- 96% of online survey respondents had a Nissan EV. 59% used their EV as a secondary car as against 36% using it as their primary car. EVs mainly came from an employer (67%) or were leased (31%).
- Some respondents would be interested in changing supplier to take advantage of cheaper /greener tariffs for charging the EV (57%).
- Charging was mostly done at night (61%) or when needed (14%) – when the battery is less than half full (39%) or less than a quarter full (27%). Open-ended answers suggested respondents charge regularly e.g. daily, when finished using it, or when near a charger. 86%

did not use timers; those who used timers did so to take advantage of off-peak electricity rates. Our interviews highlighted the importance of: seasonality (heating in winter), range anxiety / access to charging points, need to plan more. Cost and novelty came up more frequently as motivations than environmental concerns.

Positive experiences were low running cost, novelty, driving experience and quietness. Negative experiences were range anxiety, availability of public charge points, cold weather driving, and battery life. EV typically owned by a working couple and used as a week-time car (work, daily commutes, school runs).

Network implications

These results show that domestic charging of EVs has raised the level of domestic peak demand but is not yet a problem for network system design and operation. But with greater concentration or if there were 2 EVs at a household, this would no longer be true. Furthermore, diversity could well be lower at particular times, e.g. pre-charging before bank holiday weekend. However, EV users are already establishing habits to charge their car when it suits them and this may be difficult to break even with appropriate ToU tariffs. There is therefore a strong case for taking appropriate action to encourage off-peak charging behaviour at an early stage. At the time of recruitment to our project, there were insufficient EV users available for us to be able to test this proposition. Further work is needed to investigate ways of doing this.

In addition to the conclusions from the monitoring results above, the partnership with Charge Your Car led to a unique collaboration involving Newcastle University[38] and EV charging data from the Switch EV project, which explored domestic charging habits in rural and urban locations and their different impacts on the distribution network, which suggested that the impact on the network would be felt first in rural locations.

[38] CLNR-L038: Integrating Smart Meter and Electric Vehicle Charging Data to Predict Distribution Network Impacts

9. Domestic customers with demand-side interventions

9.1. Domestic smart meter customers on time of use tariffs

628 British Gas customers in Northern Powergrid's operating region transferred to the tariff during 2012 and agreed to be monitored through conventional smart metering at 30 minute intervals.

Overall, comparing trial participants on the ToU tariff with smart meter customers in the control cell over the period from October 2012 to September 2013, we made several statistically significant findings:

- The *average peak power demand* during the 4 - 8 pm period (i.e. the average across the year for each customer of the highest half-hour demand each day within this time period) was lower on average, by 96 W (from 1.219 kW to 1.123 kW). When analysed by month, the difference in average peak power demand was statistically significant from November 2012 to March 2013 but not for other months
- The annual *maximum peak* during the 4-8pm period (i.e. the highest half-hour recorded on any day of the year for each customer) was lower on average by 261 W (from 4.188 kW to 3.927 kW). Again, the difference is focused more on weekdays and in the winter months.
- There was no statistically significant new increase in demand in either the period preceding or the period following the peak period on an annual basis, although there is scope for further analysis of the monthly data for the 2-4 pm period[39].
- *Annual energy consumption during the peak period* was lower by 55 kWh (from 861.6 kWh to 806.6 kWh), with the difference focused on weekdays. However, there was no statistically significant difference in *total annual electricity consumption* (on average, about 3500 kWh) between the two groups, despite the survey finding that three quarters of those ToU participants responding considered that they had made a slight or significant reduction[40].
- There was no statistically significant difference between the two groups in average peak demand at the half hour of highest aggregate demand.
- Testing of demographic differences to the ToU tariff was limited to housing tenure (renter/home owner) and the presence of dependents in the household. Home owners and households without dependents were more likely to respond to the ToU tariff than renters and those with dependents.

Trial participants were told at the outset they would not lose money from the use of ToU tariffs. It is not clear what effect this had on behaviour. For the trial participants analysed, there was no feedback to participants on whether they were saving or losing money under the ToU tariff until the end of the trial. Some 40% of participants would have ended up with electricity bills higher than

[39] The previously announced discovery of a reduction in load during the peak period accompanied by a new peak after 8 pm came from a small initial sample comparing behaviour before and after introduction of the ToU tariff.

[40] Note that this compared smart meter users with a ToU tariff with those with a smart meter alone. It could not therefore take account of the change the installation of a smart meter would have.

under a flat-rate (had they not been guaranteed that they would not lose money). Because an average customer making no changes to their behaviour would have neither gained nor lost from the ToU tariff, those who would have lost money were those whose monitored usage had a higher than average proportion at peak times. They may or may not have changed their behaviour in response to the trial.

The majority of people surveyed said they changed the timing of appliance use in response to the ToU tariff. Those who claimed to change electricity use in response to ToU tariffs tended to be older, home-owners or those renting from registered social landlords, without a NEET in the household, and/or a two person household. Most considered that they used less energy overall while on the ToU tariff. Laundry was identified by most respondents as an activity that they had moved to a different time. This was followed by washing dishes and cooking.

The vast majority felt the tariff was quite or very easy to understand. Those who found it quite difficult have a lower average age.

Commercial implications

- Participants in this trial were told that they were protected from an increase in electricity bills, which were capped at the level they would have been at under a flat-rate tariff. An enhanced level of response might be expected in a trial without a "safety net".
- As implemented, this ToU tariff rewarded a reduction in consumption during the peak period throughout the year - and was effective in doing so - but did not reduce demand at the times of greatest system peak demand. Alternative ToU tariffs, such as Critical Peak Pricing, might be tried as a way of reducing demand during these times[41].
- There was no difference in annual electricity consumption between ToU customers and trial participants with a smart meter alone. The trial was not designed to measure any impact from the installation of a smart meter itself.
- Identifying traditional socio-demographic groups for commercial propositions may not be appropriate. Instead, it may be most appropriate to focus on 'socio-technical' groups (e.g. customers with high income, large houses, and 2+ fridges) or different kinds of 'flexibility capital' (e.g. shift workers, those with dishwashers that can be programmed)
- Realising value for DNOs from customers may require interventions in specific geographical/network areas – our work has limited insight here.

Network implications

The difference in peak demand seen in this trial is unlikely to be significant enough in itself to help in network planning. However, ToU could be used as part of a solution or would help if imposed by

[41] Though our social science research suggests that this may not be the case, because the shifts come in change in routines/practices, and critical peak pricing if not done 'routinely' will not lead to this shift. Where CPP is used, e.g. around air-conditioning, it has become habitual because it is used so often.

another player e.g. energy supplier. But our advice is that a supplier would be unlikely at present to introduce a ToU tariff if there was no demand from a DNO.

9.2. Domestic customers on the smart washing machine restricted hours trial

The restricted hours trial tested customers' willingness to accept a default time-based restriction on the use of a specific appliance, and also the degree to which they exercised the over-ride that we provided. This combined the ToU tariff with an automated service that switched certain appliances (smart washing machines or smart heat pumps) off during the four hour peak period from 4pm to 8 pm on weekdays, with technology provided to allow customers to override this automated service when they wished.

Trial participants participating in this part of the trial and receiving a smart washing machine could set it to turn off automatically as peak time began, turn on automatically at the most economical time, or choose the most convenient time themselves. The trial participant could chose to pause the cycle or disable the energy control mode at any time without penalty.

The main findings were that:

- 43 customers chose never to engage the energy control, compared with 23 who used it at least once.
- Overall, the level of engagement on weekdays was 10%
- Customers that were classified as engaging showed near zero consumption at peak times
- Weekday restricted hours witnessed 10% of customers participating
- Weekend consumption gave similar patterns in terms of a lower level of appliance use between 4-8pm even though the cheaper tariff applied across the full 48 hour period
- Customers whose appliance status was in a engaged mode over the weekday saw an increase in load at the end of the peak period as washing machines started, but customers who had disengaged also saw an increase in demand at 8pm increase suggesting that customers may have altered their appliance usage habits without using the energy control
- Customers who engaged reduced their weekday consumption by 28% compared to those customers that disengaged
- For participating trial customers the 95th percentile exceeded 1.8kW immediately after the peak period

Customers perceived their new washing machines positively. In particular, the big drum meant fewer loads for some. It was more economical, the spin speed meant drier clothes, but there was a long washing cycle (3hrs).

Network implications

For those who had engaged the 'energy control', the trial successfully reduced load during the peak period. The peak that occurred following the end of the peak period could be reduced by the manufacturers including a randomisation element. The level of engagement was low and the reasons for this need further examination. If energy control buttons on washing machines become more prevalent, finding ways to encourage engagement could prove valuable in reducing peak load.

9.3. Domestic customers on the smart washing machine direct control trial

This trial involved 80 British Gas customers. Participants were offered a payment of £50-worth of vouchers on joining the trial, and a further £50-worth of vouchers at the end of the trial. They also received the smart washing machines that were the subject of the trial. These goods were worth approximately £1000 and were installed for free.

Under the terms of the direct control proposition, up to a maximum of 15 interruption events could be called in any one year, between 4pm – 8pm on weekdays. During the trial, 11 events were called between 11/3/14 and 31/3/14. Each of these events lasted for four hours, from 4pm – 8pm.

An average of 4% of customers who received the signal delayed the washing machine cycle, while a further 12% ran their machines during the DSR period. This is consistent with DSR having an effect on behaviour: on almost a third of occasions when the user attempted to start a cycle on the machine during a received DSR event, they delayed it.

This is likely to underestimate the effect of the DSR events, since it is possible that users avoided starting cycles during the peak times, without using the delay function. By comparing the average washing machine power usage of individuals receiving DSR events to days without DSR events, we find a statistically significant (at the 5% level) decrease in average power during the 4pm to 8pm peak window of 11 W (the decrease in average power used between the peak time of 6pm to 6:30pm is 26 W, although not statistically significant).

Due to communication failures, 37% of DSR events were not received by customers. This highlights the need for continuing technical developments to increase the effectiveness of this type of DSR. However, even including these customers, the fall in peak demand is almost statistically significant at the 5% level.

These results show that some consumers clearly do respond to events, although the small number of households interviewed asserted that there had been no change to their previous washing regimes. This discrepancy may reflect the fact that washing routines vary by household: households which (for example) routinely carried out washing on weekends would be unaffected by the DSR events.

Network implications

Given the small numbers involved in the trial, any conclusions must be treated with caution. Nevertheless, this trial is unique and ground-breaking. It has demonstrated the end to end process of a DNO successfully calling a response from a DSR supplier automatically using 'smart grid' systems and that direct control of appliances can reduce peak load, albeit not by much at present (partly due to the relative infrequency with which most households use a washing machine compared to other appliances such as heating). The technology is new and will improve. The small reduction in peak means that this intervention is unlikely to have much impact on distribution network planning. However, if the technology becomes more widespread (and particularly if mandated by product standards), this intervention could be of use for national system balancing.

9.4. Domestic customers with air source heat pumps on time of use tariffs

This trial included 17 customers but data recorded for the entire period, between 1st September 2013 and 1st May 2014, for only 7 customers. The data set has been published on the project web site but there is not sufficient data to provide a statistically valid comparison with the group with air source heat pumps on an unrestricted tariff.

9.5. Domestic customers with air source heat pumps on direct control trials

This trial comprised 17 domestic customers, including some non-British Gas and out of region customers. Participants received a DECC-subsidised ASHP installation, worth an average of £3,500, and a year's free broadband, worth £277. Because of the difficulty with finding suitable and willing participants despite a national trawl, some participants were recruited from among the staff of the trial partners, and the participants may not therefore be representative of the wider population as a result of their relationship to the energy industry and the trials. Given the small size of this trial, the high level of the subsidy received on joining and the fact that recruitment for this trial was not random, the learning that can be drawn from this test cell is largely qualitative in nature.

All participants were supplied with a 'smart grid capable' ASHP, which included integrated direct control functionality and ten-minute load monitoring. This was supplemented by additional heat meters and temperature sensors. A thermal store was also installed, to provide heat when the heat pump was switched off during 'direct control' mode.

Data collected in this trial suggests that heat pump electricity consumption has two distinct peaks – one of around 2 kW in the morning, and then a smaller one (1.5 kW) in the evening. This profile is different to the sample profiles published in DECC's heat pump trials, and may reflect a particular characteristic of the operation of these heat pumps with storage (for example, these may be the times when priority is given to charging the heat store).

14 interruptions were called over a 36 day period during the peak heating season in February and March 2014. The first four interruptions lasted half an hour. Thereafter the interruptions lasted an hour. Four events were called between 4pm and 4.59pm, two events were called between 5pm and 5.59pm and eight events were called between 6pm and 7pm. All interruptions were called on week days.

The equipment used for this trial would cancel the interruption if the consumer adjusted their thermostat during (or immediately before) the interruption. Consumers may have therefore inadvertently cancelled interruptions, and further research into the user interface for thermostats could be helpful to determine whether this was the case. Nevertheless, interruptions were successfully carried out the majority (67%) of the time. For those customers that did not cancel the interruption (during three interruptions occurring between 6pm and 7pm), electricity consumption fell close to zero during the time of the intervention (compared to around 1.5 kW on days without DSR events). However, there was a strong peak immediately at the end of the intervention, which is indicative of a quick "payback" for this form of DSR, based on the particular technology installed.

We carried out 21 semi-structured interviews with domestic customers but found that the negative experiences of overcoming a new technology made it impossible to explore their reaction to the interventions. Evidence from these interviews suggest that users found the heat pumps to be unreliable - reporting issues with hot water supply, an increase in energy bills due to technology malfunction (one person had a 66% increase in bills) and noise.

Network implications

The existence of peak loads in the morning and early evening on non-intervention days and the peak immediately following an intervention suggests a particular characteristic of the type of ASHP with thermal storage used. This characteristic, together with the mixed attitude of customers and the additional space requirement for the thermal store, limits the potential benefit of this intervention at present. Nevertheless, the trial has been ground-breaking, using innovative equipment, and clearly demonstrates the technical potential for this intervention. The size of the peak reduction makes it of interest to a DNO, but the utility of the intervention will depend on what cost the DNO would have to bear, and whether the large payback spikes can be mitigated.

9.6. Domestic solar PV customers with automatic in-premises balancing for hot water charging

We carried out trials of two separate solutions to load-balancing within the customers' premises. The first trial used hot water heating, engaged automatically without the need for user intervention. Unfortunately challenges with data quality with the equipment could not be resolved and reliable outputs could not be generated with the automatic balancing trial.

From our survey results, respondents reported small changes to timing of shower practices, but were more motivated to switch appliance use times than by hot water usage.

9.7. Domestic solar PV users using in-home displays for manual in-premises balancing

The second trial used an in-home display (IHD) to provide a visual stimulus that net exporting was occurring, so customers had an opportunity for load-balancing.

Compared with trial participants with a smart meter but no PV, the following results were statistically significant:

- Average annual gross electricity consumption was 1170 kWh higher (4674 kWh as against 3507 kWh) and was significantly higher in nearly every month (but less so at weekends)
- Electricity consumption during the day was higher (at 30% compared with 27%)
- Average and maximum peak demand was higher (1.6 kW and 4.9 kW as against 1.2 kW and 4.2 kW, respectively) with the difference focused more in the summer months

There was, however, no significant difference in any of these variables between trial participants with PV and manual in-premises balancing and those with PV alone.

In the survey and interviews, participants said that, through the use of the Traffic Light Display, they had made shifts in laundry and dishwashing. However, on the basis of the monitoring, manual in-premises balancing would be unlikely to make a significant contribution to DSR.

10. Small and medium-sized enterprises

10.1. Basic profiling of small and medium sized enterprise (SME) customers

This dataset provided half-hourly smart meter data in kW for a range of business customers. The published dataset covers a monitoring period of one full year from 1 September 2011 to 30 August 2012 with a total of 1,514 customers.

SME consumption per customer tends to be an order of magnitude higher than domestic consumption, making these energy users of particular importance for understanding both current and future demand. The demand profiles of individual SMEs also vary to a much greater extent than households. They are heterogeneous in terms of their business activities, and hence also in terms of their overall demand for power and the timing of that demand during the day. This heterogeneity presents particular problems when trying to extrapolate conclusions from the trials to the wider SME market.

For SMEs, the daily demand profile tends to be shaped differently to domestic consumers. Weekday demand is characterised by high demand during 9-5pm hours, with no early evening peak. The peak demand generally is spread across the standard working day of 8am to 5pm. Power demand is driven by the firm's specific business activity, which for many activities, may be relatively more constant throughout the working day. Weekend demand has a peak until early afternoon.

Many businesses consume less electricity per hour during the early evening peak than during the day or night. Smaller businesses tend to consume a higher proportion of their total electricity in the early evening peak. Larger businesses consume more evenly across the 24hr period.

There is some seasonal variation, but this is not as marked as for domestic premises. Seasonally electricity demand for SMEs is highest in January and February, whereas the peak for domestic occurs in December. It is highest for Commercial and Office Enterprises and lowest for those in the Public Sector & Other Industry classification. This means that the kind of businesses with the highest electricity demand could be those involved in the wholesale and retail trade, hotels and restaurants, transport, storage and communication, financial intermediation, real estate, renting and business activities, while the lowest consuming group included education, health and social work, other community, social and personal service activities.

The largest firms do not necessarily have the highest power demand. In terms of business size, organisations with 10-49 employees had proportionately the highest demand (more than those with 50-249), suggesting that the relationship between number of employees and electricity demand is not linear.

On the day of greatest network stress, the mean peak demand was 6.2kW between 10am and 2pm.

From the surveys and interviews, most SME trial participants think reducing energy use is important (72%), but most have no environmental policy or don't know whether they have one (90%). Some have sought professional energy advice (32%).

Some businesses operate 24 hrs a day (20%) and many are open at weekends. Most own their own premises (68%). Most do not have a Display Energy Certificate (72%). Most have central heating (69%). Half have programmable thermostats. Energy use is dominated by lighting, administration and office equipment, cooling and heating equipment. Some processes are re-schedulable but not interruptible. Some businesses have intermittent demand for high loads that could be flexible. Interconnectedness is seen as critical.

Many had installed at least one energy efficiency measure. Most popular were double-glazing (43%), loft insulation (28%) and cavity wall insulation (11%). Only two trial participants had installed micro-generation - solar panels.

Network implications

These findings are important in an area which has been little studied in the past and where data is poor. Because of the considerable variability in the SME community, the overall results themselves do not have implications for network planning or operation, but provide an important baseline. However, the fact that most SMEs do not contribute significantly to the evening peak is important. There could be value in targeting those that do have an evening peak.

10.2. Enhanced profiling of small and medium sized enterprise (SME) customers

This test cell monitored up to 80 British Gas customers all with smart meters. All participants already had a smart meter installed or were scheduled to do so. Data and technical information was provided at 10 minute intervals for the total meter load and the disaggregated for loads beyond the meter which accounted for over 50% of on-site consumption. The trial did not stipulate any changes to supply tariffs. The participants therefore remained on their existing tariff and were able to renew their contract during the course of the trial should this be required.

Detailed demand profiles were collected as part of this trial for a range of different appliances used by SMEs. We were interested in the following two questions for each appliance in relation to their potential for DSR:

- Does the demand profile suggest there sufficient demand in the peak hours currently to shift?
- Intuitively, (including based on past learning), could this load be interrupted and moved outside of the peak period?

The trial has produced detail demand profiles for 11 different technologies across six different SMEs. Therefore for some of the SMEs there is data for more than one appliance.

SME1 – heater

This heater is set to be on mostly between the hours of 5pm and 9am. This is indicative of a form of storage heating, which could have the potential to be set to run at different times. In particular, this heater is currently set to run during the network peak (4pm – 8pm). If this is a common feature of SME heating systems, there may be benefits available to DNOs if it is possible to delay the start time of these systems.

SME2 – air conditioning

Demand for air conditioning by this firm is a diurnal activity, concentrated between 8am and 8pm. Usage of the air conditioning, while present in the evening peak period, is often tapering down between 5pm and 8pm. The peak usage is focused on the weekend, suggesting the activity of this firm may relate to a leisure activity. The potential for weekday reductions in peak demand are still present but much reduced compared to the weekend. Demand is very weather dependent, so winter demand is considerably lower, and so air conditioning demand from this firm does not correlate well with winter system peaks, suggesting that this type of appliance is not a strong candidate for DSR. However there may still be value for managing summer peaks (for instance, in central London).

SME3 – chillers

Typical for a refrigeration load, the power cycles rapidly throughout the day, with greater demand between the hours of 7am and 8pm. Demand is therefore high throughout the evening peak suggesting there is some potential for load shifting. Intuitively demand should increase in warm weather, and this seems to be borne out in the data although it only has a small effect, with demand remaining high in each of the seasons. The firm had a consistent pattern of demand between weekdays and weekends suggesting it is operating seven days a week e.g. a retail business. In winter the average demand during the peak remains high with limited variability around the mean. This suggests there is some potential for load shifting if the chillers can be switched off earlier than currently is the case, without any adverse impact on the refrigerated products.

SME3 – shop floor fridges

The demand for power from the fridge units is volatile during the day as is typical for this type of load. There is greater demand between the hours of 6am and 9pm, likely to be consistent with the opening hours of the business. Demand is therefore high throughout the evening peak. The profiles do seem to be weather dependent to a small degree with the highest demand in the high summer period. The pattern of demand is consistent between weekdays and weekends. In winter the average demand during the peak remains high suggesting there is potential to shift demand for short periods of time provided the business can be assured of the refrigerated product quality being maintained.

SME3 –fridges walk in

The results are different to those of the chiller, and fridges on the shop floor, despite being from the same firm (perhaps suggesting that in this case the heat exchanger is external and operates at ambient temperature, while the others exhaust within the building). There is still considerable volatility as is expected for a fridge, but these fridges have their highest demand during the night. This suggests that they may be used for restocking of the retail business overnight, and are less likely to be accessed during the working day. Throughout the peak period therefore the potential for DSR is considerably less. Although this is a refrigeration technology it has a very different profile to other fridges used by the same SME. This suggests that there are a broader set of factors which also determine the degree of flexibility potential, beyond simply the appliance itself.

SME3 - lighting

The power demand does not vary to a large extent by day of the week or season. In one sense, the potential for DSR is high since demand is constant throughout the evening peak. This varies little during the winter period, as evidenced by the very small confidence interval around the mean, but the potential can only be realised if lighting can be reduced without impact on the retail experience for customers.

SMEs 4 and 5 both provided examples of an intermittent high power load (such as a welder or a table saw). There may be more potential for these 'high power' practices to be flexible and therefore amenable to DSR interventions. The loads are generally focused during working hours, and the variability of when they will be used is high. However, they also usually fall outside of the evening peak periods suggesting their usefulness for DSR may be limited.

SME6 - swimming pool

The pool is heated between 5pm and 7am in winter, and 7pm and 5am in the summer. It then effectively retains its heat during the day, leading, with a high degree of certainty, to a significant increase in demand during the winter evening peak period. As a result there could be benefits if the heating of the pool could be delayed until after the evening peak.

The overall company-wide load was also monitored. In 10.1 above, we found that, for SMEs, the daily demand profile tends to be shaped differently to domestic consumers, with a less pronounced evening peak. Power demand is driven by the firm's specific business activity, which for many activities, may be relatively more constant throughout the working day. Although the sample size here is much smaller, a similar picture is visible.

Network implications

These results provide valuable new information about detailed SME activities. Some activities, such as lighting, are less susceptible to demand side management, although lighting load could be reduced significantly through timers, motion sensors, and energy efficient lighting such as LEDs. Others, such as chillers, have the capability of being moved from peak time if working priorities permit. There is also scope for better energy management, for instance setting timers to begin operation after the peak period. Whilst these interventions would reduce electricity consumption in peak periods, there is no evidence yet that they would contribute to reducing peak load and so there may be no specific network benefits.

10.3. SME smart meter customers on time of use tariffs

This grouping was constructed in exactly the same way as that in 10.2 above, but for a different set of SMEs. During the course of the 12 month monitoring period each participant was placed on a static 3-rate Time of Use Tariff. The tariff structure varied throughout the day with prices around 80% higher in the super peak period compared to the day time, and varied slightly depending on the profile class of each SME. However, the rates were not dynamic, i.e. they did not change at short notice and were fixed for the whole 12 months monitoring period.

Because of the heterogeneity of the participants, any comparative assessment is only possible by comparing the performance of the same SME with and without the ToU tariff. Unfortunately, we had such data for only one SME.

Comparing the average daily profiles for the whole period during and after the trial, this showed counterintuitively that during the trial, demand was reduced during the day peak, but increased (very slightly) during the super peak. We therefore investigated whether changes in other demand drivers had dominated the impact of the tariff. We next compared the average daily profiles for the same winter period during and after the trial. However, this again showed demand increasing in the super peak period. We finally compared the last 2 weeks of the trial and the first two weeks after the trial – by taking two periods very close to each other we can perhaps better control for wider changes in the firms' business. In this comparison a reduction in demand throughout the day is apparent, but the largest reduction is during the day peak, rather than super peak. This again suggests that the ToU tariff was not the key driver of changes in demand.

We therefore conclude that, based on the evidence of this case study, there is not sufficient evidence to suggest that the ToU tariff has had an effect on the daily demand profile of this firm.

Network implications

Although few conclusions on the impact of ToU tariffs on SMEs can be drawn from this example, there is clearly interest from SMEs in ToU tariffs and so further work would be useful. However, it demonstrates the need, because of the heterogeneity of the SME community, to conduct monitoring both with and without the ToU tariff for the same SME.

10.4. SME customers with restricted hours tariff and SME customers with direct control

The restricted hours trial was designed to look at the impact of the same 3-rate ToU tariff used in 10.3 above and was therefore constructed in the same way. However, it also included the restricted use of electricity consuming equipment during the super peak period, although the customer could override. For the direct control trial, disaggregated loads were made available for direct control by the network operator.

It was extremely challenging to recruit for these test cells. While this limited the insights from customer behaviour under the tariff from this test cell, we have gained significant learning about the problems associated with recruiting SMEs for DSR trials. Over 20,000 SMEs were approached about participating in CLNR trials. Despite that fact that several hundred expressed an interest in participating in the restricted hours and direct control trials, only two businesses actually joined the restricted hours trial and none joined the direct control trials.

Difficulties in securing SMEs involvement in these trials were driven by the risks perceived by SMEs around the impact of electrical interruption on the daily running of the business. Feedback suggests that unwillingness to join in the trial did not reflect a fundamental opposition to the principles of the project as a whole, which was evidenced by many of those approached participating in other test cells. SMEs cited a number of reasons why they were concerned about uncertain electrical interruptions:

- They were service providers and the hours and the type of process used were controlled and driven by the service users, and there was little or no movement on these time frames from the users.
- The need to capture passing trade in the case of shops, restaurants, hotels and public houses, as well as retaining clients, requires flexibility in opening times.
- Regulatory concerns were central for a lot of SMEs:
    - for example in the farming sector animal welfare is a major concern and is governed by the requirements of DEFRA and other agencies; and,
    - within hotels, public houses and restaurants the need for environmental and Health & Safety requirements is a major consideration, for example the need to prevent the loss of hot water in toilets, safely store prepared foodstuffs and avoid prosecution due to infringement of regulations or personal injury.

In addition to concerns about electrical interruptions, there were also a range of practical issues which limited participation. For example, many of those sites initially interested in participation failed the physical survey to check the state of installation for metering equipment. Similarly there were issues with change of ownership on the site or security issues around the equipment.

Two customers signed up to the restricted hours tariff:

- a hospitality business, where the interruptible load was a chiller unit in a beer cellar; and
- an office, where the interruptible load was an immersion heater (unfortunately, the data collected displayed irregularities that meant it could not be robustly analysed).

Both of these types of load involved thermal processes (cooling or heating) which store energy. Intuitively, they were therefore well suited to load interruption.

Data was only usable from the cellar chiller. The chiller unit was automatically switched off every day during the super peak hours (4pm – 8pm), unless the hospitality business chose to override this signal. It is evident from the monitoring that the DSR generally worked: load during the 4pm-8pm window is almost always zero. Closer examination of the data reveals that there were only three occasions on which the business owner used the override and ran the chiller. Two of these occurred within the first week, and one on the final day. They could therefore represent technical issues in setting up the timer. Absolutely no usage of the chiller occurred in the intervening 214 days, despite the increasing temperatures in summer. Although we can't be sure of the temperature of beer, this is evidence that the owner was satisfied with the temperatures achieved.

Network implications

Albeit from a final sample of one, it is evident therefore that the restricted hours DSR can be successful in reducing load during the peak window. This potentially is of use to both suppliers and DNOs. The difficulty remains in recruiting suitable SMEs and meeting their concerns about being able to continue operating their mainstream business despite the intervention.

11. Conclusion, lessons learnt and implications for DNOs

11.1. Lessons learnt about the conduct of large customer trials

CLNR remains the largest LCNF project so far. The number of customer participants makes it one of the largest investigations into customers' electrical usage and behaviour in the world. Quite apart from the importance of the research findings from the project, there are valuable lessons to be learnt from the experience of carrying out such a project.

The project brought together a unique group of partners to deliver an integrated trial that focused on the customer and network side of the smart grid issue. In so doing, it had to work across boundaries and cultural differences both in the energy industry itself and between the industry and the range of academic disciplines that were involved.

CLNR is an innovation project. The industry and regulator are often criticised for being too conservative, and not having sufficient capacity to innovate. CLNR trialled a whole host of social and technical innovations on real networks, with real customers, in real time. With innovation comes risks, both of failure and delay. We addressed these risks as they arose and found ways to deal with the challenges caused. It is important to ensure that the project management is capable of reacting in an agile way to areas of uncertainty. Three key areas were recruitment of trial participants, installation of smart appliances and monitoring equipment and data recording and analysis.

A number of issues arose which affected the **recruitment** of customers to the trials. We considered it sufficiently important to record the ways in which we addressed these challenges and the lessons they provide for the future that we commissioned and published a project lessons learnt on trial recruitment[42]. Among the key lessons were:

- The high ambition level of the project has driven innovative approaches towards successful test-cell recruitment and brought forward creative and workable solutions. This high bar for the project from its inception, should also deliver a strong dividend from the project in terms of new insights, lessons and outcomes.
- Despite the technology-related challenges in filling some test-cells, there were also a number of instances in which the trial team anticipated customer problems which in the end did not materialise. Rather than second-guessing customers' possible negative responses, focus groups and/or similar small-scale customer exploration might help to avoid unduly 'low expectation' in design of possible 'customer offers'.
- Greater awareness from the outset of the somewhat different goals that project partners had in trial recruitment may have smoothed the process of detailed test cell design and recruitment.

[42] CLNR-L036 Lessons learned from trial recruitment: Customer-Led Network Revolution trials

- A trial with such a large number of test cells, and demographic and technical sub-groups within those test cells, adds significant complexity. A balance needs to be found between testing a sufficiently varied range of options and real-world constraints.
- Working with a recognised and respected university gives the trials credibility and encourages customer participation.
- Inclusion of smart meters (and IHDs) in the trial-offer does seem to make the offer more attractive in recruiting participants.
- Reasonable numbers of residential customers are interested in time-of-use (ToU) tariffs and also in exploring tariffs involving restricted use and direct control. It needs to be clarified how far this interest extends further to other customers who might have to change usage patterns significantly to benefit.
- SMEs contacted expressed initial keen interest in the prospect of lower bills. However, in the end the firms contacted were not amenable to remaining with the trial for restricted-use or for direct control tariffs. The ToU tariff test-cell has been half-filled against the original target.
- There is appetite among PV owners to enhance the use of their PV units.

Several issues arose in relation to **installation** of smart appliances and monitoring equipment:

- Arranging times for installation can be difficult if it involves people having to take time off work.
- Installation of secondary monitoring equipment (which was needed for non-British Gas customers) often necessitated installing an isolation switch. This could only be arranged through the meter operator for the customer's supplier. There were frequently long delays in this process.
- Ensuring adequate space for the installation of possibly bulky equipment or appliances sometimes prevented the participation of a willing customer.
- Many premises did not have access to broadband or even a telephone land line. This is important for the future installation of smart appliances.
- Smart appliances are still at an immature stage. There are issues of compatibility between devices and manufacturers, and communications issues.

Inevitably, with such a large project, **data issues** arose. These included failure of data communication in customers' premises, data compatibility issues between project partners and the amount of effort needed to get the data into a suitable state for analysis. For future projects, a data manager, whose role would be to ensure the end-to-end integrity and compatibility of data flows, would be advisable.

11.2. Implications for DNOs

Learning Outcome 1: understanding of current, emerging and possible future customer (load and generation) characteristics

The basic and enhanced monitoring of customers with smart meters has provided valuable information about domestic consumer load profiles and their make-up. The data created an overall picture of current domestic electrical energy consumption in the UK. This has been used to provide a key input to the recommendations to update ACE49[43]. The enhanced monitoring provided a more detailed picture of the make-up of domestic demand than had been available previously. It was larger and more recent than the Household Electricity Survey (HES). The data, together with the results from the survey and interviews, also provided a baseline against which to measure the impact of the installation of low carbon technologies (LCTs) and/or various types of customer intervention, which are described further on in this report.

Of the domestic appliances monitored, washing machines and dishwashers offer the greatest flexibility in terms of time of use and our surveys suggest customers are prepared to be flexible. We had limited data on direct electrical heating and electrical water heating but these would merit further investigation into their potential for demand side response as would the half of electricity consumption that was not attributable to monitored appliances.

Enhanced monitoring of LCTs provided important new information to assist system planning as increased numbers of LCTs are introduced. Micro-CHP led to a small reduction in the evening peak, but of limited significance for system planning. The network impact of concentrations of ASHPs and PV is dealt with in the optimal systems report, but the suggestion from the monitoring that the existence of PV panels is associated with higher peak electricity demand may need to be taken into account in network planning.

Domestic charging of EVs has raised the level of domestic peak demand but is not yet a problem for network system design and operation. But with greater concentration or if there were 2 EVs at a household, this would no longer be true. The collaboration involving Newcastle University and EV charging data from the Switch EV project suggested that the impact on the network of EVs would be felt first in rural locations. Furthermore, diversity could well be lower at particular times, e.g. pre-charging before a bank holiday weekend. However, EV users are already establishing habits to charge their car when it suits them and this may be difficult to break even with appropriate ToU tariffs. There is therefore a strong case for taking appropriate action to encourage off-peak charging behaviour at an early stage. Further work is needed, which was beyond the scope of this project, to investigate ways of doing this.

We also discovered effects apparently associated with the appliances themselves. The ASHPs had a 3am demand spike. The heat pumps with thermal storage had peaks in the early morning, early evening and after a planned interruption. Both of these effects need to be reported back to the manufacturers and can probably be avoided.

[43] CLNR-L185: Review of the distribution network planning & design standards for the future low carbon electricity system

Learning Outcome 2: to what extent are customers flexible in their load and generation, and what is the cost of this flexibility?

For a DNO, what is needed in terms of customer flexibility is a lower level of peak load at times of particular network stress, for example at network peak or after an interruption. It also needs to be specific to the location of network stress. A reduction in electricity consumption at other times, even if these occur during the early evening period, is of less interest.

The ToU trial, while encouraging a lower level of electricity use over the 4-8pm period compared with the control group, did not result in a lower level of peak demand significant enough in itself to impact network planning. However, ToU could be used as part of a solution or would help if imposed by another player e.g. an energy supplier. Alternatively, critical peak pricing might lead to a more significant response.

The use of Economy 7 and 10 tariffs are effective in conjunction with storage heaters in reducing demand at peak. There was insufficient evidence to determine their impact on electrical water heating.

Given the small numbers involved in the smart washing machine direct control trial, any conclusions must be treated with caution. The small difference in peak means that this intervention is unlikely to have much impact on distribution network planning. However, if the technology becomes more widespread (and particularly if mandated by product standards), this intervention could be of use for national system balancing. Direct control of ASHPs with thermal store threw up the existence of peak loads in the morning and early evening on non-intervention days and the peak immediately following an intervention. This suggests a particular characteristic of the type of ASHP used. This limits the potential benefit of this intervention at present. Nevertheless, both direct control trials have been ground-breaking, using innovative equipment, and clearly demonstrate the technical potential for this intervention. The size of the peak reduction in the case of the ASHP makes it of interest to a DNO, but the utility of the intervention will depend on what cost the DNO would have to bear.

We have insufficient evidence to indicate whether PV with in-house balancing, whether manual or automatic would make a significant contribution to DSR. More work is clearly needed.

We commissioned Element Energy to examine, in the light of the findings from CLNR, the role of the various customer-led interventions and their value to the electricity system, especially for DNOs[44]. Element's conclusion in relation to residential DSR was that there were no major barriers to implementation, although pre-requisites existed for roll-out as business as usual. These were smart metering, three-rate DUoS tariffs and modified settlement codes. Clear incentives for suppliers to offer tariffs and for customers to take them up were needed. Residential ToU tariffs were expected to become more prevalent toward the end of ED1 and into ED2.

[44] CLNR-145: Commercial Arrangements Report

SMEs

It is worth setting out our conclusions on SMEs separately. Our findings are important in an area which has been little studied in the past and where data is poor. Some activities, such as lighting, are not susceptible to demand side management. Others have the capability of being moved from peak time if working priorities permit. There is also scope for better energy management, for instance setting timers to begin operation after the peak period. Whilst these interventions would reduce electricity consumption in peak periods, there is no evidence yet that they would contribute to reducing peak load and so there may be no specific network benefits.

Although few conclusions on the impact of ToU or restricted hours tariffs on SMEs can be drawn from our trials (one example in each category), there is clearly interest from SMEs in ToU tariffs and so further work would be useful. However, it demonstrates the need, because of the heterogeneity of the SME community, to conduct monitoring both with and without the ToU tariff for the same SME. The restricted hours tariff trial was successful in reducing load during the peak window. This potentially is of use to both suppliers and DNOs. The difficulty remains in recruiting suitable SMEs and meeting their concerns about being able to continue operating their mainstream business despite the intervention.

Because of the considerable variability in the SME community, the monitoring results themselves do not have implications for network planning or operation, but provide an important baseline.

11.3. Implications for electricity suppliers

Electricity suppliers have different needs in relation to demand side response from DNOs. They are interested in reducing electricity consumption at times when generating costs are high and they can aggregate the responses achieved over a wide geographical area.

Since static ToU tariffs have been demonstrated to reduce the amount of electricity consumed during the peak period this could prove to be of value to suppliers. An enhanced level of response might be expected in a trial without a "safety net". Given the lack of different response between demographic groups, it may be that using traditional socio-demographic groups to test commercial propositions may not be appropriate. Instead, it may be most appropriate to focus on 'socio-technical' groups (e.g. customers with high income, large houses, and 2+ fridges) or different kinds of 'flexibility capital' (e.g. shift workers, those with dishwashers that can be programmed).

On the 'smart' proposition, customers are more accepting of new, complex and innovative technology, propositions and tariffs than might have been anticipated. The mass take up of residential heat pumps in the 'able to buy market' is not likely in the short-medium term and debatable in the long term. The penetration of EVs is similarly uncertain. We have a greater understanding of smart/connected home communications technology and the challenges with Big Data analysis. We've had some insight into the skill sets that might be required from the 'engineer of the future' who may require ICT skills as well as electrical/heating. We've learnt the importance of working with the technology manufacturer for DSR appliances and the subtleties of implementing a solution that causes minimal disruption to the customer experience and maintains levels of comfort/convenience.

Appendix 1: Equipment installed

Whole house/premises monitoring

For all trial participants involved in the trials, there was a project design requirement to collect whole house/premises electricity consumption, import and export. Depending on the trial and the technology, building, communication or operational constraints, this was collected in one of three different ways:

1. A **smart meter**, installed by British Gas Smart Metering as part of their smart meter foundation programme. The smart meter collects half hourly consumption data in kWh, via British Gas' smart meter head end system.
2. A **non-fiscal secondary meter**, installed by British Gas's installation partners on the project, Passiv Systems. This meter collects import/export data in kWh on either a 10 minute or 1 minute resolution, dependant on the trial via Passiv System's zigbee enabled hub and communicated either via broadband or 3G modem. The installation of this type of meter required the installer to isolate the customer's electricity supply via a double pole isolation switch which must be installed only by a regulated meter operator appointed by the customer's electricity supplier.
3. A **non-fiscal polymeter**, installed by British Gas' installation partners on the project, Passiv Systems, at the customer's consumer board, collecting import/export in kWh at a 1 minute resolution from up to 16 individual circuits in the home

Individual Loads

Many of the trials required the collection of electricity consumption/generation from an individual load, such as an appliance or low carbon technology this data was collected in one of three different ways:

1. **In-line meter or smart plugs**, installed by British Gas's installation partners on the project, Passiv Systems. These collect import/export data in kWh on either a 10 minute or 1 minute resolution (dependant on the trial) via Passiv System's zigbee enabled hub and communicated back to Passiv's Head End System either via broadband or 3G modem.

2. **Smart washing machine**. Hotpoint AQUALTIS model AQ113D 69 EH/A zigbee enabled smart washing machine installed by British Gas, collecting 10 minute resolution consumption data and appliance statistics via a Datamobile GRID BOX gateway device and sent back to British Gas' demand management system provided by GreenCom Networks. British Gas developed machine protocols to enable tariff based and/or remote automatic scheduling of wash cycles as well as display of custom text messages. Both British Gas and appliance manufacturer Indesit both felt in the best interest of customers to implement a simple customer override of all automatic scheduling.

3. **Smart heat pump.** 'Smart Grid Ready' NEURA NDA Nano thermal heat pump installed with a highly insulated Gledhill 300 litre stratified thermal storage tank, collecting 10 minute resolution consumption data and appliance statistics via a Datamobile GRID BOX gateway device and sent back to British Gas' demand management system provided by GreenCom

Networks. Detailed modelling and analysis determined that a 300 litre thermal store would permit approx 0.5 kW load reduction during the 4 hours of the evening peak for a 3 bed semi in the North East, the thermal store also improves efficiency, increasing economic benefits compared to alternative heating methods

PV within-premise balancing

Coolpower's EMMA system was installed by British Gas's installation partners on the project, Solar & Wind Applications. It diverts surplus power from on-site generation such as solar PV to immersion heaters whilst holding electricity export close to zero. The EMMA collects 10 minute resolution consumption, generation and export data via coolpower's data management system.

In Home Displays (IHD)

Two types of In Home Displays were used throughout the trials:

1. Landys+Gyr Eco Meter. Trial participants would have been provided a Landys+Gyr Eco Meter IHD at point of installation of their smart meter by a British Gas Smart Energy Expert. Using this IHD, customers can view the cost of energy they are using over the last week, the last 28 days or the last year, they can also see their carbon emissions over different periods of time. The IHD's are also equipped with Traffic Lights to make it easy to see how much electricity they are using. A red light means a customer's energy usage is high. If it's green, then it's low. The IHD also has a blue light, which notifies of a message that has been sent to the device by British Gas.

2. Passiv Controller. Trial participants on the Manual Within Premises Balancing Trial were provided with an IHD from British Gas' installation partner on the project, Passiv Systems at point of installation of their monitoring equipment, The Passiv Controller visually shows when they are generating/exporting electricity via their solar PV system and advises them to use this in their home, rather than exporting to the grid.

Appendix 2: Trial recruitment and retention of domestic customers

The following tables set out key aspects of the recruitment and retention of customers for the domestic monitoring and intervention trials.

We had a gross target of a number of customers we aimed to recruit to each test cell on the assumption that there would be a 1/3 dropout rate during the trial. Accordingly, the net target was 1/3 lower than the gross target. In reality the dropout rate during the trials was very low.

Test Cell 1a: Basic profiling of domestic smart meter customers (no LCTs, no interventions)

Trial Description

Proposition:	**Smart Meter Monitoring Trial**
Description:	Monitoring of customers' domestic overall consumption.
Purpose:	Allows network operator to understand in more detail energy usage across the day and how this varies with demographic profile. This also acts a control cell for the CLNR trial.
Customer Target:	9,000 British Gas Smart Meter Customers (6,000 net target).
Non-British Gas Customers	No.
Out of Region Included	Yes 50% in region, 50% out of region.
Equipment:	British Gas Smart Meter (30 minute data).
Tariff:	Remains on existing tariff
Channels:	Opt Out letter British Gas smart metering population
Payment to customer:	N/A

Recruitment Campaign

Opt Out Reasons	**Customers**
Believes would not benefit from trial	7
Cost Reduction	1
Customer does not have Broadband	7
Elderly	42
Happy with current situation	9
Happy with current tariff	13
Inconvenience of installing equipment	4
Lifestyle not suited	78
Moving Home	14
Not interested	73
Technology Driven	1
Terms & Conditions	2
Wants more information	4
Total	**255**

Customer Journey

Customer Consent to Join Trial		**9137**
Drop-Out Pre-Activation	Customer Request	228
	Technical Issue	0
	Non-Contactable	0
Set Up	Low Carbon Technology Installed	0
	Smart Meter Installed	0
	Monitoring & Equipment Installed	0
	Tariff Switch	0
	Customer Request	0
Drop Out During Activation	Technical Issue	0
	Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**8909**
Drop Outs During Trial	Customer Request	467
	Technical Issue	0
	Non-Contactable	0
Decommissioning During Trial	Early Exit	0
	Technical Issue	0
	No Extension	0
	End of Trial	0
Customers at end of Trial		**8442**

Trial Servicing

Total no. of customers for which any data was received during the trial	9113
Service Calls/Service Visits	0

Issues with recruitment

Interoperability of some of the smart meters already installed and meter agent assigned to them.

Test Cell 2a: Enhanced profiling of domestic smart meter customers (No LCTs, no interventions)

Trial Description

Proposition:	**Enhanced Home Monitoring Trial**
Description:	Enhanced monitoring of customers' disaggregated domestic loads and overall consumption. Domestic loads to be monitored include: Cooking, Space & Water Heating, Cold & Wet Appliances, Consumer Electronics & Home Computing, Lighting.
Purpose:	Allows network operator to understand in more detail energy usage across the day and how this varies with demographic profile. This also acts a control cell for the CLNR trial. The additional monitoring in this cell differentiates from Test Cell 1, giving usage of particular appliances as well as whole home.
Customer Target:	600 gross (400 net target). Due to the intrusive nature of the installation, we targeted 'Friendlies' i.e. employees of partner organisations.
Non-British Gas Customers	Yes.
Out of Region Included	Yes.
Equipment:	• Circuit monitoring of all circuits at consumer unit plus overall premises consumption - MicroWatt Polymeter 16 (10 min data). • Up to 7 smart plugs on specified appliances – Passiv Systems (10 min data). • Passiv Hub.
Tariff:	Remains on existing tariff
Channels:	"Friendlies" British Gas, Northern Powergrid, Durham University and EA Technology.
Payment to customer:	£50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers

Customer Journey

Customer Consent to Join Trial		264
Drop-Out Pre-Activation	Customer Request	31
	Technical Issue	1
	Non-Contactable	18
Set Up	Low Carbon Technology Installed	N/A
	Smart Meter Installed	0
	Monitoring & Equipment Installed	187
	Tariff Switch	N/A
Drop Out During Activation	Customer Request	13
	Technical Issue	7
	Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**187**
Drop Outs During Trial	Customer Request	4
	Technical Issue	0
	Non-Contactable	0
Decommissioning During Trial	Early Exit	4
	Technical Issue	0
	No Extension	14
	End of Trial	165
	Exhausted	4
Customers at end of Trial		**170**

Trial Servicing

Total no. of customers for which any data was received during the trial	180
Service Calls/Service Visits	125

Issues with recruitment

British Gas decided to recruit Partner Company employees to this test cell as they were concerned about the intrusiveness of the large circuit monitoring 'box' required.

Test Cell 2a (HW): Enhanced profiling of domestic smart meter customers (electrically heated hot water on a restricted hours tariff)

Trial Description

Proposition:	**Peak Electricity Saver trial**
Description:	Monitoring of cumulative energy consumption and tank temperature of an immersion heater through an Economy 7/10 tariff as well as outside of Economy 7/10 hours through the boost facility.
Purpose:	Given the lack of industry data, this allows network operator to understand in more detail the consumption profile of immersion heaters and whether this matches the existing Economy seven tariffs.
Customer Target:	150
Non-British Gas Customers	Yes.
Out of Region Included	Yes.
Equipment Installed:	• Mains isolation switch - British Gas Metering Operations. • Secondary meter on main supply – Passiv Systems (10 minute import/export). • In-line monitor on immersion heater – Passiv Systems (10 min data). • In-line monitor on boost facility – Passiv Systems (10 min data). • Hot Water sensor and temperature strings (5 sensors) - Passiv Systems. • (Providing a constant data feed of tank temperatures, indicating heating times, standing losses and usage).
Tariff:	Existing Economy 7/10 Tariff.
Channels:	British Gas Supply Customers, Community Groups, Social Housing.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Customer Journey

Customer Consent to Join Trial		218
Drop-Out Pre-Activation	Customer Request	2
	Technical Issue	27
	Non-Contactable	5
Set Up	Low Carbon Technology Installed	0
	Smart Meter Installed	0
	Monitoring & Equipment Installed	145
	Tariff Switch	0
Drop Out During Activation	Customer Request	6
	Technical Issue	11
	Exhausted/Non-Contactable	1
	Moved to another Test Cell	0
Customers Activated		**145**
Drop Outs During Trial	Customer Request	13
	Technical Issue	8
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	13
	Technical Issue	8
	No Extension	38
	End of Trial	80
	Exhausted	6
Customers at end of Trial		**80**

Trial Servicing

Total no. of customers for which any data was received during the trial	~
Service Calls/Service Visits	65

Issues with recruitment

Finding customers with electric-only Economy 7 hot water from supplier based records was difficult. Social Housing stock proved to be a better target group.

Test Cell 2a (SH): Enhanced profiling of domestic smart meter customers (electrically heated hot water and storage heaters on a restricted hours tariff)

Trial Description

Proposition:	**Peak Electricity Saver trial**
Description:	Monitoring of cumulative energy consumption and tank temperature of an immersion heater through an Economy 7/10 tariff as well as outside of Economy 7/10 hours through the boost facility.
Purpose:	Given the lack of industry data, this allows network operator to understand in more detail the consumption profile of immersion heaters and storage heaters and whether this matches the existing Economy seven tariffs.
Customer Target:	150
Non-British Gas Customers	Yes.
Out of Region Included	Yes.
Equipment Installed:	• Mains isolation switch - British Gas MO. • Secondary meter on main supply – Passiv Systems (10 minute import/export). • In-line monitor on immersion heater – Passiv Systems (10 min data). • In-line monitor on boost facility – Passiv Systems (10 min data). • Hot Water sensor and temperature strings (5 sensors) - Passiv Systems. • In-line monitor per radiator - Passiv Systems (10 min data). • Room Temperature Sensor - Passiv Systems. • Radiator Temperature Sensors - Passiv Systems.
Tariff:	Existing Economy 7/10 Tariff.
Channels:	British Gas Supply Customers, Community Groups, Social Housing.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Customer Journey

Customer Consent to Join Trial		194
Drop-Out Pre-Activation	Customer Request	12
	Technical Issue	2
	Non-Contactable	9
Set Up	Low Carbon Technology Installed	0
	Smart Meter Installed	0
	Monitoring & Equipment Installed	75
	Tariff Switch	0
Drop Out During Activation	Customer Request	44
	Technical Issue	34
	Exhausted/Non-Contactable	7
	Moved to another Test Cell	0
Customers Activated		**75**
Drop Outs During Trial	Customer Request	7
	Technical Issue	4
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	7
	Technical Issue	3
	No Extension	24
	End of Trial	38
	Exhausted	3
Customers at end of Trial		**75**

Trial Servicing

Total no. of customers for which any data was received during the trial	39
Service Calls/Service Visits	65

Issues with recruitment

Finding customers with electric-only Economy 7 hot water from supplier based records was difficult. Social Housing stock proved to be a better target group.

Test Cell 3: Enhanced profiling of domestic customers with air source heat pumps

Trial Description

Proposition:	Heat pump monitoring trial
Description:	In line monitoring of customer's Air Source Heat Pump (ASHP) electrical power consumption and whole house consumption.
Purpose:	Understand the pattern of use that ASHP users have and their electrical power consumption in "real-world" scenarios as part of broader understanding of what impacts widespread HP adoption is likely to have.
Customer Target:	Gross target 600 (net target 400).
Non-British Gas Customers	Yes (Majority).
Out of Region Included	Yes.
Equipment Installed:	• Smart Meter (British Gas Customer) – British Gas Smart Metering (30 min data). • Secondary Meter (non-British Gas Customer) – Passiv Systems (10 minute import/export). • Mains Isolation Switch (non-British Gas Customer) – Electricity Supplier. • ASHP In-line monitor – Passiv Systems (10 min data). • Air Source Heat Pump – Existing/British Gas New Energy.
Tariff:	Remains on existing tariff.
Channels:	Business Development Activity - British Gas New Energy, British Gas Community Energy, Northern Powergrid.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers. • Average £3,500 DECC Subsidised ASHP installation. • 1 Year Free Broadband - £277.

Customer Journey

Customer Consent to Join Trial		402
Drop-Out Pre-Activation	Customer Request	14
	Technical Issue	0
	Non-Contactable	12
Set Up	Low Carbon Technology Installed	333
	Smart Meter Installed	0
	Monitoring & Equipment Installed	333
	Tariff Switch	N/A
Drop Out During Activation	Customer Request	16
	Technical Issue	7
	Exhausted/Non-Contactable	9
	Moved to another Test Cell	47
Customers Activated		**345**
Drop Outs During Trial	Customer Request	0
	Technical Issue	8
	Exhausted/Non-Contactable	3
Decommissioning	Early Exit	6
	Technical Issue	7
	No Extension	32
	End of Trial	276
	Exhausted	4
Customers at end of Trial		**296**

Trial Servicing

Total no. of customers for which any data was received during the trial	180
Service Calls/Service Visits	315

Issues with recruitment

Low number of heat pumps installed, since it was necessary to find customers willing to accept (and pay part of) installation of pump.

Test Cell 4: Enhanced profiling of domestic customers with micro-CHP

Trial Description

Proposition:	**Micro Combined heat and power boiler monitoring trial**
Description:	Monitoring of Micro CHP units (µCHP) installed in homes and whole home monitoring via sub-meter of home.
Purpose:	Understand the pattern of use that µCHP systems have in "real-world" scenarios and how customers interact with units vs. their normal daily consumption patterns.
Customer Target:	20 as a 'proof of concept'.
Non-British Gas Customers	Yes.
Out of Region Included	Yes.
Equipment Installed:	• Secondary meter on main supply – Passiv Systems (10 minute import/export). • Mains Isolation Switch – British Gas Metering Operations. • Mains Isolation Switch (non-British Gas Customer) – Electricity Supplier. • In line monitoring of µCHP – Passiv Systems (10 minute energy profile). • Baxi Ecogen µCHP unit – British Gas Central Heating Installations (CHI).
Tariff:	Remains on existing tariff.
Channels:	British Gas Central Heating Installations, PH Jones and Partner organisations, plus "Friendlies" from: Northern Powergrid, Durham University and EA Technology.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers. • £5,000 subsidised µCHP installation / £5,000 parts + Free engineer labour.

Customer Journey

Customer Consent to Join Trial		**15**
Drop-Out Pre-Activation	Customer Request	2
	Technical Issue	0
	Non-Contactable	0
Set Up	Low Carbon Technology Installed	11
	Smart Meter Installed	0
	Monitoring & Equipment Installed	11
	Tariff Switch	N/A
Drop Out During Activation	Customer Request	0
	Technical Issue	0
	Exhausted/Non-Contactable	1
	Moved to another Test Cell	0
Customers Activated		**11**
Drop Outs During Trial	Customer Request	1
	Technical Issue	0
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	1
	Technical Issue	0
	No Extension	0
	End of Trial	9
	Exhausted	1
Customers at end of Trial		**9**

Trial Servicing

Total no. of customers for which any data was received during the trial	11
Service Calls/Service Visits	0

Issues with recruitment

Need to find customers willing to accept (and pay part of) installation of micro-CHP unit and who could fit unit into their home.

Test Cell 5: Enhanced profiling of domestic customers with solar photovoltaic (PV)

Trial Description

Proposition:	**Solar Panel Monitoring Trial**
Description:	Monitoring of customers energy use and PV performance.
Purpose:	Understand the pattern of use that PV owners have: total generation, in-home use of this and export in "real-world".
Customer Target:	150 gross target (100 net target).
Non-British Gas Customers	Yes, includes Gentoo recruitment of social housing rent-a-roof customers to backfill customers lost to A Shade Greener rent-a-roof customers.
Out of Region Included	No.
Equipment Installed:	• *Solar PV – Existing installation.* • Mains isolation switch - British GasMO. • Mains Isolation Switch (non-British Gas Customer) – Electricity Supplier. • Secondary meter on main supply – Passiv Systems (10 minute import/export). • In line monitoring of PV - Passiv Systems (10 minute energy profile).
Tariff:	Remains on existing tariff.
Channels:	British Gas New Energy, British Gas Community Energy /Social Housing groups, British Gas FiT payments, Northern Powergrid G83 Applications.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Recruitment Campaign

Opt-in Reasons	**Customers**	**%**
Cost Reduction	9	14
Cost Reduction – Lifestyle	0	0
Cost Reduction – Behaviour Change	0	0
Eco Friendly	44	67
Technology Driven	6	9
Vouchers Incentive	6	9
Wants more information	0	0
None Given	1	2
Total	**66**	

Customer Journey

Customer Consent to Join Trial		271
Drop-Out Pre-Activation	Customer Request	8
	Technical Issue	57
	Non-Contactable	33
Set Up	Low Carbon Technology Installed	0
	Smart Meter Installed	0
	Monitoring & Equipment Installed	160
	Tariff Switch	N/A
Drop Out During Activation	Customer Request	5
	Technical Issue	4
	Exhausted/Non-Contactable	1
	Moved to another Test Cell	0
Customers Activated		**160**
Drop Outs During Trial	Customer Request	3
	Technical Issue	1
	Exhausted/Non-Contactable	3
Decommissioning	Early Exit	3
	Technical Issue	1
	No Extension	4
	End of Trial	147
	Exhausted	5
Customers at end of Trial		**152**

Trial Servicing

Total no. of customers for which any data was received during the trial	156
Service Calls/Service Visits	33

Issues with recruitment

Need to find PV customers who owned their unit and weren't on a 'rent-a-roof scheme'.

Test Cell 6: Enhanced profiling of domestic customers with electric vehicles (EV)

Trial Description

Proposition:	**Electric Vehicle Customers (existing Tariff)**
Description:	Monitoring of customer's electric vehicle charging patterns and electricity usage on existing tariff.
Purpose:	Understand the pattern of use that electric vehicle users have for charging their vehicles (loads, times, length of charges etc.) in "real-world" scenarios as part of broader understanding of what impacts widespread EV adoption is likely to have.
Customer Target:	150 gross target (100 net target).
Non-British Gas Customers	Yes.
Out of Region Included	British Gas included out of region, CYC all in region
Equipment Installed:	• If British Gas customer: Smart Meter – British Gas Smart Metering (30 min data). • Secondary Meter (non-British Gas Customer) – Passiv Systems (10 minute import/export). • Mains Isolation Switch (non-British Gas Customer) – Electricity Supplier. • In-line monitor for EV charge point – Passiv (10 min data).
Tariff:	Remains on existing tariff.
Channels:	Charge your Car participants and direct recruitment by British Gas.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Issues with recruitment

159 EV-driving customers' household and electric vehicle charging demand were monitored, the majority being recruited via a joint partnership between CLNR and Charge Your Car (North) Ltd (CYC), and a smaller number recruited directly by British Gas.

Test Cell 9a: Domestic smart meter customers on time of use tariffs

Trial Description

Proposition:	**Off-Peak Saver 3 Rate Tariff Trial**
Description:	Monitoring of customers smart meter (half-hourly) with 3 tariff rates depending on time of day.
Purpose:	Testing the impact of time of use pricing designed to move energy usage away from network peaks (i.e. 4pm – 8pm).
Customer Target:	600 gross (400 net target).
Non-British Gas Customers	No.
Out of Region Included	No.
Prerequisites:	Smart Meter/ Eligibility Criteria British Gas Smart Meter Foundation Programme.
Equipment:	Smart Meter – British Gas Smart Metering (30 min data).
Tariff:	• 0700-1600 Day – 4% Below Standard Rate. • 1600-2000 Peak – 99% Above Standard Rate. • 2000-0700 Night - 31% Below Standard Rate. • Weekends are flat night rate all weekend. • A standing charge will be applied in addition to these unit rates.
Channels:	600 existing British Gas supply customers some of these may have smart meter installed already.
Payment to customer:	£50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Recruitment Campaign

Opt-in Reasons	**Customers**	**%**
Cost Reduction	99	12
Cost Reduction – Lifestyle	342	41
Cost Reduction – Behaviour Change	204	25
Eco Friendly	54	7
Technology Driven	38	5
Vouchers Incentive	8	1
Wants more information	0	0
None Given	83	10
Total	**828**	

Customer Journey

Customer Consent to Join Trial		843
Drop-Out Pre-Activation	Customer Request	0
	Technical Issue	0
	Non-Contactable	0
Set Up	Low Carbon Technology Installed	N/A
	Monitoring & Equipment Installed	288
	Tariff Switch	682
Drop Out Pre Activation	Customer Request	0
	Technical Issue	0
	Exhausted/Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**682**
Drop Outs During Trial	Customer Request	161
	Technical Issue	0
	Exhausted/Non-Contactable	0
Decommissioning During Trial	N/A	0
	N/A	0
	N/A	0
Customers at end of Trial		**570**
Total Customers Decommissioned		N/A
Customers Exhausted		0

Trial Servicing

Total no. of customers for which any data was received during the trial	682
Service Calls/Service Visits	0

Issues with recruitment

None.

Test Cell 10a: Domestic customers on the smart washing machine restricted hours trial

Trial Description

Proposition:	**Smart Washing Machine and Peak Electricity Saver**
Description:	Monitoring of customers smart meter with 3 tariff rates depending on time of day, in addition restricted use of a Wet White Good (e.g. Washing Machine) which will be provided free of charge.
Purpose:	Testing the impact of time of use pricing with appliance automation designed to move energy usage away from network peaks (i.e. 4pm – 8pm).
Customer Target:	600 gross, (400 net target).
Non-British Gas Customers	No.
Out of Region Included	No.
Equipment Installed:	• Smart Meter – British Gas Smart Metering (30 min data). • Smart Washing Machine – Hotpoint AQUALTIS model AQ113D 69 EH/A. • Gateway – Datamobile GRID BOX.
Tariff:	**ToU Tariff:** 0700-1600 Day – 4% Below Standard Rate. 1600-2000 Peak – 99% Above Standard Rate. 2000-0700 Night - 31% Below Standard Rate. Weekends are flat night rate all weekend. A standing charge will be applied in addition to these unit rates. **Restricted Hours:** Wet White Good will not work as default in Peak (1600-2000). Customers are able to override without penalty, but would be charged at peak rate for consumption.
Channels:	75 British Gas supply Customers, then “Friendlies” British Gas, Northern Powergrid, Durham University and EA Technology.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers. • Washing machine to be installed free of charge.

Customer Journey

Customer Consent to Join Trial		**85**
Drop-Out Pre-Activation	Customer Request	9
	Technical Issue	25
	Non-Contactable	0
Set Up	Low Carbon Technology Installed	53
	Smart Meter Installed	29
	Monitoring & Equipment Installed	53
	Tariff Switch	53
Drop Out During Activation	Customer Request	0
	Technical Issue	1
	Exhausted/Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**53**
Drop Outs During Trial	Customer Request	0
	Technical Issue	0
	Exhausted/Non-Contactable	1
Decommissioning	Early Exit	0
	Technical Issue	0
	No Extension	0
	End of Trial	53
	Exhausted	0
Customers at end of Trial		**53**

Trial Servicing

Total no. of customers for which any data was received during the trial	49
Service Calls/Service Visits	26

Issues with recruitment

Off-the-shelf technology proved to be not available and resulted in delay. In the end a new 'product' was developed straight from the laboratory.

Test Cell 11a: Domestic customers on the smart washing machine direct control trial

Trial Description

Proposition:	**Smart Washing Machine and Peak Electricity Manager**
Description:	Monitoring of customers smart meter, in addition direct control of a Wet White Good (e.g. Washing Machine) which will be provided free of charge.
Purpose:	Testing the impact of direct control to move energy usage away from periodic network peaks to manage the grid loads.
Customer Target:	600 gross (400 net target).
Non-BG Customers	No.
Out of Region Included	No.
Equipment Installed:	• Smart Meter – British Gas Smart Metering (30 min data). • Smart Washing Machine – Hotpoint AQUALTIS model AQ113D 69 EH/A. • Gateway – Datamobile GRID BOX.
Tariff:	Remains on existing tariff. **Direct Control:** Network operator / supplier able to interrupt use of single appliance for a number of specified periods throughout the year (customer has ability to override). Maximum 15 times – 4hours each interruption – may not be called upon.
Channels:	"Friendlies" British Gas, Northern Powergrid, Durham University and EA Technology.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers. • Washing machine to be installed free of charge.

Customer Journey

Customer Consent to Join Trial		**161**
Drop-Out Pre-Activation	Customer Request	9
	Technical Issue	45
	Non-Contactable	3
Set Up	Low Carbon Technology Installed	100
	Smart Meter Installed	50
	Monitoring & Equipment Installed	100
	Tariff Switch	0
Drop Out During Activation	Customer Request	0
	Technical Issue	1
	Exhausted/Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**100**
Drop Outs During Trial	Customer Request	0
	Technical Issue	0
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	0
	Technical Issue	0
	No Extension	0
	End of Trial	84
	Exhausted	16
Customers at end of Trial		**100**

Trial Servicing

Total no. of customers for which any data was received during the trial	100
Service Calls/Service Visits	51

Issues with recruitment

Off-the-shelf technology proved to be not available and resulted in delay. In the end a new 'product' was developed straight from the laboratory.

Test Cell 12: Domestic customers with air source heat pumps on time of use tariffs

Trial Description

Proposition:	**Heat Pump and Off-Peak Saver 3 Rate Tariff Trial**
Description:	Monitoring of customer's Air Source Heat Pump (ASHP) electrical power consumption and customer's smart meter consumption with 3 tariff rates depending on time of day.
Purpose:	Understand the pattern of use that ASHP users have and their electrical power consumption in "real-world" scenarios as part of broader understanding of what impacts widespread HP adoption is likely to have; and specifically testing the impact of Time of Use pricing designed to move energy usage away from network peaks (i.e. 4pm – 8pm) with HP owner.
Customer Target:	600 gross, 400 net target.
Non-British Gas Customers	No.
Out of Region Included	Yes.
Equipment Installed:	• Smart Meter – British Gas Smart Metering (30 min data)ASHP In-line monitor – Passiv Systems (10 min data)If not an existing installation: Air Source Heat Pump – British Gas Renewable Heat Team.
Tariff:	**ToU Tariff:** 0700-1600 Day – 4% Below Standard Rate1600-2000 Peak – 99% Above Standard Rate2000-0700 Night - 31% Below Standard RateWeekends are flat night rate all weekendA standing charge will be applied in addition to these unit rates.
Channels:	Business Development Activity - British Gas New Energy, British Gas Community Energy, Northern Powergrid.
Payment to customer:	• £50 Joining / £50 End of trial – to be delivered in vouchers. Average £3,500 DECC Subsidised ASHP installation. • 1 Year Free Broadband - £277.

Customer Journey

Customer Consent to Join Trial		81
Drop-Out Pre-Activation	Customer Request	4
	Technical Issue	2
	Non-Contactable	1
Set Up	Low Carbon Technology Installed	12
	Smart Meter Installed	12
	Monitoring & Equipment Installed	12
	Tariff Switch	7
Drop Out During Activation	Customer Request	3
	Technical Issue	5
	Exhausted/Non-Contactable	2
	Moved to another Test Cell	47
Customers Activated		**12**
Drop Outs During Trial	Customer Request	5
	Technical Issue	0
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	~
	Technical Issue	~
	No Extension	~
	End of Trial	~
	Exhausted	~
Customers at end of Trial		**7**

Trial Servicing

Total no. of customers for which any data was received during the trial	7
Service Calls/Service Visits	0

Issues with recruitment

The length and complexity of the customer journey: heat pump, mains isolator, broadband, phone line, smart meter, time of use tariff and monitoring kit all required for this Test Cell made it difficult to recruit and retain customers.

Test Cell 14: Domestic customers with air source heat pumps on direct control trials

Trial Description

Proposition:	**Heat Pump and Energy Supply Manager Trial**
Description:	Monitoring of customer's Air Source Heat Pump (ASHP) electrical power consumption, customer's smart meter consumption and response to direct control of HP draw.
Purpose:	Understand the pattern of use that ASHP users have and their electrical power consumption in "real-world" scenarios as part of broader understanding of what impacts widespread HP adoption is likely to have; and specifically testing the impact of direct control to move energy usage away from periodic network peaks to manage the grid loads.
Customer Target:	150 gross (100 net target).
Non-British Gas Customers	Yes.
Out of Region Included	Yes.
Equipment Installed:	• Smart Meter – British Gas Smart Metering (30 min data). • Secondary Meter (non-British Gas Customer) – Passiv Systems (10 minute import/export). • Mains Isolation Switch (non-British Gas Customer) – Electricity Supplier. • ASHP – British Gas New Energy ("Smart Grid capable" variety with integrated direct controls functionality,10 minute load monitoring and additional heat meters and temperature sensors as required for the DECC subsidy). • Thermal store (provides heat while heat pump in 'direct control' mode).
Tariff:	Remains on existing tariff. **Direct Control:** Network operator / supplier able to prevent use of single appliance for a number of specified periods throughout the year. Maximum 15 times – 4hours each interruption – may not be called upon (note that for ASHP full 4 hour interruption unlikely to be achievable due to technical constraints on thermal storage size, heat pump would be off for part of the interruption and operating at a reduced duty cycle for the remainder).
Channels:	Business Development Activity - British Gas New Energy, British Gas Community Energy, Northern Powergrid.
Payment to customer:	• £50 Joining / £50 End of trial – to be delivered in vouchers. • Average £3,500 DECC Subsidised ASHP installation. • 1 Year Free Broadband - £277.

Customer Journey

Customer Consent to Join Trial		**19**
Drop-Out Pre-Activation	Customer Request	0
	Technical Issue	0
	Non-Contactable	0
Set Up	Low Carbon Technology Installed	17
	Smart Meter Installed	0
	Monitoring & Equipment Installed	17
	Tariff Switch	0
Drop Out During Activation	Customer Request	1
	Technical Issue	1
	Exhausted/Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**17**
Drop Outs During Trial	Customer Request	0
	Technical Issue	0
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	~
	Technical Issue	~
	No Extension	~
	End of Trial	16
	Exhausted	1
Customers at end of Trial		**16**

Trial Servicing

Total no. of customers for which any data was received during the trial	22
Service Calls/Service Visits	0

Issues with recruitment

This intervention required finding customers willing to accept (and pay part of) installation of a heat pump. There were also difficulties finding homes technically suitable to accommodate the smart heat pump with a thermal store, particularly in social housing. In addition the concept of an interruptible heating supply was completely new and required a big leap of faith on behalf of customers.

Test Cell 20(Auto): Domestic solar PV customers with automatic in-premises balancing for hot water charging

Trial Description

Proposition:	**Solar Panel Electricity Generation and Usage Trial**
Description:	Monitoring of customers' Passiv sub-meter (half-hourly) energy use and PV performance with automatic diversion of any excess generation (normally exported to the grid) into hot water storage.
Purpose:	Understand the pattern of use that PV owners have: total generation, in-home use of this and net generation use within the home to establish if automatic intervention can prevent mass-export on networks in the future (entire street's worth's of housing exporting electricity up to the grid on sunny days).
Customer Target:	600 gross (400 net target across both PV balancing test cells combined).
Non-British Gas Customers	Yes, includes Gentoo recruitment of social housing rent-a-roof customers to backfill customers lost to A Shade Greener rent-a-roof customers.
Out of Region Included	No.
Equipment Installed:	• *Solar PV – Existing installation.* • Cool Power 'EMMA' system, for PV to hot water control, includes 10 minute monitoring of generation and import/export.
Tariff:	Remains on existing tariff.
Channels:	British Gas New Energy, British Gas Community Energy /Social Housing groups, British Gas FiT payments, Northern Powergrid G83 Applications.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Recruitment Campaign

Opt-in Reasons	**Customers**	**%**
Cost Reduction	63	79
Cost Reduction – Lifestyle	0	0
Cost Reduction – Behaviour Change	0	0
Eco Friendly	11	14
Technology Driven	5	6
Vouchers Incentive	0	0
Wants more information	0	0
None Given	1	1
Total	**80**	

Customer Journey

Customer Consent to Join Trial		208
Drop-Out Pre-Activation	Customer Request	0
	Technical Issue	51
	Non-Contactable	0
Set Up	Low Carbon Technology Installed	99
	Smart Meter Installed	0
	Monitoring & Equipment Installed	99
	Tariff Switch	0
Drop Out During Activation	Customer Request	6
	Technical Issue	14
	Exhausted/Non-Contactable	0
	Moved to another Test Cell	0
Customers Activated		**99**
Drop Outs During Trial	Customer Request	0
	Technical Issue	0
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	0
	Technical Issue	0
	No Extension	0
	End of Trial	0
	Exhausted	0
Customers at end of Trial		**99**

Trial Servicing

Customers Reported Data	99
Service Calls/Service Visits	0

Issues with recruitment

Finding PV customers who owned their unit and not on a 'rent-a-roof scheme' and had sufficient space for the EMMA unit proved difficult.

Test Cell 20(IHD): Domestic solar PV customers using in-home displays for manual in-premises balancing

Trial Description

Proposition:	Solar Panel Electricity Generation and Usage Trial
Description:	Monitoring of customers' energy use and PV performance with additional real-time notice of excess generation (export to the grid) e.g. when PV generation exceeds current consumption do customers turn on other appliances.
Purpose:	Understand the pattern of use that PV owners have: total generation, in-home use of this and net generation use within the home to establish if real-time information can prevent mass-export on networks in the future (entire street's worth's of housing exporting electricity up to the grid on sunny days).
Customer Target:	600 gross, 400 net target across both PV balancing test cells combined.
Non-British Gas Customers	Yes, includes Gentoo recruitment of social housing rent-a-roof customers to backfill customers lost to A Shade Greener rent-a-roof customers.
Out of Region Included	No.
Equipment Installed:	• Solar PV – Existing installation. • Mains isolation switch - British GasMO. • Secondary meter on main supply – Passiv Systems (10 minute import/export). • In line monitoring of PV - Passiv Systems (10 minute energy profile). • In-home display – Passiv Systems
Tariff:	Remains on existing tariff.
Channels:	British Gas New Energy, British Gas Community Energy /Social Housing groups, British Gas FiT payments, Northern Powergrid G83 Applications.
Payment to customer:	• £50 Joining / £50 Extension/ £50 End of trial –M&S Vouchers.

Recruitment Campaign

Opt-in Reasons	Customers	%
Cost Reduction	73	72
Cost Reduction – Lifestyle	0	0
Cost Reduction – Behaviour Change	0	0
Eco Friendly	18	18
Technology Driven	2	2
Vouchers Incentive	4	4
Wants more information	2	2
None Given	2	2
Total	**101**	

Customer Journey

Customer Consent to Join Trial		233
Drop-Out Pre-Activation	Customer Request	18
	Technical Issue	24
	Non-Contactable	13
Set Up	Low Carbon Technology Installed	0
	Smart Meter Installed	0
	Monitoring & Equipment Installed	156
	Tariff Switch	0
Drop Out During Activation	Customer Request	0
	Technical Issue	7
	Exhausted/Non-Contactable	1
	Moved to another Test Cell	0
Customers Activated		**156**
Drop Outs During Trial	Customer Request	12
	Technical Issue	2
	Exhausted/Non-Contactable	0
Decommissioning	Early Exit	3
	Technical Issue	2
	No Extension	4
	End of Trial	143
	Exhausted	7
Customers at end of Trial		**152**

Trial Servicing

Total no. of customers for which any data was received during the trial	153
Service Calls/Service Visits	33

Issues with recruitment

We had difficulties in finding PV customers who owned their unit and weren't on a 'rent-a-roof scheme'.

Appendix 4: Related documents

This table presents relevant outputs from the CLNR trials for further reading.

CLNR Learning Outcome 1 and Learning Outcome 2 Trial Outputs	
Baseline Monitoring of Domestic and SME customers	• CLNR-L216: Insight report: Baseline domestic profiles • CLNR-L242: High Level Summary of learning: domestic smart meter customers • CLNR-L099: Insight report: Small and medium enterprises (SME's)
Enhanced Monitoring of Domestic Customers	• CLNR-L094: Insight report: Enhanced domestic monitoring
Time of Use Tariffs (ToU)	• CLNR-L093: Insight report: Domestic time of use tariff • CLNR:L243: High Level Summary of learning: domestic smart meter customers on time of use tariffs
Solar Photovoltaic (PV)	• CLNR-L090: Insight report: Domestic solar PV customers • CLNR-L244: High Level Summary of learning: Solar PV customers
Electric Vehicles (EV)	• CLNR-L092: Insight report: Electric vehicles • CLNR-L254: High Level Summary of learnings: Electric vehicle users
Heat Pumps (HP)	• CLNR-L091: Insight report: Domestic heat pumps • CLNR-L245: High Level Summary of Learning: Heat Pump Customers
Micro-CHP (mCHP)	• CLNR-L086: Report on enhanced profiling of domestic customers with Micro-CHP
Domestic Direct Control	• CLNR-L096: Insight report: Domestic direct control trials
Social Science Outputs	• CLNR-L052: Social science report April 2014 • CLNR-L100: Domestic survey report • CLNR-L101: SME survey report • CLNR-L102: Domestic customers: energy practices and flexibility • CLNR-L103: SME customers: energy practices and flexibility • CLNR-L104: Heat pump survey • CLNR-L106: Driving the Electric Vehicle: Survey data visualisation • CLNR-L236: Key social science findings: domestic and SME customers
Additional CLNR Outputs	
Reports	• CLNR-L247: Developing the smarter grid: the role of industrial & commercial and distributed generation customers • CLNR-L248: Optimal solutions for smarter network businesses • CLNR-L145: Commercial Arrangements study – Phase 2 • CLNR-L185: Review of the distribution network planning & design

	standards for the future low carbon electricity system
Test Cell Protocol	• CLNR-L107: Test cell protocol
Academic Conference Paper	• CLNR-L038: IEEE ISGT 2013: Integrating smart meter and electric vehicle charging data to predict distribution network impacts

Customer-Led Network Revolution

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