CUSTOMER-LED NETWORK REVOLUTION

PROJECT CLOSEDOWN REPORT

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1. PROJECT BACKGROUND

The move to a low carbon economy, in particular the growth in low carbon technologies (LCTs), will place additional strain on electricity distribution networks, which were not designed with this change in mind. Innovative solutions could reduce the need for significant network investment and thus avoid delaying the take-up of LCTs.

The network costs associated with mass uptake of LCTs could be significantly reduced, and delivery accelerated, by using a combination of:

- network technologies, such as enhanced automatic voltage control, real time thermal rating and electrical storage; and
- flexible customer response from both demand and generation.

This will only happen if new commercial arrangements between suppliers, distribution network operators (DNOs) and customers are developed.

While network management and demand response technologies already exist and are well documented, they had not previously been deployed at distribution level in a market with the degree of vertical separation of Great Britain (GB). The Customer-Led Network Revolution project aimed to provide the knowledge and experience necessary to bridge this gap. It did this by bringing together Northern Powergrid the distribution network operator for the Northeast, Yorkshire and northern Lincolnshire and the largest national unaffiliated energy retailer (British Gas), together with a multi-disciplinary academic team from Durham and Newcastle Universities and network consultants EA Technology, to assess a range of customer-side solutions (innovative tariffs and load control incentives in association with different LCTs) alone and in combination with network-side technology (including voltage control, real time thermal rating and energy storage). The project was designed to deliver robust learning that is applicable to a high percentage of GB electricity distribution networks and demographic groups.

Network issues relating to the take-up of LCTs will start to be a problem on pockets of network by 2015 and a wider more significant issue from 2020. Therefore knowledge gained from the project will be relevant to DNOs in both the ED1 and ED2 periods[1].

The challenges considered by this project have relevance to all DNOs and other projects funded by the Low Carbon Networks fund. The Low Carbon London project operated by UK Power Networks is one such project that is considering its own solutions to the challenges for networks presented by society's decarbonisation. This project bears some similarities to CLNR in scope and timing (both commenced and completed at the same time). Stakeholders of this project may therefore be interested in also considering their findings.

[1] The first and second electricity distribution price control periods under the new 'RIIO' price control model. ED1 covers 2015-2023 and ED2 2023-2031

2. EXECUTIVE SUMMARY

The Customer-Led Network Revolution (CLNR) has successfully delivered an ambitious programme of work over a four-year period. Although principally funded by the Low Carbon Networks fund for the benefit of electricity distribution network customers, it has produced learning that offers important insights to policy makers and the broader energy industry as we seek to address the challenges caused by the decarbonisation of society in the period to 2050.

A significant investment of £31m has been made in trialling a range of customer and network flexibility techniques to deliver increased network capacity at least cost to customers. This has resulted in a rich body of research and learning completed at end December 2014 with net benefits estimated in the range £5bn to £26bn in the period 2020 to 2050[2] . However, the learning and benefit does not stop there. The insights generated on CLNR will act as a springboard for Northern Powergrid, its partners and other parties to ensure that the development of smarter grids continues to make effective progress.

THE PROJECT HAS DELIVERED IMPRESSIVELY – WITH REAL CUSTOMERS ON REAL NETWORKS

CLNR was a major smart grid demonstration project which brought together the key stakeholders in the electricity system (customers, energy suppliers and distributors) developing innovative technologies and commercial arrangements. In addition to the integration of people, processes and technology, this is one of the most significant trials undertaken in GB of customer electricity practices and attitudes (particularly domestic and small and medium enterprises). The following provide an overview of the scope, scale and achievements of the CLNR project:

The CLNR customer trials involved *ca.* 11,000 domestic, 2,000 SME, industrial & commercial (I&C) and distributed generation customers

- Published three rich baseline datasets for domestic; SME and I&C customers
- Domestic participants included *ca.* 650 on time of use (ToU) tariffs, 380 with heat pumps, 470 with solar photovoltaic (PV) panels and 160 electric vehicle (EV) users.
- 16 I&C customers provided a total of 17MW of DSR in trials for large scale fast reserve.
- A wealth of customer insight and analysis undertaken by Durham University from *ca.* 1,250 surveys and *ca.* 250 face-to-face interviews completed with more than 130 customers.
- We have published customer load and generation profiles based on data we collected with profiles for various subgroups such as customers with solar PV, heat pumps or on ToU tariffs.

CLNR has been one of the most extensive network technology integration trials undertaken

- The active network management (ANM) system deployed for CLNR is one of the most sophisticated wide area control schemes in operation in Europe - using real-time monitoring inputs, plus state estimation and optimisation rather than relying on pre-programmed rules.
- We installed and commissioned a range of novel network technologies and undertook *ca.* 200 trials of the electrical energy storage (EES), enhanced automatic voltage control (EAVC), real-time thermal rating (RTTR) and demand side response (DSR) interventions deploying the interventions singly and in combinations under the control of the ANM system.

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[2] range dependent on different DECC low carbon technology take-up scenarios

- Over 100 operational and control staff were trained to support the safe and reliable operation of the network equipment in the four trial zones.
- Newcastle University created advanced modelling techniques that predicted and validated the physical trials and facilitated the scaling up of the learning for GB-wide application.

CLNR has delivered significant learning and leaves a comprehensive legacy

- We have published our network trial data demonstrating the performance of the various network technologies trialled, making this available to other DNOs and researchers.
- We developed practical DNO 'how to' guidance including the prototype NPADDS (Network Planning and Design Decision Support) tool, policy and technical recommendations, and application guides for equipment, training materials and lessons learnt reports.
- We made recommendations to update UK electricity industry technical network planning standards based on data collected for the CLNR trials.
- The partnership with energy supplier (British Gas) has delivered important insights into potential future commercial arrangements and learning on the practicalities of delivering end solutions that are compatible with customers' needs.
- Key project learning has been shared at over 50 external industry forums and conferences including the Smart Grid Forum, the Energy and Climate Change Select Committee, international conferences and in peer-reviewed papers for the IEEE Transactions on Power Systems and Applied Energy journals.
- We communicated with our stakeholders through press and social media channels and via a monthly e-news bulletin sent to our 900+ opt-in mailing list subscribers.

IMPORTANT LEARNING HAS BEEN DELIVERED TO BENEFIT CUSTOMERS

There have been a few surprises - low carbon technologies are less disruptive and domestic customers are more flexible than previously predicted

- Regular domestic customers contribute less to system peak demand than previous assumptions – we are recommending a new design assumption of 0.9kW per customer (42% less than previous).
- We observed a significant level of naturally occurring diversity in energy practices from home to home and even from day to day within homes. The majority of domestic customers appear inherently flexible. This exceeded our expectations.
- The impact of solar PV is lessened due to diversity of panel alignment and thereby producing their peak output at different times of the day – our new default planning assumption is to apply a 10% discount to the previous assumption of full output, as used by the industry in the TRANSFORM® model.
- For customers with electric vehicles and heat pumps, rather than a conservative assumption of the full 3kW rating of the equipment, as used by the industry in the TRANSFORM® model, we propose an uplift of only around 1kW per customer to allow for diversification.
- Micro-CHP units tended to offset the household evening peak demand by a few hundred watts in winter. This technology could therefore be beneficial for both network planning and electricity generation costs.
- We have found little evidence of customers' new LCT installations creating power quality problems. In practice, it seems as though the equipment which customers are choosing is both

relatively benign individually, multiple installations don't seem to interfere with each other and the natural customer diversity means that individual issues are not compounded.

We have developed a route map to guide the development of smart grid technology and systems to 2050 – we will start relatively simple and increase the complexity as and when required

- Our proposed approach is hierarchical - DNOs can start with relatively simple forms of localised ANM to resolve local issues. Then, as we see more network constraints from more low carbon technologies, DNOs are likely to need to deploy more solutions; whether in isolation or combination (e.g. EES and DSR). As the number of constraints and the number of solutions multiply then so does the need for more sophisticated wide area control systems to join up and add to the localised solutions delivered earlier.
- The smart/smarter/smartest path over the next 35 years comprises:
  - From better default thermal rating, to bespoke thermal rating, to full RTTR and demand side management (DSM) for a single asset, to an area controller optimising the use of DSM to resolve multiple potential power flow constraints;
  - From better default voltage settings, to bespoke voltage settings, to additional active control devices (using bespoke settings and local control), to an area controller optimising the set points of multiple active control devices;
  - From separate control for voltage and power flow issues to integrated wide area control.
- Safety and reliability have to be designed into the smart grid from the outset. Our suite of outputs for DNOs factors in these imperatives.

From our trials with domestic customers we consider that time of use tariffs, enabled by smart meters, could deliver value in the next 10 years, when delivered in conjunction with energy suppliers…

- We found that time of use tariffs are popular with and easily understood by domestic customers. The majority (60%) saved money 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 since they were guaranteed to pay no more than if they had been on a flat tariff. We do not know how our results would have changed if customers had faced the full financial incentive. 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 not statistically significant.
- Customers reported that it was the household practices of laundry and dishwashing that were most commonly used to flex the times at which electricity was used. It was also clear from our qualitative learning that the older generation and those with younger children tended to find it most difficult to flex their use of electricity compared to others in the trial.
- More development by the industry and policy makers of both the tariff design and customer engagement will be needed to incentivise better the desired peak load shift at the time it matters most for networks (typically winter peak) while also protecting customers from unavoidable or unaffordable price rises. More sophisticated tariffs, such as dynamic time of use (trialled by Low Carbon London) or critical peak pricing, may be beneficial, but this needs further research.
- The value to DNOs of domestic time of use tariffs will increase with more electric vehicle charging. However, for off-peak charging of electric vehicles to become commonplace we need

to resolve an apparent confidence issue observed in today's customers. There is insufficient confidence from some customers that an unmonitored (perhaps automated) overnight charge would be successful and result in a sufficiently charged battery for when they set off in their vehicles in the morning.

- Restricted hours and direct control trials were operated with either a smart washing machine or a heat pump with thermal store. The technology was proven, but the benefit from smart washing machines was limited and whilst the heat pumps successfully reduced individual customer peak load by 2.5kW, there were real barriers identified with this heating solution. Specifically, the retrofitting of heat pumps and the associated thermal store to domestic properties proved to be particularly challenging, with disadvantages due to the relatively high cost, the required insulation standards, the space required, the disruption caused during installation and the different mode of operation (compared to traditional central heating).
- SMEs showed significant reluctance to flex their electricity use and disrupt their business activities. Relative to their size, this reluctance was arguably the most marked and it demonstrated that DNOs will have to develop new, potentially bespoke methods, to engage with this heterogeneous customer group. For those that did participate in the trials, reduced demand was satisfactorily demonstrated during the peak period.
- PV within-house balancing, both manually and automatically triggered, was demonstrated successfully from a technical and a customer engagement perspective, but we have insufficient statistical evidence to indicate that this would make a significant contribution to DSR.
- All of the domestic interventions described above were successfully demonstrated and through time could form part of the future smart grid, but on the basis of our findings with the trialled 2020 distribution tariffs and the current technology costs, they are only likely to be cost effective in the next decade or so if used to deliver benefits for energy suppliers as well as avoiding reinforcement of the network. Successful implementation therefore requires development with energy suppliers.

...and I&C DSR is fit for business as usual today

- We conclude that I&C DSR may be considered as a viable option today to address forecast network constraints and a ceiling price can be calculated based upon the price of the lowest cost alternative. We have shown an overall reliability up to ca. 80% - i.e. customers were able to respond well when requested to reduce load. The location of DSR provision in specific geographic locations will be challenging, requiring DNOs to improve engagement techniques to seek out and secure the resource that is available.
- The main use by Northern Powergrid in the 2015-23 period is likely to be a post-fault response to manage the security of supply at major substations forecast to be occasionally loaded above capacity during the winter evening peaks. DSR typically yields 10-15% capacity uplift.
- By deferring the need for reinforcement we give ourselves the time to evaluate all the options, plan the use of our resources and see if the local conditions change so that reinforcement is ultimately no longer necessary.
- Separately, our analysis of the distribution use of system (DUoS) price signal passed on to half-hourly metered customers since 2010 showed that it did not have an immediately noticeable effect on the number of units consumed by industrial & commercial (I&C) customers in the Northeast and Yorkshire during peak load periods. Our survey with energy suppliers showed that

currently only around 5% of customers see these signals in their end bills. This will have to change in order for this widespread price signal to influence consumption routinely out of the peak period.

CLNR has provided improved data on the services provided by distributed generators

- Our studies on output from 62 distributed generation sites have demonstrated that wind farms contribute less to system security than we thought (14% contribution down from 24%). For other generator types, the existing ETR130 contribution factors look appropriate.
- Our trials successfully demonstrated that operating generation in voltage control mode on a DNO network could be an effective means of managing voltage through the control of reactive power thus potentially reducing the number of times that generation is constrained off due to voltage issues.

Electrical energy storage has proven to be an effective form of demand side management alongside customer flexibility

- Our trials have shown that electrical energy storage and DSR provide similar system benefits, can be combined efficiently to commercial advantage, and can be driven by a single well-designed control system. Therefore, we expect to treat all sources of such demand side management the same way. We will seek a contracted-out real power response service.
- We have developed a suite of solutions for deploying electrical energy storage onto distribution systems, both as storage owner and distribution system operator. Our outputs include documents defining requirements for procurement, installation, operation and maintenance.
- There are some practical limitations to using storage in addition to the cost today. Today's units are relatively large, heavy and noisy, so they can't be used everywhere. Round-trip efficiency of the 2500kVA/5000MWh unit is about 80% and the low voltage units are significantly less.

THE PATH FOLLOWED HAS BEEN CHALLENGING AT TIMES…

Over the course of the project there were a number of material changes in external circumstances which meant that additional time was needed to deliver the learning outcomes. These circumstances, described in the change request approved by Ofgem, included the shortage of heat pump and EV trial participants that we resolved with new partnerships and a £2.2m grant from DECC; and the difficulties in the procurement and manufacture of some of the novel technology in what proved to be a relatively immature supply chain. In all respects, we found alternative routes to deliver the learning but we needed one more year to complete the project (in December 2014).

To manage within the constraints presented by these externalities we modified our overall 'design, model, deliver and analyse' approach to the trials. This led to delivery of the modelling capability as a valuable output in its own right – the techniques created to validate, extend, extrapolate, enhance and generalise (VEEEG) both the CLNR trial results and those of other projects have been recognised as being of 'archival' value by for others working on smart grid development. This 'R&D infrastructure' has value beyond CLNR and is beneficial to others developing smart grids.

…BUT KEY MILESTONES HAVE BEEN ACHIEVED

Despite the difficulties experienced in delivering what has been an ambitious and challenging undertaking we have managed to deliver almost all of the outputs specified in the successful delivery reward criteria to time. The single exception was the August 2014 milestone to publish the datasets where we did not publish them for all customer test cells. Manipulating and processing the range of huge complex datasets for the customer trials was a more difficult task than envisaged.

The socio-technical CLNR dataset will be so large, diverse, detailed and well explained that it looks likely to become a unique national asset and will still be used a decade from now. Aggregated anonymised datasets have already been published by the project website. The route to publication of the project disaggregated data is being evaluated in conjunction with the national centre for Big Data and Cloud Computing at Newcastle University (separately funded by the Department for Culture, Media & Sport).

Consultation

This report is a draft for consultation and will be updated to reflect the outcomes of the consultation and of a parallel peer review by UK Power Networks. The consultation period closes on 20th February 2015. For information on how to provide written feedback, please contact Liz Sidebotham on 0191 229 4242 or liz.sidebotham@northernpowergrid.com. This report will be updated to describe the consultation process, the key outcomes and how we have updated the report to reflect the consultation feedback and the peer review. A final version will be issued by the end of March 2015.

3. DETAILS OF THE WORK CARRIED OUT

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 & commercial customers and distributed generators 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.

The project set out to find out whether customers could be flexible in the ways they use and generate electricity and how DNOs can contribute to reducing customers' energy costs and carbon footprint in the years to come. It was also 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 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.

We monitored 10,006 domestic customers (9,096 general, 344 heat pumps (HP), 160 photovoltaic (PV), 14 CHP, 159 electric vehicles (EVs) and 233 with electric hot water / storage heating); 1,880 small commercial customers; and 160 merchant generators and analysed the consumption data. Additionally, DNO metering data for 17,639 I&C customers was collated for analysis to support the time of use tariff signal effectiveness study.

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 was 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 in voltage control as a means of managing voltage through the control of reactive power which could provide an alternative to real power curtailment under certain circumstances .

We trialled interventions with 1,144 customers (1,097 residential customers – 628 residential Time of Use (ToU) without any LCTs, 307 PV, 128 controllable wet white goods and 34 heat pumps – 47 SME customers, 44 on ToU and 3 on restricted hours and 16 I&C/generation customers on individual DSR contract arrangements).

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 and DSM resources 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.

We established four test-bed networks:

- Urban network at Rise Carr, Darlington (County Durham). On the 6kV network served from Rise Carr primary substation:
  - We installed a 2500kVA/5000kWh electrical energy storage unit, connected via a step-up transformer to the primary substation 6kV busbar;
  - At Darlington Melrose and Mortimer Road secondary substations, we replaced the existing 6100/433V transformer with a unit with an on-load tap-changer, and installed a 50kVA/100kWh electrical energy storage unit at the remote end of one of the LV feeders from one substation.
  - At High Northgate secondary substation, we installed a 100kVA/200kWh electrical energy storage connected to the substation 433V busbar.

- Rural network at Denwick (North Northumberland):
    - On the 20kV network served from Denwick primary substation, we focussed on two feeders serving the area around Wooler and supporting about 2MW of load, which run in parallel to a firm busbar at Hedgeley Moor Switch House, where we had previously installed a mechanically-switched capacitor bank.
    - In Wooler, we fitted Wooler Bridge substation with a transformer with an on-load tap-changer and a remote 50kVA/100kWh electrical energy storage unit, and connected a 100kVA/200kWh electrical energy storage to the 433V busbar at Wooler Ramsey.
- PV cluster at Maltby (Rotherham, South Yorkshire):
    - We replaced the existing 11000/433V transformer at Mortimer Road 45548 substation for a unit with an on-load tap-changer, and installed a 50kVA/100kWh electrical energy storage unit at the remote end of one of the LV feeders from that substation. The feeder chosen served a group of customers with a high take-up of solar PV.
- Heat pump cluster at Hexham (Northumberland):
    - At Hexham Sidgate Lane we tested the flexibility afforded by secondary transformer RTTR and secondary (feeder) EAVC. At this location we monitored voltage, power flow and power quality.

We chose the Rise Carr and Denwick networks to demonstrate that similar solutions can address different constraints and deliver different opportunities. Rise Carr is a compact urban network, while Denwick is an extended rural system. That these networks run at 6kV and 20kV respectively makes little difference to their construction and operation, as we generally use the same design tools for 6, 11 and 20kV; again, we made this choice to demonstrate how the same techniques apply at different voltage levels. If a solution works on an urban 6kV network and a rural 20kV network, we can be confident that it will work almost anywhere. We chose the Mortimer Road and Hexham cluster network areas partly to create a small initial prototype to test the solutions, but mainly to trial our new solutions on LCT-rich network.

We installed new smart RTUs at every control point as a deliberate design decision to give us fall-back local control and to interface to the area controller. This gave us:

- Both primary substations, to drive the existing OLTC and, at Rise Carr, to drive the EES;
- The three secondary substations with OLTC;
- The existing capacitor bank at Hedgeley Moor and an existing 20kV regulator at Hepburn Bell, on the alternate feed from Hedgeley Moor into Wooler town;
- The two secondary substations with a 100kVA EES; and
- The three remote 50kVA EES.

These smart RTUs built on the latent capability of modern SCADA outstations, to provide significant local intelligence within the substation. Features included:

- Measurement processing;
- Local voltage management, i.e. identifying excursions beyond user-defined voltage limits and requesting an appropriate intervention;
- Thermal modelling, implementing the transformer RTTR algorithm described in detail later, to work out the real-time capability in amps;
- Local thermal management, i.e. comparing the real-time capability calculated in the modelling module to the present demand, to identify excursions beyond that calculated RTTR limit and requesting an appropriate intervention;
- Device management, providing the intelligence to manage the interface to active controls like OLTC and EES. This includes protocol conversion, but also extends to providing safe modes and set-points when reverting to local control on loss of communication with the area controller; and
- Coordination and mode management, arbitrating between local voltage and thermal management, and managing the interface with the area controller.

Those smart RTUs and a monitoring suite were connected by VPN over PSTN to an area controller sited adjacent to our Northern system control centre. The monitoring showed us not just what happened at the point of control but also, in conjunction with a state estimator, allowed us to gauge network conditions all the way from the primary transformer to the end of the LV network.

When managing voltage, we wanted to understand what was happening at the point of delivery to our customers. We did this by combining monitoring with a state estimator which covered both HV and LV networks. We used points of control at many voltages, specifically: LV (50kVA and 100kVA EES); HV (secondary OLTC, regulators and capacitor banks); and EHV (66/20 and 33/6 primary transformers), but all were managed by reference to what was happening at LV.

Similarly, the combination of monitoring and state estimation allowed us to manage power flows across the whole network from LV main to primary transformer, again crossing the voltage levels to use (for example) LV connected storage to offload a 33kV connected primary transformer.

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 was the prototype NPADDS tool, to guide network planners in selecting non-network, novel network and conventional network solutions.

4. THE OUTCOMES OF THE PROJECT

This project was aimed at finding smarter, more cost-effective alternatives to traditional reinforcement. Its object was therefore maintaining current planned level of network performance potentially at a lower cost than traditional methods rather than directly improving network performance. The outcomes are described in detail in three key learning reports[3]; CLNR-L246: Developing the smarter grid, the role of domestic and small and medium enterprise customers, CLNR-L247: Developing the smarter grid, the role of industrial & commercial and distributed generation customers, and CLNR-L248: Optimal solutions for smarter distribution systems and are summarised as follows:

[3] For a guide to the structure of the outputs suite see section 12 ‘Learning Dissemination’. A list of key project learning documents is included in appendix 11.

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

Understanding of current, emerging and possible future customer (load and generation) characteristics

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. Customers consume on average about 3,500kWh during the year, with a range of roughly 200kWh 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. However, there is limited use of these appliances during weekday peak times. About half of consumption at peak was not attributable to the devices that were monitored, and offers scope for further research. 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. After diversity, heat pumps had the effect of doubling the household peak load, but clusters are likely only in social housing and potentially new build off-gas 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 to address the forecast growth in the number of EVs.

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. Some processes are re-schedulable but not 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 CLNR has made a start at improving understanding and where there is a vast opportunity for further research in how best to engage SME customers.

Impact of customer interventions

Static time of use tariffs - Time of use tariffs are popular with domestic customers, where more save money (60%) than lose out (40%) and electricity consumption during the peak demand period is lower than in the control group by up to *ca.* 10%, although peak demand was not statistically significantly different from the control group at the time of maximum network peak demand. Compared to the control group, overall annual electricity consumption was lower amongst our time of use trial participants; but this difference was not statistically significant. The reduction in peak demand seen in this trial would not be significant enough in itself to assist in network planning. However, TOU could be used as part of a solution and could help if introduced by another party such an energy supplier.

Other interventions - The restricted hours and direct control trials tested customers' willingness to accept 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 2.5kW, there were technical issues and problems of customer acceptability. SMEs were reluctant to face restrictions on their electricity usage but the one example was successful. Encouraging customers via an IHD to use their PV generation rather than export made no significant difference despite high customer engagement.

Developing the smarter grid: the role of industrial & commercial and distributed generation customers

Static demand-side response – The April 2010 tariff reform, which led to the introduction of the peak pricing signals in the common distribution charging methodology (CDCM), has had little impact on the behaviour of customer electricity consumption patterns and, four years later, still only about 5% of half-hourly customers see the peak pricing signals in the form of the red/amber/green DUoS tariff time bands in their electricity bill. Suppliers put this down to their customers wanting simplicity. The aggregate profile of I&C customers does not actually exhibit a peak in the red time band as it tends to fall away from 16:00 onwards. However, any reduction that this sector can make during this period would serve to offset the residential peak and so it would be useful if suppliers could actively promote multi-rate tariffs to this group that mirrored the DUoS time bands.

Dynamic demand-side response – Our I&C DSR trials have shown that there is good potential for providing capacity to address post-fault peak loading constraints at EHV and HV and there are no major barriers to its use by DNOs in locations where there are sufficient willing and flexible customers located downstream of a network constraint. This will not always be the case but, where it is, we recommend that DSR should be the first choice option for addressing constraints. The key issues to address to enable DSR to be become more prevalent relate to the task of identifying and signing up these customers, at a price that is efficient relative to the counterfactual reinforcement costs, in a market where there is competition with other users of DSR (i.e. National Grid STOR). An arrangement where different parties are able to share DSR resource may create value for all stakeholders and is under development by the ENA DSR sharing group.

This report provides the results of our trials and describes a simple pricing methodology for setting a ceiling price based upon the counterfactual reinforcement scheme costs, years of scheme deferment, DSR set up and operating costs and the level of assumed DSR reliability. This gives an indicative ceiling price in the region of £17 per kW/yr or £2000 per MWh for a typical use case but the price will vary on a project by project basis.

We found that it is easier to procure DSR from standby generation than find a truly flexible load but we also found that reliability from the generation sites was not as good, particularly when it came to availability which was only 50%. This will improve as providers get more used to the idea but it also highlights a need for more research to identify flexible loads. The loads that we used were refrigeration and gas compression both of which provided 100% availability and 100% utilisation.

Generator voltage support – Operating generation in voltage control mode on a DNO network is an effective means of managing voltage through the control of reactive power. We have successfully trialed this with a 54MW wind farm and such an approach could provide an alternative to real power curtailment under certain circumstances.

Generator contribution to network security – A review of distributed generation profiles from a range of generation types has confirmed the contribution to system security as being appropriate as set out in "ENA ETR130 methodology for assessing the contribution of DG to network security" with the exception of wind turbines which we recommend should be reduced as follows:

Wind farms	**Persistence T_m (hours)**						
	0.5	**2**	**3**	**18**	**24**	**120**	**360**
ENA ETR 130	28%	25%	24%	14%	11%	0%	0%
CLNR trials	19%	15%	14%	8%	6%	0%	0%

Wind farm F factors: Comparison of ETR 130 figures against CLNR calculations

With respect to the overall methodology for calculating the contribution to security we recommend that a fully probabilistic risk-based planning approach be developed, using information from CLNR trials and the work from other LCNF studies, to support the "Review of ER P2/6 Working Group" of the Distribution Code Review Panel on the review of ETR 130 methodology for assessing the contribution of DG to network security.

Optimal solutions for smarter distribution systems

DNOs will be able to reduce the level of conventional reinforcement that would otherwise be required to address the growth in low carbon technologies (LCTs) by, instead, turning to smarter lower cost solutions.

The learning from our CLNR project has shown that there is no 'one-size-fits-all' solution to address the impact of LCTs and has demonstrated that the solutions can start relatively simply and evolve over time as the complexity of the constraint increases.

Power flow solutions often also solve voltage issues, which gives a logical order for DNOs, as follows:

Confirm the issue

- Model the issue to identify potential capability gaps
- Where necessary, monitor the network to validate the model

For thermal issues:

- Where cost-effective, carry out a bespoke thermal rating study, e.g.
  a. transformer thermal tests;
  b. soil thermal resistivity tests;
  c. wind speed measuring/modelling.

- Invite tenders for demand side management (demand side response, generation side response and electrical energy storage) priced against deferring the lowest cost conventional alternative.
- Where multiple demand side management (DSM) resources exist, capable of addressing multiple series power flow constraints, deploy an area coordinating control scheme.
- Reinforce where required to close the remaining capability gap.

For any remaining voltage issues

- Apply default 3% load-drop/generation-rise compensation setting on all active voltage control devices.
- Carry out bespoke voltage setting analysis for:
  a. increased load-drop/voltage-rise compensation settings;
  b. tighter dead-bands.
- Where contracts permit, direct controllable distributed generation (DG) to operate with bespoke reactive power settings (e.g. P-V mode).
- Where contracts permit, direct controllable DG to operate with bespoke real power settings (e.g. trimming real output to avoid breaching a defined upper voltage limit at the terminals).
- Invite tenders for DSM (here, for both real and reactive power, to address voltage issues), priced against deferring the conventional alternative.
- Deploy as many additional control devices as required, with bespoke analysis of settings:
  a. in urban areas, on load tap changer (OLTC) at the local substation serving the affected cluster;
  b. in rural areas, high voltage (HV) regulators.
- Deploy area control to coordinate the set-points of voltage control devices (including constrained DG).
- Reinforce where required to close the remaining capability gap.

The table below provides an overview of how the learning from CLNR will be taken forward by Northern Powergrid:

Method	Northern Powergrid deployment
New Customer Demands for Network Planning	We use the rich CLNR information set on existing customers' behaviour to: 1. publish existing network design coefficients for general domestic customers with high, medium and low annual consumption; 2. publish new sets of design coefficients, in an industry standard format and therefore suitable for existing industry standard tools, to represent emerging customer behaviour, specifically i) electric vehicles; ii) heat pumps; iii) solar PV.

Method	Northern Powergrid deployment
ToU tariffs	We will establish time-of-use tariffs for the distribution element of all customers' bills, once half-hourly metering becomes more widespread via the roll out of smart metering, and we will support the development of time-of-use tariffs by electricity suppliers.
Demand Side Management (DSM)	For those few major substations which we expect to approach capacity through 2023 (the imminent ED1 regulatory period), we will go to the market for DSM as an alternative to network solutions. We expect third parties to be better placed than DNOs to exploit additional income streams from EES, so we will explicitly rule EES in as an option for the contracted DSM service alongside DSR and GSR (but rule it out as a DNO capital investment).
Enhanced Ratings	Where initial assessment indicates reducing thermal margins, we will roll out bespoke rating assessments for transformers, overhead lines and underground cables - initially addressing constraints at the higher voltages, where the benefits are much greater relative to the cost.
RTTR	For DG connection customers and the providers of 'negawatts', we will offer real time thermal rating (RTTR) solutions on overhead lines and on transformers, to optimise the commercial viability of those developers' schemes.
Enhanced Voltage Control	We will roll out the use of enhanced load-drop (generation-rise) compensation to the target voltage setting of automatic voltage control relays.
Additional Voltage Control	a) We will roll out secondary distribution transformers with on-load tap changers (OLTC) for PV clusters. b) We will roll out the use of HV voltage regulators for HV feeders to customer groups whose load characteristics differ significantly from those around them.
Smart RTUs	We will deploy smart RTUs to manage the use of DSM at primary substations.
Area control	We will build on learning from CLNR, other recent Northern Powergrid schemes and from other DNOs' ANM projects, to roll out co-ordinated control for faster, lower cost solutions to connect DG to congested parts of the distribution system.
NPADDS	We will work with other DNOs to combine the learning generated from the range of design tools developed, mostly as prototypes, over recent years
TRANSFORM®	We will propose updates to TRANSFORM® to reflect: a) the reduced impact of LCTs relative to previous assumptions; b) better information on the costs and benefits of smarter solutions

The CLNR project demonstrated the application of individual solutions to address simple constraints but also demonstrated the integration and optimisation of multiple solutions to address more complex, perhaps multi-level constraints. It delivers the necessary understanding, tools and policy recommendations so that DNOs can adopt these solutions into business as usual in a co-ordinated way. It was always intended that CLNR would achieve increases in integration readiness levels (IRL) rather than raise the technology readiness levels (TRL) of individual technologies. However, we can also report that CLNR has also raised the TRL of a number of technologies, as shown in the table below. An explanation of TRL and IRL ratings are included in appendix 8.

As we have mentioned elsewhere, in some cases we discovered during the procurement process that technologies that we had expected to be high TRL commercial off the shelf (COTS) products were in fact at a lower TRL. The increases in TRL and IRL achieved by CLNR can be clearly seen in the table below. Further detail can be found in a suite of materials delivered by the project which describe how and when to deploy the solutions, and how to specify, install and operate the equipment. This suite, which is listed in Appendix 11, comprises policy updates, lessons learned reports, a cost benefit analysis, technical recommendations for purchase, equipment application guides, operational guidance notes, and training materials. Because of the high TRLs and IRLs in conjunction with this documentation, we consider that electrical energy storage and enhanced network monitoring are technically ready for deployment (although EES has some commercial hurdles in relation to its current cost), and EAVC and RTTR are ready to deploy, subject to further discussions with the Health and Safety Executive, in relation to revisiting their guidelines to ESQCR. With the GUS area control system, we have advanced the TRL and IRL of its various component parts, but as a whole system, we consider that it requires more development before it is commercially ready for wide-scale deployment.

Equipment		**TRL**			**IRL**		**Readiness for deployment**
		Before-expected	**Before - discovered**	**Now**	**Before CLNR**	**Now**	
Electrical Energy Storage (EES)	2.5MVA battery at primary substation (EES1)	9	7	9	6	8	Ready for deployment
	100kVA battery at distribution substation (EES2)	7	6	9	6	8	
	50kVA battery at distribution substation (EES3)	7	6	9	6	8	
Enhanced Automatic Voltage Control (EAVC)	Primary substation transformer with on-load tap changer (EAVC1)	8	8	9	6	9	Ready for deployment, subject to HSE revisiting their guidelines to ESQCR, to provide clarity on how to measure voltage, preferably explicitly referring to BS EN 50160
	Secondary substation transformer with on-load tap changer (EAVC2)	8	6	8	6	9	
	HV Regulator (EAVC3)	8	8	9	6	9	

Equipment		TRL			IRL		Readiness for deployment
		Before-expected	Before - discovered	Now	Before CLNR	Now	
	Switched capacitor bank (EAVC4)	8	8	9	6	9	
	LV main distributor regulator (EAVC5)	9	9	9	7	9	
Real Time Thermal Rating (RTTR)	Primary substation transformer (RDC)	8	5	8	6	9	The solution is ready for deployment, subject to HSE revisiting their guidelines to ESQCR, to provide clarity on how to assess the "sufficiency" of an asset and the "maximum likely temperature" of an overhead line. CLNR has highlighted how both these concepts are probabilistic rather than deterministic, so we need the law to recognise safe and efficient methods of designing power systems
	Secondary substation ground mounted transformer (RDC)	8	5	8	6	9	
	Overhead lines HV	9	7	9	5	9	
	Overhead lines EHV	9	7	9	5	9	
	Underground cables EHV	9	4	8	4	9	
	Underground cables HV	9	4	8	4	9	
	Underground cables LV	9	4	8	4	9	
Grand Unified Scheme (GUS)	GUS central controller	6	6	7	6	7	The version of the local and central controllers used for CLNR is, in itself, TRL9, because we've proven it on the operational system. Building on that success, we'd upgrade the specification for the BAU version of both local and area controllers, so we've downgraded the final TRL in this table to reflect that extra work
	14 GUS remote distribution controllers (RDC)	6	6	7	6	7	
	GUS Data Warehouse	9	9	9	7	9	
	Demand response system integrated into GUS control	7	7	9	6	9	
Monitoring	70 instances of monitoring equipment (of 3 different types) at a range of network locations	9	7	9	6	9	Ready for deployment
	iHost data warehouse	9	9	9	8	9	

5. PEFORMANCE COMPARED TO THE ORIGINAL PROJECT AIMS

We set out to deliver cost effective solutions to managing the additional strain that will be placed on electricity distribution networks that will be caused by the transition to a low carbon economy, in particular the change to load and generation patterns due to the forecast growth of LCTs.

We have achieved this by delivering learning that quantifies the impact of future load and generation profiles, quantifying the scale and cost of both network flexibility and customer flexibility and providing a decision support tool and a control system that are able to optimise from a range of solutions to provide the most appropriate solutions for deployment to address a range of constraints and, once deployed, operate the solutions in real-time to provide the optimum response based upon real-time network monitoring / modelling. Despite the many difficulties we encountered, we remained true to the project aims and have successfully undertaken trials with significant numbers of real customers on real networks, have deployed and monitored on both rural and urban networks the full range of planned smart grid technologies (enhanced monitoring, real time thermal rating, battery storage, enhanced voltage control and demand side response) and developed the overarching optimisation / control system that brings it all together. We developed new research and modelling techniques through the development of the Validation – Extension – Extrapolation – Enhancement - Generalisation (VEEEG) post-trial analysis methodology that enhanced the applicability of the results from the CLNR trials and demonstrate application to most of the GB distribution network.

We have achieved the project aims, within the original budget, but also delivered substantial additional learning not originally envisaged. This extends the breadth and richness of the learning as well as providing detail of our experiential learning and delivery of methodologies which can be used by others in the field. More detail on this additional learning is available in appendix 1. We have performed well against our successful delivery reward criteria, achieving the specified activities and outputs, as set out in the table below.

Ref.	Criterion	Status
1	Commence installation and commissioning of network equipment relating to learning outcome 3 – September 2011	Completed on time
2	Complete installation and commissioning of network equipment relating to learning outcome 3 – December 2013	Completed on time
3	Project close down report produced – December 2014	Completed on time
4	Project website up and running by end May 2011 and updated in line with project developments	Completed on time
5	Industry stakeholder forum held on an annual basis, by end May 2011, May 2012 and December 2013	Completed on time
6	Distributor project review meetings held by end July 2012 and December 2013	Completed on time
7	Regional stakeholder panel meeting held on an annual basis	Completed on time

Ref.	Criterion	Status
	by end March 2011, March 2012 and December 2013	
8	Demand profiles grouped by customer type, interim by end 2012, finalised August 2014	Fully completed (95% on time) 14 of the datasets (covering *ca.* 95% of trial participants) and a guide to the datasets were published on time. The balance was published before project end.
9	Demand profiles grouped by low carbon technology type interim by end 2012, finalised August 2014	
10	Output profiles of existing generation types, interim by end 2012, finalised August 2014	
11	Output/ demand profiles before and after a range of interventions interim by end April 2013, finalised August 2014	
12	Network data showing performance of selected network technologies by end October 2014	Completed on time
13	Publish analysis of load profile data by end October 2014	Completed on time
14	Publish analysis of generation profile data by end October 2014	
15	Provide an understanding of, and disseminate by end December 2014 to other distributors, how advanced voltage control, thermal ratings and storage may be integrated to enable more low carbon technologies to be accepted on the network. Provide a view of the costs associated with these arrangements	Completed on time Advance copies provided to Ofgem and the DNO peer reviewer on time with full publication in January 2015
16	Undertake, and disseminate by end December 2014 to other distributors, a critical review of how commercial models and arrangements between distributor and supplier may evolve to facilitate customer-side response	Completed on time Advance copies provided to Ofgem and the DNO peer reviewer on time with full publication in January 2015

6. REQUIRED MODIFICATIONS TO THE PLANNED APPROACH DURING THE COURSE OF THE PROJECT

In the September 2010 bid, we set out what we would deliver in each learning outcome and the method to do this. We have encountered many and varied difficulties, as would be expected in any project, not least an innovation project of this scale, complexity and ambition. To achieve our objectives within the overall budget we had to find ways to overcome these issues. In some cases this meant modifying our approach although the trial methodology remained fundamentally unchanged.

Some of the issues we encountered were due to material changes in external circumstances, and these circumstances were the subject of a formal change request to Ofgem:

- Scarcity of customers with heat pumps and EVs, requiring the recruitment of non-British Gas customers which entailed more complex monitoring systems to be designed and installed, and the sourcing of additional £2.8m DECC funding to achieve heat pump installations.

- Rent-a-roof PV providers not agreeing to the necessary monitoring, requiring the recruitment of additional customers.
- The decision by a manufacturer of smart appliances identified at the bid stage not to enter the UK market, requiring the sourcing of a new supplier.
- The procurement and manufacture of novel network technology has taken longer than planned, due to a variety of external factors.

Addressing these issues required four material changes to the project:

1. The final outputs of learning outcome 1 (monitoring) and learning outcome 2 (customer flexibility) delivered by the end of August 2014 (respectively 21 and 17 months later than in the original plan).
2. The final outputs of learning outcome 3 (network technology) delivered by December 2014 (15 months later than in the original plan).
3. The final outputs of learning outcome 4 (optimum solutions) and learning outcome 5 (effective delivery) delivered by December 2014 (15 months later than in the original plan).
4. The overall budget remained the same as in the Project Direction due to efficiencies and the use of contingency budget, but extended over one more year to the end of 2014 and was rebalanced across the Project Direction categories.

Neither the quality of learning, nor the cost of its achievement, was affected by the increased length of the project, only the timescales of the delivery where the final outputs were delivered one year later than planned.

Appendix 2 provides an update on the combinations of customer type (domestic/SME/I&C/DG), technology type (none, HP, EV, PV, responsive load/generation, PV load balancing) and commercial proposition (flat rate, TOU, RH, DC) that were trialled. Despite the external circumstances described above, we recruited sufficient customers to allow each customer type, each technology type and each type of commercial proposition to be trialled.

Appendix 3 describes the changes to the detailed design of the customer profiling (learning outcome 1) and customer flexibility (learning outcome 2) trials. It explains:

- why we recruited customers from outside the Northern Powergrid region;
- why we created subgroups within the enhanced monitoring of general load domestic customers to study electric space and water heating;
- the choice of technologies for the interventions trials;
- why we changed the commercial proposition for within-premises balancing for PV customers;
- how we studied the effect of heat pumps on the network; and
- the design of the time of use tariff.

Appendix 4 describes the size of the data sets relative to what was proposed in the bid. The test cells are categorised as follows:

- Proof of concept (test cells 4, 18, 19);
- Analysis of existing data (test cell 7); and
- 'Statistical' or 'case study' (all remaining test cells).

7. SIGNIFICANT VARIANCE IN EXPECTED COSTS

Despite the one-year time extension, we will complete the project and conduct the subsequent closedown phase within the original £31m budget.

In the early stages of the project we reviewed our procurement strategy and to reflect this Ofgem approved restructuring changes to the original budget in the December 2010 project direction. This moved £1.109m of budget from the 'EA Technology' contractor cost line to various cost lines for network equipment, and £172k of budget from the 'Commercial analyst' employment cost line to the 'DUoS tariff design' contractor cost line. This budget became the baseline budget for the project.

In 2012, we raised a formal change request seeking a one year extension from an original completion date of the end of 2013 to a revised completion date of the end of 2014. At the same time we requested a second restructuring of the detail of the project budget i.e. movement of budget between cost lines to reflect changes in costs associated with the addressing the externalities described in the change request. The budget agreed during the change request process is referred to as the revised budget. With project efficiencies and the use of some of the contingency budget we have been able to cover the cost of extending the project such that it will be delivered within the same overall budget.

The following table summarises actual costs, based upon actuals to end December 2014 and a forecast of the closedown costs to end March 2015, and compares this to the baseline budget and to the revised budget. The overall costs remain within the baseline budget but, for all cost categories except equipment costs, the actual cost varies from the baseline budget by more than +/-10%, and these variances, as well as the variances of equipment costs are discussed below the table.

	Baseline budget	Revised budget	Actual expenditure	Expenditure compared to baseline budget		Expenditure compared to baseline budget	
	£m	£m	£m	£m	%	£m	%
Box 6 (Employment costs)							
Project Manager	1.013	2.537	2.409	1.396	138%	(0.128)	-5%
Technical Engineer	1.514	1.231	1.390	(0.124)	-8%	0.159	13%
Project Accountant / Procurement	0.244	0.088	0.078	(0.166)	-68%	(0.010)	-12%
Administrator	0.216	0.110	0.116	(0.100)	-46%	0.006	5%
Commercial analyst/manager	0.321	0.409	0.234	(0.087)	-27%	(0.175)	-43%
	3.308	**4.375**	**4.227**	**0.919**	**28%**	**(0.148)**	**-3%**
Box 7 (Equipment costs)							
600 systems for direct management of PV export	0.859	0.281	0.290	(0.569)	-66%	0.009	3%
450 'smart energy' systems	0.299	0.074	0.073	(0.226)	-75%	(0.001)	-1%
1,670 detailed energy profiling systems	0.417	1.378	1.365	0.948	227%	(0.013)	-1%
600 Load controllable white goods	0.149	0.165	0.164	0.015	10%	(0.001)	0%
Domestic CHP	0.197	0.080	0.080	(0.117)	-59%	(0.000)	0%
Direct control other	0.193			(0.193)	-100%	0.000	
Customer trials equipment subtotal	***2.114***	***1.978***	***1.973***	***(0.141)***	***-7%***	***(0.005)***	***0%***
Electrical Energy Storage	5.569	5.829	6.420	0.851	15%	0.591	10%
Network Monitoring	0.355	0.511	0.522	0.168	47%	0.011	2%
Voltage control	0.565	0.484	0.721	0.156	28%	0.237	49%
Real time thermal rating	0.888	0.493	0.460	(0.428)	-48%	(0.033)	-7%
Control interfaces	2.643	3.370	3.189	0.546	21%	(0.181)	-5%
Network trials equipment subtotal	***10.020***	***10.687***	***11.311***	***1.292***	***13%***	***0.624***	***6%***
	12.134	**12.665**	**13.284**	**1.150**	**9%**	**0.619**	**5%**
Box 8 (Contractor costs)							
British Gas	3.206	3.867	3.923	0.717	22%	0.056	1%
EA Technology Limited	3.927	4.086	4.050	0.123	3%	(0.036)	-1%
Durham Energy Institute (Durham University)	2.790	3.640	3.966	1.176	42%	0.326	9%
Expert challenge function	0.051	0.050	0.033	(0.018)	-35%	(0.017)	-34%
DUoS tariff design	0.222	0.233	0.184	(0.038)	-17%	(0.049)	-21%
Dissemination	0.264	0.317	0.264	0.000	0%	(0.053)	-17%
	10.460	**12.193**	**12.419**	**1.959**	**19%**	**0.226**	**2%**
Box 9 (Customer and user payments)							
Domestic customers	0.531	0.281	0.235	(0.296)	-56%	(0.046)	-16%
Small commercial customers	0.237	0.218	0.125	(0.112)	-47%	(0.093)	-43%
	0.768	**0.499**	**0.360**	**(0.408)**	**-53%**	**(0.139)**	**-28%**
Box 10 (Other costs)							
IT costs	0.140	0.110	0.145	0.005	4%	0.035	32%
Contingency	3.346	0.600	0.000	(3.346)	-100%	(0.600)	-100%
Decommissioning	0.828	0.507	0.491	(0.337)	-41%	(0.016)	-3%
Other	0.050	0.084	0.108	0.058	116%	0.024	28%
	4.364	**1.301**	**0.744**	**(3.620)**	**-83%**	**(0.557)**	**-43%**
Total costs	**31.034**	**31.033**	**31.034**	**0.000**	**0.00%**	**0.001**	**0.00%**

Box 6: Employment costs

The employment costs are 28% or £919k above the original budget. We incurred £1.40m of additional cost for project management staff who were needed to address the multiple and complex challenges we faced (see section 6) and for an additional year. This was partially offset by £478k of reductions in the cost of other staff groups.

Box 7: Equipment costs

Overall equipment costs are £1.15m or 9% above the original budget. This comprises a reduction of £141k or 7% in the cost of equipment for the customer trials, and an increase of £1.29m or 13% in the cost of the equipment for the network trials.

Customer trials equipment

The numbers of customers participating in trials which required equipment other than just a standard smart meter was lower than budgeted for at the bid stage. This is why the expenditure for some types of equipment (systems for managing PV export, smart energy systems, CHP) is below budget. The absence of costs for 'direct control other' reflects the cancellation of the direct control test cells for domestic EV customers and for SMEs, and the decision to use aggregators to call demand side response, rather than to deploy new equipment for this purpose. The increase in costs for load controllable white goods of £15k or 10% reflects the fact that we took a strategic decision to fully rather than part subsidise the smart appliances. More significantly, the costs of detailed energy profiling systems increased by £948k or 227%, and the issues behind this are explained in appendix 7.

Network trials equipment

The most significant increase in costs were for the six electrical energy storage units at £851k or 15% more than baseline, and for control interfaces at £546k or 21% more than the baseline budget. Conversely, the cost of the real time thermal rating came in at £428k or 48% under budget.

Box 8: Contractor costs

Overall contractor costs are £1.96m or 19% above the baseline budget, with the majority of the cost increase being due to the £717k increase in British Gas costs and £1.18m increase in Durham University costs. These increases in contractor costs are due to the complexity of the issues encountered during the project and the need for a one-year extension. In contrast, despite the one-year extension, EA Technology's increase in costs were limited to just 3% due to efficiencies in ways of working that they were able to achieve.

Box 9: Customer and user payments

The cost of customer and user payments is down by £408k or 53% due to the reduced numbers of customers participating in active trials.

Box 10: Other costs

This includes the contingency budget which we have used in full. Decommissioning costs have reduced by £337k or 41% reflecting a reduction in the number of customers participating in active trials.

Summary

This table below illustrates the summary position which is explained as follows:

- The personnel costs are a total of £2.94m greater than the baseline budget;
- The costs for the customer trials are £0.89m below the baseline budget;
- The costs of the network equipment are £1.30m greater than the baseline budget;
- With the net effect of these movements and by drawing down the full £3.35m contingency budget, we have completed the project within the baseline budget.

	Baseline budget £m	Actual expenditure £m	Expenditure compared to baseline budget £m
Box 6 (Employment costs)	3.31	4.23	0.92
Box 8 (Contractor costs)	10.46	12.42	1.96
Box 10: Other	0.05	0.11	0.06
Subtotal of personnel costs	**13.82**	**16.75**	**2.94**
Box 7: Customer trials equipment subtotal	2.11	1.97	-0.14
Box 9 (Customer and user payments)	0.77	0.36	-0.41
Box 10: Decommissioning	0.83	0.49	-0.34
Subtotal of customer related costs	**3.71**	**2.82**	**-0.89**
Box 7: Network trials equipment subtotal	10.02	11.31	1.29
Box 10: IT costs	0.14	0.15	0.01
Subtotal of network equipment costs	**10.16**	**11.46**	**1.30**
Box 10: Contingency	**3.35**	**0.00**	**-3.35**
Total costs	**31.03**	**31.03**	**0.00**

8. UPDATED BUSINESS CASE AND LESSONS LEARNT FROM THE METHOD

The learning from the project has been used to update the original business case that was presented in the bid.

On the assumption that the project learning is adopted nationally (where the learning is replicable), it is estimated that the project will deliver, to consumers over the period 2020 – 2050, a present value (i.e. discounted to 2014 value) of **between £4.87bn and £25.6bn** of net financial benefits, including value from between 10.8MtCO_2 and 32.5MtCO_2 emission savings. The cost to customers of undertaking the project was **£31m**.

The extreme values of these ranges correspond to the lowest and highest scenarios for future penetration rates from the latest DECC LCT Growth Projections. The realisation of these benefits is dependent on the rate of proliferation of low carbon technologies.

These benefits comprise the following high level benefit areas:

- **network capital cost savings** from avoided costs associated with reinforcing the electricity distribution networks to support additional load and increased variability of supply and demand;
- **direct customer benefit** from payments to customers associated with DSR flexibility;
- **carbon emission savings** relating to acceleration of the connection of LCTs; and
- **generation capital cost savings** from avoided costs associated with reducing peak generation requirements.

NPV net financial benefits over period 2020-2050 £billion in 2014 money	**Original business case**	**Revised business case**	
		Low	**High**
Network capital cost savings	£2.33	£3.25	£17.70
Direct customer benefit	£0.36	£1.30	£7.00
Carbon emission savings	£2.64	£0.32	£0.94
Generation capital cost savings	£0.96		
Total	**£6.30**	**£4.87**	**£25.64**

The revised benefits of £4.87-£25.64 billion can be compared with the benefit estimate in the previous business case of £6.30 billion (present value in 2014), noting that the previous business case also included the avoided peak generation benefit, which is not included in this business case. More detail on the calculation of the revised business case is in Appendix 10.

Comparing the financial benefits accruing from the CLNR project, which were estimated at bid stage, with those calculated for this business case, it can be seen that:

- The network capital cost savings from this business case range from greater to significantly greater than the previous value;
- The direct customer benefits from this business case range from greater to significantly greater than the previous value; and
- The carbon emission savings benefits range from significantly lower to lower than the previous value. This is predominantly due to the change in forecast uptake of PVs from 2038 onwards.

The costs and benefits of the technologies have been assessed by EA Technology by applying CLNR outputs into the Transform™ model, in place of the relatively simple, bespoke cost benefit assessment model which was used to prepare the business case for the bid. Transform™ is the industry standard approach to forecasting benefits and costs of changes to distribution networks to accommodate low carbon technologies. It is used by Ofgem and all DNOs.

The CLNR project has successfully purchased, commissioned and tested a wide range of smart solutions for distribution networks. For all of these technologies, the costs and benefits have been carefully monitored and assessed and network cost benefits based on the anticipated business-as-usual installed costs and monitored performance of the smart solutions have been calculated for each ED period and from 2020 to 2050 using the Transform™ Model. The technologies and learning assessed were:

- Enhanced Automatic Voltage Control;
- Real Time Thermal Rating (RTTR) of transformers, underground cables and overhead lines;
- Demand Side Response (DSR);
- Electrical Energy Storage; and
- New LCT load profiles.

The calculations and our learning from installing these technologies show that CLNR has been a major success in identifying potential improvements to current "business as usual" practices. The major findings and their impact on benefits are as follows:

- The major smart grid technologies which appear most likely to succeed include:
    - EAVC HV regulator;
    - EAVC distribution OLTC;
    - DSR for I&C customers;
    - RTTR for primary and secondary transformers; and
    - RTTR for EHV and HV overhead lines.

Energy storage is currently an expensive technology for DNOs but could become competitive for an energy service company to provide services to multiple parties in a few years' time.

- For the time period from 2020 - 2050, the full suite of CLNR smart technologies is predicted to reduce distribution network reinforcement costs by between £3.25bn and £17.7bn dependent on the uptake rate of LCTs.
- Between 2020 and 2050, payments associated with DSR flexibility of between £1.3bn and £7bn are predicted to be made by DNOs to I&C customers.
- Over the time period 2020 to 2050, a reduction in emissions of between 10.8MtCO2 and 32.5MtCO2 is predicted.

There are a number of additional benefits not captured in the updated business case:

- A possible further reduction of at least £500m from 2020- 2050 based on better load profile data for LCTs has been identified. This learning will be added into the Transform Model governance process for further consideration by the DNOs.
- There is further scope for substantial savings from the learning of this project in some areas which will require further work. These areas include:
    - A review of Engineering Recommendation P27 where we are considering new rating values for OHLs on redundant circuits.

    - Time of Use Tariffs for DSR for domestic customers, which will require further research, development and regulatory review.
- In addition to the network benefits, resulting from capital investment savings quantified above, the CLNR project has helped to keep the UK in the vanguard of smart technology development and this will undoubtedly lead to opportunities for job creation and carbon reduction.
- The key objective of the CLNR project has always been to demonstrate a holistic approach to managing the smart grid with our aim being systems integration, rather than trialling of individual technologies or solutions, and the way in which we approached this integration. We deliberately set out not to use the systems of one supplier, but to seek individual specialist suppliers and integrate them into a flexible control system. Although this made delivery more complex, we maintain that as well as delivering better value for money than contracting a single large supplier and system integrator, it is better for overall market development and the for the future roll-out of low carbon network control systems.
- By advancing a wider awareness of the network issues associated with the low carbon transition and of possible solutions (see section 12).

We have not discovered significant problems with the approach and technique being trialled – all the solutions we have studied have the potential to deliver benefits to customers, either via reduced connection costs or DUoS charges, or directly by payments to customers for demand side services. The likely timescale for adoption at scale on a business as usual basis varies depends upon the solution in question, and this is covered in section 11.

We did, during the course of the project, need to make a number of detailed design changes to ensure that we could deliver the planned learning (see section 6). That this was necessary reflects the fact that this was an R&D project and we were attempting to trials solutions in advance of them being widely adopted, not because there were significant problems with those solutions.

9. LESSONS LEARNT FOR FUTURE INNOVATION PROJECTS

CLNR was the largest LCN fund project. The high number of customer participants makes it one of the largest investigations into customers' electrical practices and behaviour ever recorded. This section looks at lessons learned during the CLNR project. We recognise that quite apart from the importance of the research findings from this project, there are valuable lessons to be learnt from the experience of carrying out such a project that would be of benefit to future innovation projects.

The CLNR 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 broad range of social and technical innovations on real networks with real customers, and in real time. With innovation comes risk, both of failure and of 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 and configuration of smart appliances, and the implementation of monitoring equipment for control, 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 an independent report[4] on this. 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 learned 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.
- A project 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 did seem to make the offer more attractive in recruiting participants.
- Reasonable numbers of residential customers were 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.

[4] CLNR-L036: Project lessons learned from trial recruitment (2013)

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

- Arranging times for installation was difficult as it often involved 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 an important consideration future project's installing smart appliances.
- Smart appliances are still at an immature product lifecycle 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.

Industrial & Commercial (I&C)

Although we plan to introduce I&C DSR into business as usual, further innovation will continue to be needed to develop suitable solutions. The following lessons from CLNR are therefore valid.

- Locating customers that are willing to offer the level of DSR response required by DNOs is difficult.
- The nature of call off required is likely to reduce the number of customers that are capable or willing to participate in these schemes.
- When targeting a tight geographic area the initial customer drop-out rates can be high. The DSR reliability levels experienced during the trials means that DNOs need to over-procure capacity to achieve the required level of network security.
- The contract arrangements need to be simple to understand, simple to operate and they must offer a fair price to the provider and the DNO in order to be viable.
- It is easier to procure DSR from standby generation than find a truly flexible load.

Network technologies and trials

All the individual technology types deployed in CLNR had been developed and trialled before the project began and so our assumptions were for relatively high TRL commercial off the shelf (COTS) solutions to be available. Most of our bid assumptions were correct in respect of TRLs; however, we found the TRLs of some technologies to be less than expected and, since we were generally not dealing with mature technologies, this is perhaps not surprising in hindsight. We found that some solutions offered as COTS and which passed acceptance testing, needed some modification. Although the readiness of some products being slightly lower than expected had a negligible effect on learning, it did have a material impact on time in terms of procurement and in the complexity of integration with other systems.

Where an innovation project involves network equipment, we would recommend early engagement with Health and Safety stakeholders within the DNO and in some cases external, such as the HSE, the emergency services and industry working groups. The identification of hazards and the mitigation measures to reduce risk should give confidence to Health and Safety colleagues and other affected colleagues such as control, operations and protection engineers, to enable the trial equipment to be successfully deployed and operated on the live network. In some cases it may be necessary to also develop new procedures to cover the installation or operation of novel equipment or new methods of installation or operation.

One needs to consider carefully and plan for the degree of ongoing specialist input that is needed to manage the introduction of novel technologies onto the network and to integrate technologies, and from where that specialist input will be obtained; in–house, outsourced, from within the supply chain.

A successful trial requires the participation from a wide number of areas of the business such as safety, control, operations, training and protection etc. When then working towards transition from a trial to roll out into BAU, the methods associated with this new equipment will require integration into all these areas of the business and some more, such as system strategy, design and maintenance, and this will require updates to a number of existing policy and procedural documents, and in some cases creation of entirely new material. Confidence in new technology is realised from experience with it, an amount of expert thinking time to consider all outcomes is essential and provision for this should be built into any project plan.

One needs to be clear about the level of reliability that is required when deciding on the communications infrastructure. For example, especially in rural areas, GPRS communications may not be able to provide the level of reliability that is required for control purposes, although it may be possible to cost effectively address this by use of roaming SIM contracts (and similarly, roaming SIMs could provide field staff on operational duty with better coverage in all areas). By deciding what should be measured and controlled remotely rather than centrally, it may be possible to reduce the communications burden and infrastructure required, while at the same time form part of the fail-safe mechanism in the event of communications loss.

In deciding where to trial new equipment, the footprint space requirement for some types of equipment is likely to be a constraining factor, just as it might be in business as usual.

Be aware that, in some cases, there may be seasonality in the performance of the technology. For example, we found that noise levels from the EES cooling systems were higher in the summer months when under full trials operations and temperatures were higher. We fitted noise attenuation shrouds installed at the rural EES units in response to residents’ concerns.

While the trials might suggest that a particular technology is not currently viable in the current DNO business model and regulatory environment, in order to gain maximum benefit from the investment in an innovation project, it is important to be able to suggest other business models that could realise a benefit and identify the circumstances and regulatory environment under which that benefit could be realised.

A series of four reports[5] provides more detail on the 'lessons learned' in relation to EES, RTTR, EAVC and GUS.

10. PROJECT REPLICATION

The network equipment that a DNO would need to implement the CLNR solutions and the anticipated business as usual costs to purchase the equipment are set out in the table below.

Equipment		**BAU cost £ Per unit**
Electrical Energy Storage (EES)	2.5MVA battery at primary substation (EES1)	£4,150,000
	100kVA battery at distribution substation (EES2)	£490,000
	50kVA battery at distribution substation (EES3)	£410,000
Enhanced Automatic Voltage Control (EAVC)	Enhanced voltage control at primary substations (EAVC1)	£45,000
	Secondary substation transformer with on-load tap changer (EAVC2)	£100,000
	HV Regulator (EAVC3)	£52,000
	Switched capacitor bank (EAVC4)[6]	£2,000,000
	LV main distributor regulator (EAVC5)	£93,000
Real-Time Thermal Rating (RTTR)	Primary substation transformer (RDC[7])	£20,000
	Secondary substation ground mounted transformer (RDC)	£15,500
	Overhead lines HV	£12,300
	Overhead lines EHV	£16,600
	Underground cables EHV	£55,000
	Underground cables HV	£55,000
	Underground cables LV	£26,000

In addition to the above physical components, a DNO would also require knowledge of how and when to deploy the solutions, and how to specify, install and operate the equipment. To this end we have produced policy updates, lessons learned reports, a cost benefit analysis, technical

[5] Lessons learned reports (CLNR-L163, CLNR-L164, CLNR-L165 and CLNR-L167) are available on the CLNR website project library

[6] The capacitor bank existed as part of Northern Powergrid's network but CLNR integrated it into the Denwick area control system.

[7] RDC means 'remote distribution controller'

recommendations for purchase, equipment application guides, operational guidance notes, and training materials. All this documentation is freely available in the CLNR project library.

The DNO would also require that its tools for network planning and design adequately reflect the solutions trialled by the CLNR project. A specification for such a system known as Network Planning and Design Decision Support or NPADDs has been developed and is also freely available in the CLNR project library. The working prototype which was developed, and which contributed to the development of the specification for an enduring system, can also be demonstrated. There have been a number of design tools developed in recent DNO R&D projects, and all DNOs need to share what each has learnt to develop something which combines the best aspects of each approach.

To implement co-ordinated area control, a DNO would also require an active network management system comprising a central controller and data warehouse, a system to call demand response, remote terminal units, and network monitoring equipment. The CLNR library contains information on all these subjects[8], which is all freely available to GB DNOs.

We recognise that there would be value in a comprehensive compare-and-contrast exercise between the DNOs, where we take stock and each share what we've learnt about the various co-ordinated control schemes that we have separately developed and deployed. We will share what we have learnt both through informal exchange and in the more structured environment of the ENA ANM WG. The outcomes of the latter will be captured in a good practice guide. There will be no one-size-fits-all solution, but we would then be better prepared to specify and implement appropriate solutions, and also to stimulate a competitive market for providing these solutions.

Finally, a DNO would need knowledge of customer current and future demand profiles to inform network planning and to establish time of use tariffs for the distribution element of customers' bills. The learning that we have created from our extensive analysis of customer data has been published and is freely available on the project library, together with the underlying data sets. We have proposed changes to industry design policy and guidance documents, in the following documents, which are available in the website project library.

- CLNR-L185: Review of the distribution network planning and design standards for the future low carbon electricity system
- CLNR-L248: Optimal solutions for smarter distribution systems

Adoption of these changes will be subject to normal industry governance.

[8] CLNR-L232: Enhanced Network Monitoring Report
CLNR-L167: Lessons Learned Report: Grand Unified Scheme
CLNR-L154: Technical recommendation for the purchase of an Active Network Management system
CLNR-L160: Application Guide: CLNR Demand Side Response Trials
CLNR-L161: Operational Guidance and Training Requirements: Grand Unified Scheme (GUS)
CLNR-L172: Training Package: Active Network Management
CLNR-L173: Training Package: Demand Side Response

11. PLANNED IMPLEMENTATION

A full description of how Northern Powergrid plans to modify its distribution system as a result of the learning from this project is included in report CLNR-L248: Optimal solutions for smarter distribution systems and summarised in the following table which:

- Summarises the Northern Powergrid implementation plans.
- Identifies the actions required by DNOs and other parties to enable implementation;
- Gives a view on the likelihood of wider implementation; and
- Provides recommendations on how the CLNR outcomes can be further exploited.

In the course of the project we have identified a number of barriers to implementation. During the consultation process on this closedown report, we will ensure that the barriers are explicitly identified as well as the next steps to address those barriers.

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
New Customer Demands for Network Planning	We will use the rich CLNR information set on existing customers' behaviour to: a) publish existing network design coefficients for general domestic customers with high, medium and low annual consumption; b) publish new sets of design coefficients, in an industry standard format and therefore suitable for existing industry standard tools, to represent emerging customer behaviour, specifically: i) electric vehicles; ii) heat pumps; iii) solar PV	These would all amend ENA ACE 105: adoption is subject to normal industry governance		We see no reason why these coefficients should not be adopted across all DNOs for all LV design assessments, except for the simplest	There are some customer groups where we struggled with recruitment. Applying CLNR methods, particularly the contribution of the academic partners, to more customers of those types could increase our confidence in the results

[9] If the Method is not ready to be implemented, the DNO should explain what needs to happen, including any necessary further work, before the Method(s) can be implemented
[10] i.e. recommendations of what form of trialling will be required to move the Method to the next TRL

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
ToU tariffs	We will establish time-of-use tariffs for the distribution element of all customers' bills, once half-hourly metering becomes more widespread via the roll out of smart metering, and we will support the development of time-of-use tariffs by electricity suppliers.		Electricity suppliers need to build on the time-of-use pricing signals already there for large customers and being made available for all customers, to offer time-of-use tariffs to their customers	We will offer ToU tariffs for all our customers; take-up will be dictated by the roll out of smart meters, the tariff offerings from electricity suppliers, the extent to which suppliers promote these tariffs and the response by customers.	This solution is ready for deployment

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
DSM (DSR, GSR and EES)	For those few major substations which we expect to approach capacity through 2023 (the imminent ED-1 regulatory period), we will go to the market for DSM as an alternative to network solutions. We expect third parties to be better placed than us to exploit additional income streams from EES, so we will explicitly rule EES in as an option for the contracted DSM service alongside DSR and GSR (but rule it out as a capital investment for our business)	Develop a capability to identify DSR potential and to market and manage DSR contracts either directly or via an aggregator or supplier.	a) Potential providers of "negawatts" from energy storage, or other sources, need to exploit the revenue streams we have identified in the Commercial Arrangements report, so that they may release the full value of their product. We expect this to bring more such providers forwards; b) EES manufacturers need to develop their products to improve their viability. this is not just about cost, but also about practical installation issues such as size, weight and noise	We will always look for negawatts as a solution to power flow constraints at major sites. Take up will be constrained only by our customers, either in whether they continue to consume more electricity and therefore advance power flow constraints, or whether they are able and willing to offer negawatts at a competitive rate relative to the lowest cost network solution	This solution is ready for deployment

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
Enhanced Ratings	Where initial assessment indicates reducing thermal margins, we will roll out bespoke rating assessments for transformers, overhead lines and underground cables We will start to address constraints at the higher voltages, where the benefits are much greater relative to the cost	This solution is ready for deployment	HSE need to revisit their guidelines to ESQCR, to provide clarity on how to assess the "sufficiency" of an asset and the "maximum likely temperature" of an overhead line. CLNR has highlighted how both these concepts are probabilistic rather than deterministic, so we need the law to recognise this as a safe and efficient method of designing power systems	Over time, as the load increases, all our higher voltage circuits will benefit from bespoke assessment	Over time, as the load increases, all our higher voltage circuits will benefit from bespoke assessment

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
RTTR	For DG connection customers and the providers of "negawatts", we will offer RTTR on overhead lines and on transformers, to optimise the commercial viability of those developers' schemes	This solution is ready for deployment	HSE need to revisit their guidelines to ESQCR, to provide clarity on how to assess the "sufficiency" of an asset and the "maximum likely temperature" of an overhead line. CLNR has highlighted how both these concepts are probabilistic rather than deterministic, so we need the law to recognise this as a safe and efficient method of designing power systems	We will make full-blown RTTR available across the higher voltage network, but we expect take-up to be low initially	Applying CLNR research methods, particularly the contribution of the academic partners, to more overhead line trials could increase our confidence in the results

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
Enhanced Voltage Control	We will roll out the use of enhanced load-drop (generation-rise) compensation to the target voltage setting of automatic voltage control relays	This solution is ready for deployment		We will roll out the use of load-drop (generation-rise) compensation to the target voltage setting of automatic voltage control relays to the vast majority of our sites, excluding only those that serve compact industrial networks	This solution is ready for deployment
Additional Voltage Control	a) We will roll out secondary distribution transformers with OLTC as a business-as-usual solution for PV clusters b) We will roll out the use of HV voltage regulators as a business-as-usual solution for HV feeders to customer groups whose load characteristics differ significantly from those around them	This solution is ready for deployment	HSE need to revisit their guidelines to ESQCR, to provide clarity on how to measure voltage, preferably explicitly referring to BS EN 50160	Take-up of the secondary OLTC and HV regulators depends upon how competitive they are with respect to other solutions: we expect to deploy a handful of each every year	This solution is ready for deployment
Smart RTUs	We will deploy smart RTUs to manage the use of DSM to off-load primary substations (see previous note on DSM)	This solution is ready for deployment		This is an enabler to DSM (see previous)	We have learnt a lot about the behaviour of these units during CLNR, so we would likely adjust the algorithms slightly before rolling out in to BaU.

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
Area control	We will build on what we have learnt in CLNR, on what we learnt from our Blyth GEMS scheme (which manages over 500MW of generation to relieve a power flow constraint at the DNO/NGET boundary), and on what we have learnt from other DNOs' ANM projects, to continue to roll out co-ordinated control as a business-as-usual solution for faster and cheaper solution to connected DG to congested parts of the distribution system	The version of the local and central controllers used for CLNR is, in itself, TRL9, because we've proven it on the operational system. Building on that success, we would upgrade the specification for the BAU version of both local and area controllers, so there is some further work to achieve this level of functionality		We expect to see three or four co-ordinated control schemes commissioned each year in GB. These may not be exactly the same as the vendor-specific CLNR solution, but many of the same principles will apply. We expect only one or two opportunities to arise before 2023 in GB which demand the complexity of the vendor-specific CLNR solution	There would be value in a comprehensive compare-and-contrast exercise between the DNOs, where we discuss what we have learnt about the various co-ordinated control schemes we have deployed We will share what we have learnt both through informal exchange and in the more structured environment of the ENA ANM WG. The outcomes of the latter will be captured in a good practice guide There will be no one-size-fits-all solution, but we would then be better prepared to specify and implement appropriate solutions, and also to stimulate a competitive market for providing these solutions
NPADDS	We will work with other DNOs to combine the learning generated from the range of design tools developed, mostly as prototypes, over recent years	The vendor-specific solution deployed in CLNR is at around TRL6, so it requires more development to become available as a commercial product		Modelling capability like that developed in NPADDS will be required by every DNO	There have been a number of design tools developed in recent DNO R&D projects, and we need to share what we have each learnt to develop something which combines the best aspects of each approach

Method	How Northern Powergrid plans to modify its Distribution System based on CLNR learning.	Implementation requirements[9]		Likelihood of wide-scale deployment	Recommendations on how the CLNR outcomes could be exploited further [10]
		DNO actions	non-DNO actions		
TRANSFORM®	We will propose updates to TRANSFORM® to reflect: the reduced impact of LCTs relative to previous assumptions; better information on the costs and benefits of smarter solutions				

12. LEARNING DISSEMINATION

This section discusses the various mechanisms, channels and tactics employed during the Customer-Led Network Revolution project to ensure the learning generated was captured and shared effectively with DNOs and other interested stakeholders. It looks at what worked well and what could be replicated by future LCN Funded projects. It is accompanied by appendix 9 which provides evidence of the key communication and dissemination activities undertaken and reports on the effectiveness of the various methods employed.

Our approach to knowledge capture and dissemination

From the outset capturing, recording and sharing the knowledge gained during this project was made a priority for the CLNR team. We recognised that project learning would take many forms and that all of it was valuable. There is the learning the project planned to produce and the experiential learning gained along the way; what we learned about recruiting and engaging with customers; about installing novel network technologies or new approaches to designing or analysing trials for example.

Much of the experiential learning was captured via a team review and write-up at key points during the project and documented in our six monthly project reports. Knowledge gained when installing and commissioning novel network technologies was captured throughout the course of the project via a mix of workshops style sessions and learning documented in the field. For the latter we would often deploy an extra person on site to observe and note down activities and where necessary capture video or photographic evidence. This exercise has enabled us to produce a comprehensive suite of lessons learned reports, project videos and technical recommendations that will be of benefit to DNOs embarking on future projects.

The learning the project planned to produce takes many forms including datasets, academic research and DNO 'how to' guides. All of these project outputs have been published on the CLNR website project library, creating a learning legacy which will be utilised long after the project ends.

Targeted communications

Whilst we considered DNOs to be our primary audience, and proactively sharing our learning with them our key objective, we recognised early on that a project as diverse as CLNR would generate outputs that were interesting to a wide range of internal and external stakeholders and that we would need to find cost-effective and appropriate ways to engage and interact with them all.

From the outset, we began to grow a list of interested stakeholders who were asked to opt-in to our mailing list, and to segment them into key audiences or 'clusters' whom we endeavoured to communicate with in a targeted and appropriate manner. We recognised that the messaging would not always be the same and that we would need to utilise different channels to communicate with each of these audiences.

We segmented our stakeholders into six key audience 'clusters' and endeavoured to communicate with them in the most appropriate and interesting way

Internal Audiences

CLNR Project Team

Projects like CLNR require multiple people from different organisations to work together, often remotely, towards a common goal. In this situation, effective communication and collaborative working methods become key.

From the outset, the multi-organisational CLNR project team used the cloud based Microsoft Office 365 platform to enable effective collaborative working. We found the benefits of using this particular platform to be that;

- it allowed the team to work remotely and without organisational restrictions;
- it enabled effective production and concurrent editing of documents and reports;
- the project announcement function enabled the sharing of project news and updates; and
- our communications and image libraries created a useful reference of approved resources for project partners.

Northern Powergrid

The learning from the CLNR project has already started to influence Northern Powergrid's low carbon outlook and business planning for the RIIO 2015-23 period[11]. As such, we have a responsibility to ensure our colleagues are kept informed about the project and understand its importance, particularly as we intend to transition the learning, recommendations and tools

[11] See http://www.yourpowergridplan.com/#!low_carbon_economy

generated by the project into business as usual. Further, the project team needed to work alongside a broad range of colleagues from across the organisation to deliver the programme of network equipment and operate the trials. It was therefore important for the broader organisation to understand the project and its objectives so that they could support its delivery.

How we kept our internal organisation informed:

- We used staff briefs, which are sent to the entire Northern Powergrid organisation to keep our colleagues informed of the latest CLNR project news and milestones.
- Staff briefs were also used to provide priority updates on the release of any new project learning or reports.
- We led workshops for staff involved in the development of key outputs and for those leading the transition into business as usual.
- We conducted 17 specialist training sessions for 84 operational staff on new network technology they might encounter in the field and ran user groups with control and design staff on the new tools being introduced.
- We took part in organisational conferences to maintain awareness and encourage engagement from across the business.
- Northern Powergrid graduate trainees undertook placements with the team to learn more about the innovative work we were doing and how it could impact on their future careers.
- We ran a series of informal workshops open to all employees. During these sessions we set out to give a high level overview of specific areas of the project and to answer the following key questions:
    - What are you doing and why?
    - What have you found out?
    - How could it affect me and my job?

DNOs and other external audiences

Throughout the course of the project we have employed a number of cost-effective methods to share our learning with external audiences, details of these methods, including what worked well and the tactics we would recommend for future projects are included in appendix 9. While proactively sharing our learning with DNOs was our priority, we recognised that there are a number of other external stakeholders, who will be interested in our outputs and that we would need to find cost-effective and appropriate methods of communicating with them too.

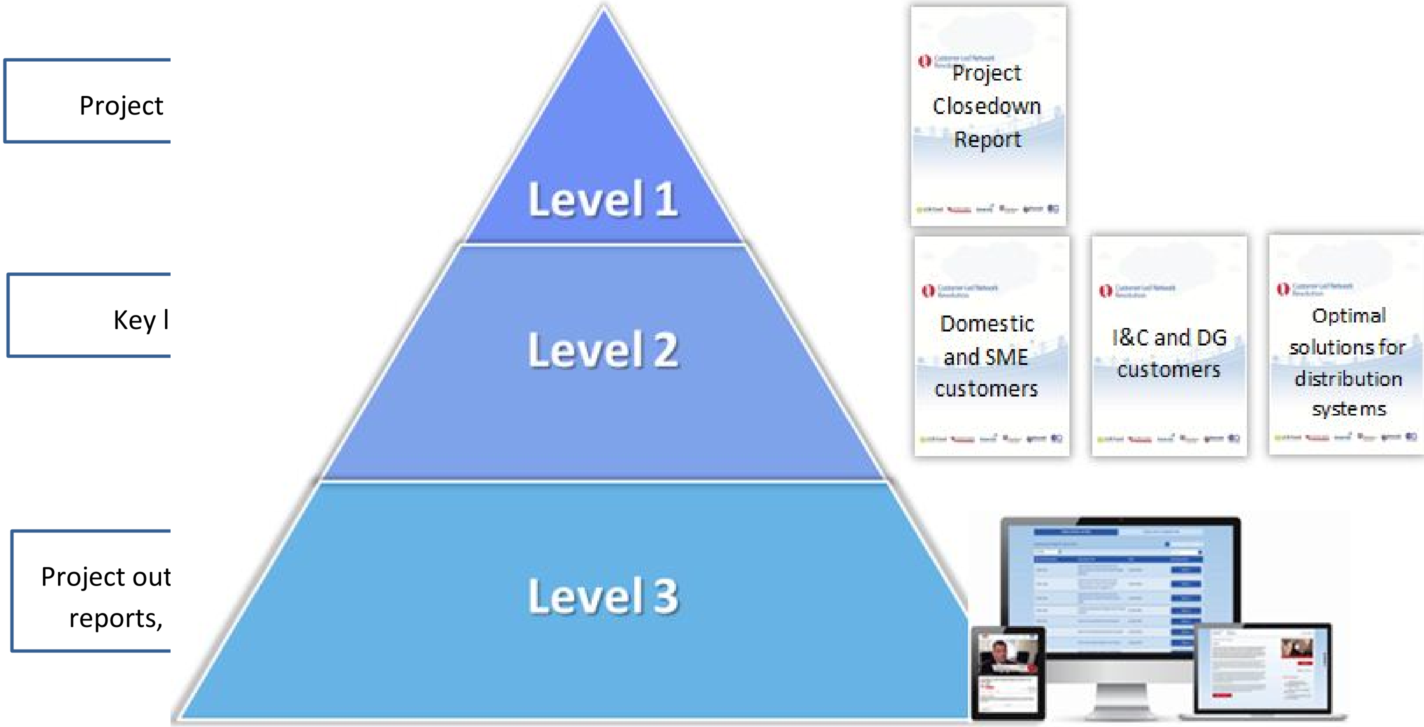
The methods we used to communicate with external audiences:

- We created the CLNR website which is the first port of call for information on CLNR and the project library creates a valuable learning legacy which will be utilised long after the project ends.
- We produced a suite of project videos to capture the lessons learned during CLNR customer trials and the installation of innovative network technologies.
- We used social media (Twitter, YouTube and LinkedIn) to engage with a wide range of stakeholders who may not have previously been aware of the project.
- We shared our learning with our peers at industry groups and forums including the Smart Grid Forum (WS6) and Energy Storage Operators Forum, as well as at our own CLNR hosted dissemination events.
- Our 900+ opt-in mailing list subscribers, received priority updates on the release of new project reports via email. They also received a bi-annual CLNR newsletter and in January 2014 we began to send them monthly e-news bulletins which were well received (see appendix 9 for stats).
- We communicated with wider audiences to inform them of the CLNR project and its relevance to the broader decarbonisation and smart grid development through the regional, national and trade press (see appendix 9 for examples).
- Several of our academic partners' papers were peer reviewed and accepted for publication in prestigious publications like IEEE and Applied Energy journals.
- We presented at a number of high profile industry and academic conferences including CIRED, IEEE PES ISGT Europe 2011 and the Low Carbon Networks & Innovation conferences.
- Communication with trial participants was handled primarily by British Gas. High quality communication materials and regular contact helped maintain high levels of engagement and trial participation.
- Key project documents are available in the ENA's smarter networks portal.

Closedown phase

The CLNR project completed in December 2014, although the dissemination of our results and findings is on-going; with activities planned well into 2015. The learning from the project will continue to inform Northern Powergrid's low carbon outlook and future business planning, and the tools and outputs generated will be transitioned into business as usual.

Proactively sharing our learning with our stakeholders is our priority and as such we have employed a three tiered strategy for the development and dissemination of our learning outputs. In doing so, we believe we have delivered additional project learning and value.



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

At Level 1, we have produced the formal project closedown report, to share the most important learning from the project. In addition, at Level 2 we have produced three key learning reports which cover;

- CLNR-L246: Developing the smarter grid: the role of domestic and small and medium enterprise customers
- CLNR-L247: Developing the smarter grid: the role of industrial and commercial and distributed generation customers
- CLNR-L248: Optimal solutions for smarter distribution systems

Level 3 consists of a comprehensive suite of project outputs including datasets, insight reports, training packages, trial analysis documents and lessons learned reports. These documents have informed our Level 1 and 2 documents and are all housed on the CLNR website project library.

Q1 2015 comprises the closedown phase of the project where we are sharing our learning and seeking feedback in particular from DNOs to ensure that our learning has been coherently presented. This report is a draft for consultation and will be updated to reflect the outcomes of the consultation and of a parallel peer review by UK Power Networks. The consultation period closes on 20th February 2015. For information on how to participate in the consultation process, please contact Liz Sidebotham on 0191 229 4242 or liz.sidebotham@northernpowergrid.com. This report will be updated to describe the consultation process, the key outcomes and how we have updated the report to reflect the consultation feedback and the peer review. A final version will be issued by the end of March 2015.

13. KEY PROJECT LEARNING DOCUMENTS

The following table provides links to the formal 6 monthly progress reports and the summary learning reports. The latter summarise the learning in way that will be relevant to our various stakeholders and also act as a bridge between the closedown report and the hundreds of detailed reports and datasets that we have published in the CLNR website project library.

The library has functionality which allows a user to search for material by keyword, and provides a synopsis of each document and information on related content.

Other, more detailed, key project learning documents are listed in appendix 11.

Summary learning reports[12]		
CLNR-L246	31 Dec 2014	Developing the smarter grid: the role of domestic and small and medium enterprise customers
CLNR-L247	31 Dec 2014	Developing the smarter grid: the role of industrial & commercial and distributed generation customers
CLNR-L248	31 Dec 2014	Optimal solutions for smarter distribution systems
6 monthly progress reports		
	June 2011	Progress report 1
	Dec 2011	Progress report 2
CLNR-G013	June 2012	Progress report 3
CLNR-G014	Dec 2012	Progress report 4
CLNR-G016	June 2013	Progress report 5
CLNR-G018	Dec 2013	Progress report 6
CLNR-G020	June 2014	Progress report 7
CLNR-G024	Dec 2014	Progress report 8

[12] Draft for consultation

14. CONTACT DETAILS

To obtain further details on the learning from the project please use our website on:

http://www.networkrevolution.co.uk

or contact us on:

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APPENDIX 1: Additional Learning

This appendix sets out actions that we have taken to deliver learning that is in addition to that envisaged in the bid.

Action	Additional learning
1. ***Delivering learning in a way that is relevant and accessible to a range of stakeholders***	The specification of the information required in section 12 of the closedown report focusses on the information needs of DNOs. However, we recognise that there is much wider interest in the learning from the project and that navigating and understanding the reports from a project as complex and multi-faceted as CLNR can be difficult for even the most expert and enthusiastic reader. We have therefore, in addition to this closedown report, delivered three additional key learning reports that summarise the learning in way that will be relevant to our stakeholders and also act as a bridge between the closedown report and the hundreds of detailed reports and datasets that we have published. The three reports are: • CLNR-L246: Developing the smarter grid: the role of domestic and small and medium enterprise customers • CLNR-L247: Developing the smarter grid: the role of industrial & commercial and distributed generation customers • CLNR-L248: Optimal solutions for smarter distribution systems Furthermore, we implemented functionality in the website project library which allows a user to search for material by keyword, provides a synopsis of each document and which provides information on related content.
2. ***Enhanced profiling of domestic smart meter customers:*** *further granularity added to disaggregated monitoring to achieve a richer dataset.*	The original bid intention was to pick out certain loads that could be monitored by the use of plug-in monitoring devices. The project at implementation stage elected to increase the range and number of disaggregated loads monitored in the home. This was achieved by using additional clip-on CTs attached at a circuit level on the consumer unit, plus plug-in monitoring devices. The key flows are: cooking; space & water heating; cold & wet appliances; consumer electronics, home computing and lighting. We have produced a rich data set from this test cell and better informed recommendations for updates to DNO network standards are the result.

Action	Additional learning
3. Enhanced profiling of domestic smart meter customers: *created an additional distinct subgroup within residential detailed monitoring test cell 2a, customers with electric hot water (HW) and storage heating (SH).*	We provided additional new learning about customers with storage heaters and electrically-heated hot water. This was not explicitly specified at the time of the bid, but since the majority of houses with electrically heated hot water also have storage heaters, we identified a knowledge gap which CLNR could fill. The revised test cell 2a provided an understanding of the pattern of use for these customers' general loads and also how those with electrically heated hot water and/or storage heaters respond to the existing E7/E10 type tariff signals. i.e. the degree to which people on these existing and long-standing DSM tariffs (e.g. E7/E10 etc.) actually respond to the price incentives and the extent to which the controls are over-ridden. A rich data set has been delivered from this test cell. We have considered whether alternative DSM solutions could be offered to those customers in the future.
4. Heat pumps: *went beyond monitoring consumption profiles and flexibility to explore customers' attitudes to operation and performance of the heat pumps.*	Wider understanding of issues which need to be addressed (e.g. need to educate in operation and gain "buy-in") if heat pumps are to be widely accepted and customers are to become a more active part of the energy system. This was achieved with a minimal incremental cost. See CLNR-L104: Heat Pump Survey Results and CLNR-L245: Report on interviews with domestic customers with air source heat pumps.
5. Heat pumps: *studied electrical performance of the technology.*	We have studied the effect of heat pumps on power quality, both individually and the impact of a cluster of heat pumps on network power quality, considering the concerns about widespread uptake of these technologies. See CLNR-L146: Assessment of power quality impacts from disruptive technologies. This was achieved with a minimal incremental cost.
6. Electric Vehicles: *used additional data from the Switch-EV project in conjunction with CLNR data which allowed the analysis of additional data on journey and recharging away from home*	We have produced a much more accurate view of where, when and how network challenges will emerge due to EV uptake. This means that GB network investment strategies should be much more appropriate going forward i.e. in the right place, of the right type and at the right time. This was achieved with no additional cost to the project to obtain the data, however there was a minimal incremental cost for the additional data analysis. See CLNR-L038: IEEE ISGT 2013 - Integrating smart meter and electric vehicle charging data to predict distribution network impacts.

Action	Additional learning
7. ***Electric Vehicles:*** *we have taken the opportunity to install network monitoring on three of the electric vehicle clusters recruited by the LCNF funded "My Electric Avenue" (I2EV) project in the Northern Powergrid region.*	CLNR only envisaged at bid stage being able to locate and monitor PV and heat pump clusters and not EV clusters both due to scarcity and the less likely clustering of electric vehicles. Our partnership with EA Technology and SSEPD on the My Electric Avenue (I2EV) project provided the opportunity to add power quality monitoring on five feeders (4 residential; 1 charge at work) each containing a minimum of 10 EVs each. This was not part of the I2EV scope and so is unique to CLNR. This was at minimal incremental cost since it required only a few field monitoring devices adding to the main CLNR monitoring system. See CLNR-L146: Assessment of power quality impacts from disruptive technologies.
8. ***Small and medium enterprises:*** *delivered a greater understanding of the barriers to offering flexibility to network operators.*	The trials for small and medium enterprise customers were adapted from bid to accommodate the inability of this customer group to offer the flexibility we were seeking. The new learning has been associated with understanding the barriers to the offering of greater flexibility and, in particular, the energy practices were investigated in more detail by the social scientists at Durham University at a minimal incremental cost to the project. See CLNR-L103: SME Customers: Energy Practices and Flexibility
9. ***Heat pumps:*** *introduced a DSR trial with air-source heat pumps (ASHP) with thermal stores (in addition trials with ASHPs only).*	Following on from detailed design reports that we had commissioned, we identified that ASHP without a thermal store might not run efficiently and would not be able to maintain comfort levels for customers when subject to the direct control signals for DSR. We trialled ASHP's both with and without a thermal store whilst the bid only included for ASHP without a thermal store.
10. ***Business (I&C) DSR:*** *additional qualitative survey undertaken.*	Additional qualitative survey results were collected and analysed regarding I&C customer appetite for demand-side response. See CLNR-L098: Report on CLNR Industrial & Commercial Demand Side Response Trials

Action	Additional learning
11. Low carbon technology insight: *additional outputs that group analysis by low carbon technology (LCT) types to understand better the benefits and issues associated with all the main technologies trialled in CLNR.*	We have produced additional outputs by LCT type that compare monitoring (LO1) results to those involving customer participation (LO2) and the behavioural studies. This has been achieved at minimal incremental cost. • CLNR-L090: Insight Report: Domestic Solar PV • CLNR-L091: Insight Report: Domestic Heat Pumps • CLNR-L092: Insight Report: Electric Vehicles • CLNR-L093: Insight Report: Domestic Time of Use Tariff
12. Customer insight, social science behavioural learning: *there has been a greater depth and richness of learning created into energy practices that have provided more value than originally scoped.*	The country's foremost social scientists have been engaged in scoping and peer reviewing the results of the ground-breaking and internationally-relevant customer insight that is unmatched by any other learning currently available. This expert 'best in field' peer review is additional to our bid commitment, has been at minimal cost, and we are grateful for the enthusiasm and interest shown by this expert community that has greatly improved the resultant output. Further, there have been more than twice as many academic conference/journal papers than originally envisaged and the value of the social insight gained has already been recognised by the provision of evidence to the Energy and Climate Change Select Committee on customer engagement implications for the national smart meter programme. It is the wider relevance of our social learning for the energy sector that is the primary source of the additional value that has been generated relative to the original bid commitments. This is the benefit of having retained Durham and Newcastle Universities throughout the project.

Action	Additional learning
13. Socio-Technical Synthesis: *has drawn together quantitative and qualitative research findings to provide a fuller understanding of the opportunities and limitations on customer flexibility.*	For example, the socio-technical view of heat pump operation has enabled us to comment on the wider institutional arrangements / business models required for heat pump deployment to work well in the future, as well as its implications for network operation and design. There are five socio-technical reports providing a wide and high level view of the learning: • CLNR-L242: High Level Summary of Learning: Domestic Smart Meter Customers • CLNR-L243: High Level Summary of Learning: Domestic Smart Meter Customers on Time of Use Tariffs • CLNR-L244 High Level Summary of Learning: Domestic Solar PV Customers • CLNR-L245: High Level Summary of Learning: Heat Pump Customers • CLNR-L254: High Level Summary of Learning: Electric Vehicle Users
14. Customer engagement: *additional outputs that capture our approach to successful customer interaction and engagement, from design through, recruitment and retention. This insight will be of great benefit to DNOs.*	We have produced additional outputs that capture our approach to successful customer interaction and engagement, from design through, recruitment and retention See CLNR-L036: Project lessons from trial recruitment and CLNR-L006: Domestic and SME tariff development for the CLNR project. We believe our success is validated by our extremely low churn rates across a wide range of test cells across thousands of customers, and that these outputs will therefore be of great benefit to DNOs in either project delivery or integration into business as usual customer engagement.

Action	Additional learning
15. Designing and running network trials: *developed an approach to design and optimise network trials*	We have developed a methodology to design network trials which uses a systematic process to define the subset of trials to deliver all of the learning required. In addition to the trial design methodology, a learning credits system has been developed as a mechanism to drive the trials towards gaining the maximum learning available from the equipment and time available, thus ensuring that the trials deliver the best learning possible. This will be useful for other DNOs to plan their future network trials efficiently in order to maximise the learning by selecting an optimum combination of trials from a larger list of potential trials. • CLNR-L220: Overview of Network Flexibility Trial Design for the CLNR Project • CLNR-L221: CLNR Learning Credits System
16. Network monitoring: *additional learning on considerations for enhanced network monitoring in business as usual.*	We deployed monitoring on network feeders at LV and HV to better understand the impact of LCTs, and to understand the behaviour and impact of the smart network solutions being trialled. The monitoring data was used for analysis of the network trials and the learning from the project has implications for control, design and planning of networks. Although monitoring was a means to achieve our planned learning objectives, we have taken the opportunity to share our learning on network monitoring. This includes CLNR-L232 Enhanced network monitoring report which recommends a cost-effective Business As Usual monitoring strategy to provide data for the purposes of planning, design and control in a cost effective manner. This advises on how to instrument a network, how much data is ‘enough’ and what data opportunities and issues the smart meter rollout will bring for DNOs.

Action	Additional learning
17. Extensive documentation of our experience with key network technologies: *setting out our lessons learned, relevant to both future innovation projects and implementation in business as usual*	Intended for use by distribution network operators and other interested parties who are considering implementing the network technologies or who are embarking on or undertaking similar projects, these reports document the lessons learned about from the process of initial design, through commissioning, to operation and maintenance. • CLNR-L163: Lessons Learned Report: Electrical Energy Storage • CLNR-L164: Lessons Learned Report: Real Time Thermal Rating • CLNR-L165: Lessons Learned Report: Enhanced Automatic Voltage Control • CLNR-L167: Lessons Learned Report: Grand Unified Scheme
18. Operational safety guidance specifications: *developed safety guidance specifications for a DNO.*	We have produced additional outputs that capture our robust approach to the safe operation of the new novel equipment on our distribution network. We have fully integrated our equipment into a live network and its control systems whilst considering the distribution safety rules and the operational practice manual (DSR/OPM). These operational safety guidance documents will be invaluable to other DNOs considering the use of similar equipment. There are three documents relating to: • CLNR-L156: Electrical Energy Storage • CLNR-L158: Transformers with on-load tap changers • CLNR-L161: Active network management (ANM) systems interfacing with existing control systems The electrical energy storage document was disseminated in March and October 2014 at IMechE events in London and Birmingham and has played an integral source for the development of the Good practice guide to energy storage. This was developed with all other UK DNOs and Northern Powergrid played a key part in its development. The Good practice guide was published in December 2014[13].

[13] http://www.eatechnology.com/products-and-services/create-smarter-grids/electrical-energy-storage/energy-storage-operators-forum.

Action	Additional learning
19. Modelling Techniques: *examined the value of the network solutions under n-1 & n-2 faulted conditions*	As well as understanding optimum solutions for LCT headroom, we have also undertaken additional work to understand how these same technologies can also improve security of supply. We considered n-1 and n-2 contingencies and how the CLNR techniques can add value in these situations with a publication[14] in the International Journal of Wind Energy, which was subject to a stringent peer review process before being deemed worthy of publication. This paper examines the contribution to distribution network reliability arising from distributed generation. In a representative network case study of the EHV network near Leeds, the number of hours during which thermal ratings would be exceeded in the event of an n-1 fault on the double circuit supply could be reduced from 472 to 28. Other papers on this subject are: • CLNR-L202: Use of Real Time Thermal Ratings to Increase Network Reliability under Faulted Conditions – CIGRÉ Regional South-East European Conference (RSEEC 2012) • CLNR-L203: Using Electrical Energy Storage to Support Customers Under Faulted Conditions – CIGRÉ Regional South-East European Conference (RSEEC 2012) • CLNR-L027: Use of real time thermal ratings to support customers under faulted network conditions – CIRED 2013 • CLNR-L025: Using electrical energy storage to support customers under faulted network conditions – CIRED 2013

[14] Quantifying the contribution of wind farms to distribution network reliability

<table>
<tr><th>Action</th><th>Additional learning</th></tr>
<tr><td>20. Modelling Techniques:
modelling of smart grid solutions using wavelet and neural net short term forecasting techniques.</td><td>We have demonstrated this modelling methodology which will benefit future research in the field. Specific outcomes of the modelling are:
• Forecasting severity and duration of power systems overload, enabling more accurate planning and control of DSR storage responses so that solutions can be designed at minimum cost (storage) and lowest nuisance factor (DSR).
• Load forecasting allows you to not only use RTTR opportunistically but also to be able to forecast how long you will have certain benefit from RTTR i.e. can plan and deploy network interventions much more efficiently.</td></tr>
<tr><td>21. Modelling Techniques:
development and evaluation of techniques as a comparator to the techniques implemented in the GUS active network management system being trialled. i.e. not only developing and trialling a smart grid control system, but looking beyond this to next incremental improvement on GUS techniques to deal with more challenging environments.</td><td>• Robust optimisation (RO): Conventional techniques can sometimes underperform in cases of high network uncertainty due to the uncertainty in load and generation profiles. RO is an approach that can deal with these situations prudently. This work therefore could be of benefit in areas of high uncertainty as an incremental improvement to control solutions being trialled on the networks.
Cuckoo search techniques: work well in cases where there are multiple objectives and a large number of control entities i.e. the solution space is very large.</td></tr>
</table>

Action	Additional learning
22. Modelling Techniques: *developed extensive IPSA scripting techniques.*	We have developed automated network analysis techniques which were used in our 'CLNR trial analysis' reports and were the focus of a number of published papers: • CLNR-L018: Distribution network voltage control using energy storage and demand side response – IEEE PES ISGT 2012 paper • CLNR-L024: Coordinated voltage and power flow control in distribution networks – CIRED 2013 paper • CLNR-L182 Integrating electrical energy storage into coordinated voltage control scheme for distribution networks - IEEE Smart Grids • CLNR-L183: Design and analysis of electrical energy storage demonstration projects on UK distribution networks - Applied Energy These automated network analysis techniques can be provided as tools to be used by other DNOs. The models are in mostly in python code and are available on request.
23. Research Methodology: *documentation of the academic research methodology associated with ACE49, which is the statistical approach for calculating demand and voltage on the LV distribution network.*	Rigorous additional academic work was undertaken to understand and benchmark how the original research methodology to produce ACE49 was undertaken back in 1981. This exercise included seeking advice from the original ACE49 project team lead (now retired) and documenting the original ACE49 methodology, plus that for ETR130. This was achieved at minimal incremental cost to the project and also provided validation of the feasibility of our CLNR outputs and requirements.

APPENDIX 2: Combinations assessed for the customer trials

A2-1 This appendix provides an update on the combinations of customer type (domestic/SME/I&C/DG), technology type (none, HP, EV, PV, responsive load/generation, PV load balancing) and commercial proposition (flat rate, TOU, RH, DC) which were trialled. Despite the external circumstances described in section 6 we recruited sufficient customers to allow each customer type, each technology type and each type of commercial proposition to be trialled. We have therefore been able to deliver a large volume of credible, useful and relevant output about customer profiles and customer flexibility.

A2-2 In the methodology appendix to the bid we set out the full range of possible combinations of customer type, technology type and commercial proposition which we considered to be most relevant to achieve the learning objectives set out in the bid.

A2-3 The subsequent detailed design work and the recruitment process developed our understanding of which combinations were most relevant to this end, were accepted by customers and could be trialled cost-effectively. Consequently, we amended the list of the combinations (i.e. test cells) to be trialled while still delivering the full scope of learning set out in the bid. We ran all the test cells for learning outcome 1 (customer profiling), but cancelled a number of test cells in learning outcome 2 (customer flexibility):

A2-3.1 All three EV intervention test cells (time of use, restricted hours and direct control) were cancelled. Market intelligence through other suppliers was that existing EV customers had already adopted a time of use tariff with EVs, suggesting that variable rate tariffs for EV customers are increasingly becoming the norm. Given this, studying a range of interventions in CLNR would have added little value, but would have diluted the quality of the enhanced monitoring of EV customers as the available EV trial participants would have to be spread across one monitoring and three intervention test cells instead of being concentrated in one monitoring test cell.

A2-3.2 The SME direct control test cell was cancelled due to lack of customer uptake. The initial recruitment process confirmed that customers were initially interested in the concept of demand side response, but that there are significant issues that need to be understood and addressed if the potential of DSR in this sector is to be sized and achieved. The learning relating to SME direct control is in the form of lessons learned from this recruitment process, rather than from trial results. Trials of the restricted hours and time of use interventions with SME customers did proceed.

A2-3.3 The heat pump restricted hours test cell was cancelled because the scarcity of heat pump customers meant that there were no eligible customers for this trial (trial participants needed to be British Gas customers since the trial relied on the tariff). Trials of the direct control and time of use interventions with heat pump customers did proceed.

A2-4 The amendments are described in detail below and the complete set of test cells can be seen in Appendix 5.

Electric Vehicles

A2-5 We had originally envisaged that the trial participants in the EV enhanced monitoring (test cell 6) would be British Gas customers on a flat rate tariff. However, to overcome the scarcity of EV customers, we extended the opportunity to participate in these trials to customers from other suppliers. When we examined the existing tariffs of all these trial participants, we found that there were a variety of tariffs in use including time of use and other forms of variable or 'green' tariff, and tariffs from a number of suppliers. The enhanced monitoring therefore studied customers on a range of tariffs.

A2-6 Since TOU effectively represents a 'base case' rather than an 'intervention' for many EV customers, test cell 15 (which was intended to trial this TOU as an intervention for EV customers) became redundant and was removed. Indeed, British Gas' market analysis indicates that such tariffs will increasingly become the norm for EV customers.

A2-7 Since EV customers are typically already incentivised to avoid peak times via various TOU tariffs, proceeding with a trial of the direct control proposition as an intervention for EV customers (TC17) would have represented poor value for money.

A2-8 Given the scarcity of EV customers and the need to deliver robust results, the trial of a restricted hours tariff with EV customers (TC16) was dropped so that the limited number of EV customers could be concentrated in the enhanced profiling test cell.

A2-9 In summary, all EV trial participants took part in enhanced profiling (TC6) and no interventions were trialled i.e. test cells 15, 16 and 17 were cancelled. This detailed restructuring of the EV trials and concentration of customers in a single test cell ensured that the project delivered relevant and robust learning in relation to EV customers' behaviour.

SME trials

A2-10 We had originally intended to conduct four different trials with SME customers: enhanced profiling and 3 types of intervention: TOU (TC9b), restricted hours (TC10b) and direct control (TC11b). To this end, we engaged with 20,000 SME customers in the Northern Powergrid region about participating in these trials, and recruited and undertook time consuming technical surveys with a significant number, demonstrating a level of interest in the concept of demand side management. However, a number of factors meant that the only intervention trial with a significant number of customers was TOU. This is summarised in the following table.

<table>
<tr><th>Trial</th><th>Total Engaged</th><th>Responded / Contacted / Surveyed</th><th>Active</th><th>Comment</th><th>Challenges</th></tr>
<tr><td>TC2b
Enhanced monitoring</td><td rowspan="4">All drawn from British Gas Business smart customer base within region ca. 20,000</td><td>172 Recruited / Surveyed</td><td>81</td><td>Hard to recruit</td><td rowspan="4">• Ca. 200 requiring meter operator migration
• Business critical or essential loads.
• Bespoke monitoring solutions
• IT/Firewall settings</td></tr>
<tr><td>TC9b
Time of Use</td><td>117 Recruited</td><td>44</td><td>Low appetite
Wrong tariff shape.
More expensive than contract prices</td></tr>
<tr><td>TC10b
Restricted Hours</td><td>140 Recruited / Surveyed</td><td>3</td><td>Interested in DSR, though in practice not viable due to operational business imperatives</td></tr>
<tr><td>TC11b
Direct Control</td><td>131 Recruited / Surveyed</td><td>0</td><td>Interested in DSR though in practice SME were unable to offer flexibility</td></tr>
</table>

A2-11 Many customers expressed an interest in the TOU tariff, but on closer consideration were of the view that the shape of the tariff on offer was unattractive as the peak period of 4pm to 8pm coincided with key business hours. Although many customers did not proceed, sufficient customers were recruited to trial the TOU intervention with SME customers.

A2-12 SMEs were interested in the idea of demand side response (restricted hours or direct control interventions) and were keen to take part. At the site technical survey stage customers gained a better understanding of the full implications; most sites were found to be either unsuitable in terms of site configuration and, more importantly, they considered that the loads which could be monitored or controlled were essential or critical to businesses operations. Although many customers opted out at this point, there were a few customers who wished to participate, so the trial of the restricted hours intervention with SME customers went ahead with this limited number of customers.

A2-13 So, while the initial recruitment process was a considerable success and confirmed that customers initially liked the concept of demand side response, it confirmed that there are significant obstacles that need to be overcome if the potential of DSR in the SME sector is to be realised. This was explored further in detailed interviews with the customers. The results have been captured in

- CLNR-L101: SME survey report
- CLNR-L052: Social Science Report
- CLNR-L103: SME customers: energy practices and flexibility

Heat pumps

Trialling the restricted hours intervention with domestic heat pump customers (TC13) required trial participants to be British Gas customers since it relied on the tariff. There were no eligible customers for this trial, so this test cell was cancelled. Trials of the direct control and time of use interventions with heat pump customers went ahead.

APPENDIX 3: Detailed design of the customer-facing trials

A3-1 This appendix provides an overview on the detailed design of the customer profiling (learning outcome 1) and customer flexibility (learning outcome 2) trials. In summary, it explains:

- why we recruited customers from outside the Northern Powergrid region;
- why we created subgroups within the enhanced monitoring of general load domestic customers to study electric space and water heating;
- the choice of technologies for the interventions trials;
- why we changed the commercial proposition for within-premises balancing for PV customers;
- how we studied the effect of heat pumps on the network; and
- the design of the time of use tariff.

Learning Outcome 1: Customer profiling trials

A3-2 Following the bid stage, we designed 'test cell population protocols' which included, amongst other factors, consideration of relevant demographic and technical customer attributes and how these could be used to ensure the test cell populations included a suitably diverse range of participants. We found that the British Gas smart meter customer base within the Northern Powergrid region was not able to provide a suitable sample in this respect. In order to achieve a sample which included a greater range of social and technical attributes, we decided that 50% of customers would come from within the Northern Powergrid region and 50% from outside the region.

A3-3 Similarly for other test cells, recruitment was extended to outside the Northern Powergrid region to assist in populating the test cells with sufficient numbers of participants for scarce low carbon technologies.

A3-4 While exploring the possibility of using electric hot water heating systems as a load for demand response, we found very limited knowledge around current electric hot water usage and customer behaviour in the UK, and that the literature on the subject appeared to be largely theoretical. We identified an opportunity to contribute to the body of knowledge by monitoring, as distinct subgroups, customers with electric hot water heating and electric storage heating.

A3-5 Although there is little research on the subject, for customers with electric space or water heating, this represents a major part of their energy consumption, and these are probably the group of domestic customers with the highest electricity usage, so to fail to study their usage and behaviours would be a missed opportunity. An understanding of these customers' usage of these heating systems is necessary not for its demand response potential, but to ensure that this distinct group of customers are not neglected in the development of load profiles.

A3-6 We therefore created additional subgroups within the trials of enhanced monitoring of regular (i.e. without any LCTs) residential customers (TC2a). This encompassed approximately 100 domestic customers who heat water electrically with a hot water storage tank, and are on restricted hours tariffs such as E7 or E10. The monitoring involved 10 minute power monitoring of the overall premises plus the electrical load of the immersion heater, and the temperature of the water in the tank. The data has been used to create new profiles for these customers who were under-represented in the population of test cell 1a.

A3-7 Similarly, we carried out enhanced monitoring for approximately 100 domestic customers who heat water electrically with a hot water storage tank, and have electric storage heaters and are on either an E7 or an E10 tariff. The monitoring involved 10 minute power monitoring of the overall premises plus the electrical load of the immersion heater, the storage heaters and some non-storage heaters where these were also used.

Learning Outcome 2: Customer flexibility trials

A3-8 Following the bid, we carried out work to confirm the choice of technologies required to achieve the intervention trials.

A3-9 Part of the detailed design of the demand response trials with general load domestic customers was the specification of the type of load which would be subject to demand response. One option considered was electric hot water heating systems. We reviewed 1,150 British Gas customers and found that the majority of customers who heat their water electrically typically do so overnight on an existing restricted hours tariff such as E7 or E10. Since electric hot water systems are not generally used in peak hours, they are not a suitable load for demand response at those times. Instead, smart washing machines were used to provide the load for demand response studies for trials of both restricted hours and direct control interventions.

A3-10 For the restricted hours intervention with regular small commercial customers (TC10b), we exercised load control of selected customer load(s), the exact nature of this load being dependent upon the customer.

A3-11 For the direct control intervention with domestic heat pump customers (TC14), an advanced heat pump with thermal storage (a large water tank) and integrated control system provided the means of intervention while minimising the impact on comfort levels in the home.

PV within premises balancing

A3-12 For the within-premises balancing intervention with domestic PV customers (TC20), we considered a range of technology options: smart appliances, electric vehicles, energy storage, smart plugs, hot water storage, and in-home displays. Smart appliances were not feasible since British Gas's supplier of smart appliances did not offer a PV within-premises balancing option, and developing this within the timescales of the project would not have been possible. Electric vehicles were not viable since their scarcity meant that there would be practical difficulties in finding enough customers who have both EV and PV. Despite extensive searches, we did not find a viable domestic scale energy storage option. Regarding smart plugs, it was difficult to find appliances that smart plugs can be attached to since most white goods have cycles and cannot be stopped and started without a smart element to the appliance itself. In contrast, using hot water storage to balance PV generation was feasible. So for within-premises balancing, the load was provided by immersion heating of hot water. In-home displays (IHDs) provided real time information on generation patterns and were used in this test cell. Within this group of customers we trialled two different approaches to load management; for one group of customers load management equipment provided an automatic balancing capability, and the other group customers needed (with the benefit of an IHD) to take manual action themselves to balance load.

A3-13 It was originally intended that the PV balancing trial would include a commercial proposition in the form of a tariff discount to reflect network and feed-in tariff (FiT) benefits of on-site consumption. However, the commercial aspect of the test cell was redesigned such that no tariff discount was offered as part of the proposition. This was because the current FiT system, under which 50% of the generation is deemed to be exported, means that PV generation will be paid for whether or not the householder consumes it. i.e. there is no downside for customers using their own PV generation as they would not have to trade off its use against the export payment forgone. Indeed, this means that both PV owning trial participants and rent-a-roof trial participants engaged in the trial under similar financial drivers. This temporary distortion to customers' signals caused by the interim deeming of exports under the FiT system, meant that no tariff discount was required for customers to accept within-premises balancing.

A3-14 With this redesign, there was no economic opportunity cost of balancing for trial participants. However, energy users have other drivers and inhibitors to balancing and we are at least as interested in the effects of these and how they interact with price signals. Examples of non-economic drivers or inhibitors of balancing include habits, competencies and attitudes to organisations, the environment and communities.

Impact of heat pump clusters on the network

A3-15 It was originally intended that the impact of heat pump clusters on the network would be investigated in conjunction with monitoring-only customers (TC3) each with enhanced monitoring and also in conjunction with customers taking up the direct control intervention (TC14). At the location of each cluster, we would monitor voltage profile and power quality on the network at the substation and on the LV feeder.

A3-16 The cluster of monitoring-only heat pump customers fitted with enhanced monitoring (TC3) was in South Shields. In addition we collected the same network data from the location of two other heat pump clusters at Hexham Redburn and Hexham Sidgate Lane. Unlike the South Shields cluster, most of the customers in the two Hexham clusters were not participating in the enhanced monitoring customer trials, and so were not included in the count of customers taking part in TC3. However, network monitoring data was collected from all three of these locations to investigate the effect of heat pumps on voltage, power flows and harmonics.

A3-17 The original intent regarding the trial of heat pumps under direct control (TC14) was first to trial this with dispersed customers for statistical analysis of customer response, then to model the aggregate effect of hypothetical clusters, and finally to use direct control with local active management to observe the effect on the network of a cluster of customers providing demand response. However, the scarcity of heat pumps meant that it was not possible to create a cluster of heat pump customers who could be offered a direct control proposition so it was not feasible to create clusters of this intervention in order to demonstrate at a single location the impact on the network and the additional flexibility afforded by network technologies.

A3-18 However, this test cell did proceed with the field trial measuring responses from these customers and the aggregate response of a cluster was modelled based on this data, rather than trialled in the field. i.e. the effect on the network of a cluster of heat pump customers providing demand response was modelled, rather than modelled and measured.

A3-19 Since the field trials of test cell 14 now refer to dispersed customers with direct control, rather than clustered customers with direct control, alternative arrangements were therefore necessary to ensure that the project included a field trial of the second aspect of test cell 14 as originally designed i.e. deploying enhanced network devices to create network flexibility in response to the impact of clusters of heat pumps. A new test cell (TC14b), coming specifically under the learning outcome 3 (network flexibility) work area, was created at Hexham Sidgate Lane to test the flexibility afforded by secondary transformer RTTR and secondary (feeder) EAVC. At this location we monitored voltage, power flow and power quality. The control signals for the interventions were generated from an artificial constraint (to reduce any risk to supply).

Time of Use tariffs

A3-20 While designing the TOU tariff we established that there would be merit in introducing an 'evening shoulder' time band to avert the emergence of new network peak following the switch from the peak rate to the night rate. However, this could not be implemented in practice without major changes in British Gas' billing systems. The TOU tariff implemented was therefore based on three time bands, as originally envisaged at bid stage. Further information on the tariff design exercise is available[15].

Ancillary services

A3-21 We trialled commercial propositions with I&C customers and distributed generators to obtain ancillary services for the distribution network. This covers both fast reserve (test cell 18), which was obtained via responsive load from I&C customers and responsive generation from distributed generators, and voltage support (test cell 19) via responsive generation from distributed generators. At the time of the bid we envisaged that this might be achieved by means of customers accepting direct load control in return for a tariff discount. The proposition we developed, and which was accepted and successfully trialled, is demand side response (DSR) in which a signal was sent to the customer requesting response and the customer was paid based on the actual response provided.

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

APPENDIX 4: Numbers of participants in the customer trials

A4-1 In this appendix we consider the size of the data sets relative to what was proposed in the bid. The test cells are categorised as follows:

- Proof of concept (test cells 4, 18, 19);
- Analysis of existing data (test cell 7); and
- ‘Statistical’ or ‘case study’ (all remaining test cells).

Proof of concept test cells

A4-2 The trials which were designed as proof of concept are micro-CHP (TC4), ancillary services for fast reserve (TC18) and for voltage support (TC19). Customers were successfully recruited to each of these test cells, so each of these trials did go ahead as a proof of concept.

Analysis of existing data

A4-3 Test cell 7 relates to the analysis of existing Northern Powergrid data to assess the impact of the April 2010 tariff reform.

‘Statistical’ and ‘case study’ test cells

A4-4 For the statistical test cells the bid specified the number of customers which we proposed to recruit to each test cell on the assumption that there would be a 1/3 dropout rate. These recruitment targets were set at such a level that if the numbers were 1/3 lower (implicitly, whether through dropout or lower recruitment) the results would still be credible and usable.

A4-5 The number of actual trial participants in some of the test cells was less than original net target. This is due to the reasons set out in section 6. However, the numbers of participants in most of those test cells remained at a level such that the quantitative results are statistically valid.

A4-6 There are three test cells where the number of participants was at a level such that the quantitative results for the specific customer/technology/proposition combination will have no real statistical validity. In each case this is due to external factors. However, having recruited the customers and not wishing to disappoint them, and being keen to gain the most learning possible from situations which are now relatively rare but which may become common in future, we proceeded with the test cells rather than cancel them. The test cells retained with very low numbers of participants are restricted hours intervention with SME customers (TC10b), direct control intervention with domestic heat pump customers (TC14) and time of use intervention with domestic heat pump customers (TC12).

A4-7 Restricted hours intervention with SME customers (TC10b): the reasons for the low numbers are discussed in appendix 2 (para A2-3.2 and paras A2-10 to A2-13). By engaging with 20,000 SME customers during the recruitment process, we have tested with a high degree of confidence the take up of time of use, restricted hours and direct control interventions. Thus, even though the direct control test cell was cancelled and the restricted hours test cell ran with just three customers, we have delivered valuable learning about the appetite and capacity of SME customers to adopt such tariffs.

A4-8 Direct control intervention with domestic heat pump customers (TC14): an award-winning advanced heat pump with thermal storage (a large water tank) and integrated control system was the controllable load. However, the equipment was much larger and heavier than a conventional air source heat pump. The heat pump measured 1040mm high x 1560mm wide x 560mm deep and weighed 236kg, and the 300-litre thermal store was 1850mm x 710mm and weighed 170kg when empty. These characteristics and the fact that a significant customer contribution was required to purchase the heat system meant that simply finding properties that were suitable for them and selling significant numbers of them was very challenging.

A4-9 For the time of use intervention with domestic heat pump customers (TC12 we needed to go outside the existing British Gas customer base to recruit heat pump customers, and this was done largely via social housing landlords. To participate in a time of use trial, a customer needed to be a British Gas customer and have a smart meter fitted (or be eligible to have one fitted). We found that most of the social housing customers had prepayment on E7 meters, but at the time British Gas were not offering smart meters for prepayment customers and to change an E7 meter to a smart meter would have meant an unacceptable increase in the length and complexity of the customer engagement. Consequently, there were few customers able to participate in this test cell, and this is why the majority of heat pump customers participated in monitoring trial (test cell 3) rather than on the time of use trial.

A4-10 We encountered a number of problems with the monitoring data which meant that not all of the data collected was reliable enough to be used in the quantitative analysis. This affected a range of test cells to varying degrees, but three test cells TC2a Hot Water, TC2a Storage Heating, and TC20 automatic premises balancing were affected to the extent that we consider those trials to be case studies. However, we have supplemented our analysis of the monitoring data with learning derived primarily from the survey and interview data, and from customer engagement activities.

APPENDIX 5: A guide to the customer trials

	Test Cell	Description	Customer Type	Load	Intervention
Learning Outcome 1: Existing and future load & generation	TC1a	Basic profiling of domestic smart meter customers	Domestic	General	None – monitoring only
	TC1b	Basic profiling of small and medium sized enterprise (SME) customers	SME	General	
	TC2a	Enhanced profiling of domestic smart meter customers	Domestic	General	None – detailed monitoring only
	[16]TC2a HW	Enhanced profiling of domestic customers with electric hot water immersion heating		General, with electric hot water immersion heating	
	[17]TC2a HW+ SH	Enhanced profiling of domestic customers electric hot water immersion heating & storage heating		General, with electric hot water immersion heating & storage heating	
	TC2b	Enhanced profiling of small and medium sized enterprise (SME) customers	SME	General	
	TC3	Enhanced profiling of domestic customers with air source heat pumps	Domestic	Heat pump	None – monitoring only
	TC4	Enhanced profiling of domestic customers with Micro-CHP	Domestic	Micro-CHP	
	TC5	Enhanced profiling of domestic customers with solar photovoltaics (PV)	Domestic	Solar PV	
	TC6	Enhanced profiling of domestic customers with Electric Vehicles (EVs)	Domestic	Electric vehicle	
	TC7	Review of the impact of the April 2010 DUoS tariff reform on the profile of industrial & commercial customers load.	Industrial & Commercial	General (for CDCM[18][19] study)	
	TC8	Establishing a new set of generation profiles to better recognise the contribution of generation to system security	Distributed Generation	Various types of distributed generation	

[16] Some documents refer to TC2aHW as TC10aHW
[17] Some documents refer to TC2aHW+SH as TC11aHW+SH
[18] Common distribution charging methodology

	Test Cell	Description	Customer Type	Load	Intervention
Learning Outcome 2: Customer flexibility	TC9a	Domestic smart meter customers on time of use tariffs	Domestic	Regular	Time of use
	TC9b	SME smart meter customers on time of use tariffs	SME	Regular	Time of use
	TC10a	Domestic customers on the smart washing machine restricted hours trial	Domestic	Regular	Restricted hours
	TC10b	SME customers with restricted hours tariff and customer override	SME	Regular	Restricted hours
	TC11a	Domestic customers on the smart washing machine direct control trial	Domestic	Regular	Direct control
	TC12	Domestic customers with air source heat pump on time of use tariffs	Domestic	Heat pump	Time of use
	TC14	Domestic customers with air source heat pumps on direct control trials	Domestic	Heat pump	Direct control
	TC18a	Demand-side response from Industrial & commercial customer with flexible load	Industrial & Commercial	Responsive load	DSR for ancillary services (fast reserve)
	TC18b	Demand-side response from industrial & commercial customer with standby generation	Distributed Generation	Responsive generation	
	TC19	Voltage support from distributed generators with the ability to control the flow of reactive power	Distributed Generation	Responsive generation	DSR for ancillary services (voltage support)
	TC20 Auto	Domestic solar PV customers with automatic in-premises balancing for hot water charging	Domestic	Solar PV	Automatic within premises balancing
	TC20 IHD	Domestic solar PV customers using in-home displays for manual in-premises balancing			Manual within premises balancing

APPENDIX 6: Network equipment

Equipment		Urban network Rise Carr, Darlington	Rural network Denwick, Northumberland	Heat pump cluster Hexham, Northumberland	PV cluster Maltby, South Yorkshire
Electrical energy storage (EES)	2.5MVA battery at primary substation (EES1)	Rise Carr	~	~	~
	100kVA battery at distribution substation (EES2)	High Northgate	Wooler Ramsey	~	~
	50kVA battery at distribution substation (EES3)	Harrowgate Hill	Wooler St. Mary	~	Elgar Drive
Enhanced automatic voltage control (EAVC)	Primary substation transformer with on-load tap changer (EAVC1)	Rise Carr	Denwick	~	~
	Secondary substation transformer with on-load tap changer (EAVC2)	Darlington Melrose	Wooler Bridge	~	Mortimer Road
	Regulator (EAVC3)	~	Hepburn Bell AND Glanton	~	~
	Switched capacitor bank (EAVC4)	~	Hedgeley Moor	~	~
	LV main distributor regulator (EAVC5)	~	~	Sidgate Lane	~
Real-time thermal rating (RTTR)	Primary substation transformer	Rise Carr	Denwick	~	
	Secondary substation ground mounted transformer	Darlington Melrose High Northgate	Wooler Bridge Wooler Ramsey	Sidgate Lane	Mortimer Road

	Overhead lines HV and EHV	~	2 locations at 66kV 4 locations at 20kV	~	~
	Underground cables EHV	Rise Carr	~	~	~
	Underground cables HV	Rise Carr	~	~	~
	Underground cables LV	Darlington Melrose	~	~	~
Grand Unified Scheme (GUS)	GUS central controller				
	14 GUS remote distribution controllers (RDC)				
	GUS Data Warehouse				
	Demand response system integrated into GUS control				
Monitoring	70 instances of monitoring equipment (of 3 different types) at a range of network locations (including power quality monitoring)				
	iHost data warehouse				

APPENDIX 7: Metering and monitoring equipment and data

This appendix provides a description of the metering and monitoring solutions designed and installed for the CLNR trials. In some cases these were more complex than envisaged at the bid stage, resulting in additional costs and extended timescales for the recruitment and installation phases of some test cells.

Whole house/premises monitoring

For all customers 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 unit 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. Customers 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. Customers 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.

Learning Outcome 1 (customer profiling) and Learning Outcome 2 (customer flexibility) trials

For trials requiring a smart meter, a standard British Gas smart meter was used and energy consumption data was collected at 30 minute intervals. This was used for the learning outcome 1 basic profiling of domestic and SME customers test cell 1) and for the learning outcome 2, time of use interventions with regular domestic customers (TC9a).

The smart meter was also used for some of the learning outcome 2 intervention test cells:

- The smart meter was used to capture whole house kWh data in conjunction with a smart appliance with built in data recorder, for the restricted hours and the direction control trials with domestic customers (TC10a and TC11a respectively). The appliance captured 10 minute interval data of appliance consumption in addition to appliance status information. The appliance has controls enabling tariff-based or external control of the load.

- The smart meter was used in conjunction with individual load monitoring of the heat pump in the heat pump TOU trial (TC12).

For trials requiring an ‘enhanced smart meter’, the intention was to use the British Gas’ phase 3 meter as the smart meter for all test cells which require enhanced metering, with additional monitoring of individual power flows as required. However, retrieving and handling the data from the smart meter would have required changes to existing British Gas data transfer and processing systems to handle the additional parameters and at the greater granularity required for the project. Due to other development work on the British Gas systems in question, this could not be done in the timescales required for the project. As an alternative solution, secondary metering equipment with separate data transfer and data processing systems was fitted alongside the existing meter to provide whole-house data i.e. average power at 10 minute intervals with an indication of import or export. For convenience the term ‘enhanced smart meter’ has been retained to refer to this arrangement.

The enhanced smart meter was used for the enhanced profiling of domestic customers in learning outcome 1 test cells (TC2, 3, 4, 5, 6):

- For regular domestic customers (TC2a): whole house load. In addition, specialised circuit monitoring devices were used to measure the power flows of specific circuits at the consumer unit. In addition, smart plugs were used to monitor the load on up to seven individual appliances. Due to the intrusive nature of consumer unit monitoring equipment and the smart plugs, participation in this test cell was restricted to staff of CLNR partner organisations.
- For customers with hot water and storage heating (TC2a), HP (TC3), CHP (TC4), PV (TC5) or EV (TC6): whole house load. In addition, specialised circuit monitoring devices were used to measure the demand of the immersion heater/storage heater HP/CHP/PV/EV/ whether import or, in the case of PV and CHP, export. Heat related data was also collected for customers with electric heating:
    - For some of the heat pump customers, we also collected internal and external temperatures and coefficient of performance data.
    - For customers with immersion heaters we collected data on the temperature of the tank at multiple points.
    - For customers with storage heaters we also monitored room temperatures and the load of some other non-storage heaters.

The enhanced smart meter was also used for two of the learning outcome 2 intervention test cells: heat pump direct control (TC14) and PV within-premises manual balancing (TC20):

- For the heat pump direct control test cell, the secondary meter (for whole house load) was used in conjunction with a ‘smart heat pump’. That pump includes 10 minute monitoring of heat pump consumption, room temperatures and parameters enabling estimation of coefficient of performance. The smart heat pump has controls enabling tariff-based or external control of the load.
- For the PV within-premises balancing test cell with manual balancing, the secondary meter (for whole house load) was used in conjunction with an additional device monitoring of individual load/generation systems with an indication of import or export. Used in conjunction with the in-home display (IHD), the customer could use the information displayed on the IHD to make decisions about adjusting loads to balance the generation.
- For the PV automatic within-premises balancing trial (TC20), the monitoring was incorporated into the PV control system and included whole house import current, PV generation current, supply voltage, plus some min/max data. All collected at 10 minute intervals.

The ‘enhanced SME smart meter’ collected data at 10 minute interval including volts, total harmonic voltage distortion, real power, reactive power, power factor, and energy. This was used in the two learning outcome 2 intervention test cells with SME customers: restricted hours and TOU.

Standard half hourly meters provided the data for the profiling trials of learning outcome 1 (impact of 2010 tariff reform TC7 and distributed generation profiles TC8) and for the ancillary services trials with I&C customers and distributed generators (TC18 and TC19).

Learning Outcome 3: Network flexibility trials

Where there were clusters of heat pumps or PVs, network voltage and power quality were monitored at the substation and at various points along the LV feeder. The heat pump clusters were at South Shields (Hillcrest), Hexham (Sidgate Lane) and Hexham (Redburn), and the PV cluster was at Maltby (Mortimer Road). The customers in the South Shields and Maltby clusters had enhanced monitoring in their premises as described above.

Power quality monitoring at the premises was carried out for a subset of 36 residential customers across the following categories: PV, heat pump, micro-CHP, EV, general load rural and general load (urban). 10 minute averages were collected for voltage, current, phase angle, voltage and current harmonic distortion and flicker. The minimum and maximum in each 10 minute interval was collected for both voltage and current. The heat pump and PV customers with power quality monitoring were clustered, at South Shields and Maltby respectively, and the CHP, EV and general load customers were dispersed.

We originally envisaged that we would be able to use smart meters to obtain measurements of voltage at the point of delivery for Enhanced Automatic Voltage Control (EAVC) solutions. However, the recovery of the required data, within the minimum timeframe necessary for real-time control, from the available smart meter technology has not been technically feasible. To overcome this problem we installed extra LV network monitoring on the project trial networks. We worked with manufacturers to enhance the specification of their standard monitoring systems to provide information at the frequency required for the real time control applications. Readings from these, supplemented by modelling, provided the necessary inputs for EAVC.

APPENDIX 8: Definition of TRL and IRL

There is a standard definition of TRLs and IRLs as follows:

		Technology readiness level	
system test, launch & operations		9	Actual system proven through successful mission operations.
	system / subsystem development	8	Actual system completed and qualified through test and demonstration.
		7	System prototype demonstration in an operational environment.
technology demonstration		6	System/subsystem model or prototype demonstration in a relevant environment
	technology development	5	Component and/or breadboard validation in relevant environment
		4	Component and/or breadboard validation in laboratory environment
		3	Analytical and experimental critical function and/or characteristic proof of concept
		2	Technology concept and/or application formulated
		1	Basic principles observed and reported

		Integration readiness level
PRAGMATIC	9	Integration is **Mission Proven** through successful mission operations
	8	Actual integration completed and **Mission Qualified** through test and demonstration in the system environment
SYNTACTIC	7	The integration of technologies has been **Verified and Validated** with sufficient detail to be actionable
	6	The integrating technologies can **Accept, Translate and Structure Information** for its intended application
	5	There is sufficient **Control** between technologies necessary to establish, manage and terminate the integration.
	4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.
SEMANTIC	3	There is **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
	2	There is some level of specificity to characterize the **Interaction** (i.e. ability to influence) between technologies through their interface.
	1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.

APPENDIX 9: Information sharing and effectiveness

This appendix provides evidence of key communications and dissemination activities undertaken by the project team and reports on the effectiveness of the various methods employed.

Throughout the course of the project, we employed a number of different channels and tactics to disseminate the learning from the project, from external media to project videos, social media to speaking opportunities. Evidence of the various activities undertaken from the beginning of the project in 2011 to its close in December 2014 are included in this appendix.

The following table lists the key dissemination and communication activities throughout the project, from early 2011 to the end of 2014. The hyperlinks in the table provide links to evidence of the activities undertaken.

Table A9.1: Dissemination and Communication Activities (2011-2014)

DATE	ACTIVITY TYPE	DESCRIPTION
28 February 2011	SDRC	Project launch event for project partners
24 March 2011	SDRC	Regional stakeholder forum inaugural meeting
29 March 2011	Industry Conference	ENA Futures Working Group
31 March 2011	Stakeholder Engagement	Yorkshire & Humber microgeneration conference
10 May 2011	SDRC	GB Smart Customer Response Trials Workshop
18 May 2011	Industry Conference	SMI: European demand response and dynamic pricing conference, London, UK
25 May 2011	Industry Conference	European smart metering conference and forum
25 May 2011	SDRC	National stakeholder forum
25 May 2011	SDRC	CLNR website go live date
31 May 2011	Industry Conference	IET Smart Grid Conference
06 June 2011	Academic Conference	CIRED 2011, Frankfurt, Germany
15 June 2011	Industry Conference	SMI: Realisation of the future smart grid conference, London, UK
20 June 2011	CLNR Report	Progress Report 1
19 July 2011	Knowledge Sharing	Irish smart meter trials workshop
21 July 2011	Industry Conference	ENA LCNF Conference, Gateshead, UK
20 September 2011	External media	British Gas energy trial invitations receive enthusiastic response
05 December 2011	Academic Conference	IEEE PES ISGT Europe 2011, Manchester, UK
14 December 2011	Stakeholder Engagement	Sustainable Electricity Networks seminar: Sharing learning from the UK's largest smart grid project
16 December 2011	CLNR Report	Progress Report 2
06 February 2012	Knowledge Sharing	Visit from Japan's Nomura Research Institute
16 February 2012	Industry Conference	Network 2012 workshop: Communicating a smarter future
26 February 2012	Academic Conference	Association of American Geographers AGM - Diagrams of power: Politics and the co-production of

DATE	ACTIVITY TYPE	DESCRIPTION
		the smart grid
28 February 2012	Industry Conference	Acumen Power Networks and Smart Grid Conference
01 March 2012	Stakeholder Engagement	Housing Associations Forum
06 March 2012	SDRC	Regional knowledge sharing event and stakeholder forum, Durham, UK.
07 March 2012	Stakeholder Engagement	IET lecture, Yorkshire and Humber network
13 March 2012	Industry Conference	IMechE conference: Energy storage for electricity networks
21 March 2012	MarComms	CLNR Spring Newsletter
29 March 2012	Industry Conference	SMI: The Future of Utilities conference
26 April 2012	Stakeholder Engagement	Northern Powergrid connections event
30 April 2012	Knowledge Sharing	Energy Storage Operators Forum (ESOF) meeting
09 May 2012	SDRC	National knowledge sharing event and stakeholder forum
18 May 2012	Stakeholder Engagement	Duchy residents association meeting
29 May 2012	Academic Conference	CIRED 2012, Lisbon, Frankfurt - Demonstrating enhanced automatic voltage control for today's low carbon network - Integrating renewable energy into LV networks using energy storage
01 June 2012	CLNR Report	Report on domestic and SME tariff development for the Customer-Led Network Revolution
06 June 2012	Industry Conference	SMI: Realisation of the Future Smart Grid, London, UK
25 June 2012	Industry Conference	Grid Scale Energy Storage conference
27 June 2012	Industry Conference	SMI: European demand response and dynamic pricing conference, London, UK
05 July 2012	Academic Conference	Royal Geographical Society - The emergence of smart grids from energy markets
10 July 2012	Academic Conference	European Association of Social Anthropologists, Nanterre, France - Smart grids; evolving relations between suppliers and consumers
12 July 2012	SDRC	DNO knowledge sharing event, Durham University, UK
15 July 2012	CLNR Report	Progress Report 3
04 September 2012	Academic Conference	UPEC 2012, Brunel University
06 September 2012	Video	About our low carbon project video
06 September 2012	Video	CLNR gets 'fully charged' with Robert Llewellyn
06 September 2012	Stakeholder Engagement	Presentation to North East Energy Leadership Council
12 September 2012	Knowledge Sharing	Energy Storage Operators Forum (ESOF) meeting
12 September 2012	CLNR Report	CLNR customer engagement plan
19 September 2012	Industry Conference	IET smart grid conference: Energy storage systems in future low carbon electrical networks

DATE	ACTIVITY TYPE	DESCRIPTION
02 October 2012	External media	Radio Newcastle interview with Jon Bird, Northern Powergrid's Sustainability Manager on CLNR work underway in Wooler, Northumberland
10 October 2012	Academic Conference	CIGRE RSEEC 2012, Sibiu, Romania - Use of battery storage to increase network reliability under faulted conditions
14 October 2012	Academic Conference	IEEE PES ISGT Europe 2012, Berlin, Germany - An interdisciplinary method to demand side participation for deferring distribution network reinforcement - Distribution network voltage control using energy storage & demand side response
23 October 2012	MarComms	CLNR Autumn Newsletter
24 October 2012	Industry Conference	ENA LCNF Conference 201, Cardiff, Wales
01 November 2012	External media	The Environmentalist, feature article entitled 'The North East flies higher'
08 November 2012	Knowledge Sharing	Presentation to Sustainability First's smart demand forum
08 November 2012	Stakeholder Engagement	British Gas's regional energy services event
14 November 2012	Academic Conference	Beyond Behaviour Change Symposium, University of Queensland, Melbourne, Australia - Systems of electricity provision and the constitution of smart energy practices
15 November 2012	Stakeholder Engagement	Consumer focus event, Durham University, UK
20 November 2012	Stakeholder Engagement	Northern Powergrid new connections event
23 November 2012	Stakeholder Engagement	UK Energy Strategy ELC event: Showcasing the capability of the North East to deliver
26 November 2012	External media	New Statesman, article entitled 'Will the UK's largest smart grid project revolutionise energy policy?'
03 December 2012	Internal	Northern Powergrid commercial arrangements user forum
06 December 2012	External media	Launch of CLNR's Twitter, LinkedIn and YouTube channels
06 September 2012	Video	Real-Time Thermal Ratings video
11 December 2012	Stakeholder Engagement	CLNR model demo at EATL London office launch
17 December 2012	CLNR Report	Progress Report 4
19 December 2012	Internal	Northern Powergrid management conference
21 December 2012	Email Campaign	Dissemination of SDRC results
21 December 2012	Video	CLNR project update video
18 January 2013	External media	Utility Week LCNF projects consumer engagement article
28 January 2013	External media	Uni students put EV travel to the test with 700 mile trek
29 January 2013	Internal	Northern Powergrid NPADDs user forum
31 January 2013	Industry Conference	Smart Grid GB conference: Seizing the smart grid opportunity, London, UK
01 February 2013	Stakeholder Engagement	Presentation to the North East Energy Leadership Council

DATE	ACTIVITY TYPE	DESCRIPTION
01 February 2013	External media	The Environmentalist, article entitled 'smarter connections'
01 February 2013	Stakeholder Engagement	Infrastructure North publication
06 February 2013	Knowledge Sharing	Energy Storage Operators Forum (ESOF) meeting
14 February 2013	Knowledge Sharing	Northern Powergrid (CLNR) & WPD (Falcon) knowledge transfer workshop
15 February 2013	Stakeholder Engagement	Northeast LEP independent economic review
19 February 2013	External media	BBC Look North feature, interview with Liz Sidebotham of Northern Powergrid on the impact of EVs on regional electricity networks
20 February 2013	Academic Conference	Society for Anthropological Sciences AGM, Albuquerque, USA
25 February 2013	Email Campaign	Promoting our new CLNR social media channels
27 February 2013	Knowledge Sharing	Presentation to Ofgem on the NPADDS network planning tool
04 March 2013	Stakeholder Engagement	IET lecture Northumbria network
07 March 2013	Industry conference	Presentation to the National Skills Power Academy
19 March 2013	Video	Monitoring modern distribution networks video
19 March 2013	Industry Conference	The Future of Utilities conference
20 March 2013	Knowledge Sharing	Visit from the Bermuda Electric Light Company
25 March 2013	External media	£54m smart grid project helping UK prepare for a greener future
27 March 2013	Industry Conference	Consumer Futures smart grid workshop
29 March 2013	External media	Customers & Northern Powergrid working together for the smart grid
03 April 2013	Internal	Northern Powergrid NPADDS strategic review for network planners
04 April 2013	External media	Utility Week article on the Green Deal
04 April 2013	Internal	Northern Powergrid NPADDs user forum
09 April 2013	Academic Conference	Association of American Geographers AGM, Los Angeles, USA - Enrolment and exclusion; Flexibility capital and the politics of smart electricity demand management
12 April 2013	External media	Battery power gives low carbon edge
14 April 2013	Policy & Regulation	Professor Harriett Bulkeley gives evidence to the House of Commons Select Committee on the UK smart meter rollout, referencing CLNR findings
16 April 2013	Industry Conference	Smart Grid GB: 'Seizing the smart grid opportunity'
17 April 2013	Industry Conference	Sustainability Live 2013
19 April 2013	Internal	NPADDS demo and presentation at Northern Powergrid's Asset Management conference
19 April 2013	Internal	Northern Powergrid Asset Management conference
22 April 2013	MarComms	CLNR Spring Newsletter
23 April 2013	External media	£54m smart grid study partners with electric vehicle network

DATE	ACTIVITY TYPE	DESCRIPTION
23 April 2013	External media	Newcastle Journal, NESCO supplement, article entitled 'Proud to celebrate our heritage powering the region'
23 April 2013	External media	Newcastle Journal, article entitled 'A smarter way to generate power'
23 April 2013	External media	Newcastle Journal, article entitled 'Energy expert makes the switch to Newcastle University'
30 April 2013	SDRC	Use description
30 April 2013	Email Campaign	Dissemination of SDRC results
06 May 2013	External media	Newcastle Journal, article entitled 'Sparking a change'
06 May 2013	External media	The Times, article entitled 'Powering the future'
06 May 2013	Academic Conference	IAS-STS 12th Annual Conference, Graz, Austria - Smart grids and the flexibility of everyday life
07 May 2013	Stakeholder Engagement	Durham University Research Showcase
11 May 2013	Stakeholder Engagement	Baywind AGM, presentation on CLNR
13 May 2013	External media	Cornwall Energy, article in their Spectrum publication
14 May 2013	Internal	Northern Powergrid Operational Seminar, Newcastle upon Tyne, UK
15 May 2013	Internal	Northern Powergrid Operational Seminar, Durham, UK
16 May 2013	Stakeholder Engagement	UKERC Conference: GB electricity demand, realising the resource, London, UK
17 May 2013	Internal	Northern Powergrid Operational Seminar, Hull, UK
21 May 2013	SDRC	Regional knowledge sharing event, Newcastle-upon-Tyne, UK.
22 May 2013	Internal	Northern Powergrid Operational Seminar, Wetherby, UK
28 May 2013	Internal	Northern Powergrid Operational Seminar, Northallerton, UK
29 May 2013	Internal	Northern Powergrid Operational Seminar, Wetherby, UK
30 May 2013	Internal	Northern Powergrid Operational Seminar, Rotherham, UK
04 June 2013	Stakeholder Engagement	Siemens conference: Changing the world to smart technology
04 June 2013	Policy & Regulation	Ofgem's smart grid forum (WS6) customer engagement workshop
10 June 2013	External media	Regional forum shares latest smart grid project findings
10 June 2013	Academic Conference	CIRED 2013, Stockholm, Sweden - Coordinated voltage and power flow control in distribution networks - Programmatic smart grid trial design development and analysis methodology - Capacity value of distributed generation for network capacity planning - Use of Real Time Thermal Rating to support customers under faulted network conditions

DATE	ACTIVITY TYPE	DESCRIPTION
		- Using electrical energy storage to support customers under faulted network conditions - A network planning and design decision support (NPADDS) tool for integration of low carbon technologies and solutions
11 June 2013	Academic Conference	The Nordic Environmental Social Science conference, University of Copenhagen, Denmark - Heat pumps and energy use practices
17 June 2013	CLNR Report	Commercial arrangements study: Review of existing commercial arrangements and emerging practice
17 June 2013	Industry Conference	SMI: Distributed energy storage conference
18 June 2013	Knowledge Sharing	Visit from the Malaysian National Utility Company
19 June 2013	Video	Regional event highlights video
20 June 2013	Policy & Regulation	Smart grid forum (WS6) on industrial & commercial DSR
20 June 2013	External media	Solar users helping to shed light on future energy needs
25 June 2013	Industry Conference	SMI: European demand response and dynamic pricing conference
28 June 2013	Knowledge Sharing	CLNR smart grid model demo and project update at Ofgem offices, London, UK
09 July 2013	Stakeholder Engagement	Discussing Northern Powergrid's low carbon outlook on our stand at the Great Yorkshire Show
11 July 2013	External media	Smart grid project tackles demand side response
16 July 2013	Internal	Presentation at the Northern Powergrid Field Operations conference
17 July 2013	MarComms	CLNR information pack produced (*ca.* 1000 distributed to date)
19 July 2013	Policy & Regulation	CLNR presentation and smart grid model demo for Chris Davies MEP
24 July 2013	CLNR Report	Project lessons learned from trial recruitment
27 July 2013	CLNR Report	Progress Report 5
07 August 2013	External media	CLNR celebrates recruitment milestone
15 August 2013	External media	Europe's smartest washing machine lands in UK homes
01 September 2013	Email Campaign	To invite and follow-up attendance at our CLNR national stakeholder engagement forum
01 September 2013	Academic Publication	Permission granted to reference CLNR data and replicate our illustrations and findings in the Australian Institute of Energy's Journal.
09 September 2013	Stakeholder Engagement	Workshops from Durham University (Making waves: energy and society) and Newcastle University (A smart future city) both discussing CLNR findings, formed part of the British Science Festival 2013 programme, Newcastle, UK
12 September 2013	Stakeholder Engagement	Innovate NE event
12 September 2013	Knowledge Sharing	Durham University share findings from social science study with the British Gas Connected Homes team.

DATE	ACTIVITY TYPE	DESCRIPTION
16 September 2013	Stakeholder Engagement	NEA Annual Conference
20 September 2013	Industry Conference	DECC's British Energy Challenge Roadshow, Newcastle upon Tyne, UK
25 September 2013	Internal	Produced take home training packs for Northern Powergrid engineers on novel network technologies they could encounter in the field
25 September 2013	Internal	Training for Northern Powergrid field operations engineers on OLTC, included site visit
27 September 2013	Internal	Training for Northern Powergrid field operations engineers on electrical energy storage, included site visit
01 October 2013	Policy & Regulation	CLNR data published in the Ecuity report for the Micropower Council & Electricity Storage Network entitled 'Smart Grids, microgeneration & storage; commercialising the benefits'
01 October 2013	Policy & Regulation	CLNR report referenced in a CEER public consultation document entitled 'Regulatory and market aspects of demand-side flexibility'
01 October 2013	SDRC	National knowledge sharing event, London, UK
06 October 2013	Academic Conference	IEEE PES ISGT Europe, Copenhagen, Denmark
09 October 2013	Academic Conference	Energy Systems in Transition Karlsruhe, Germany - Governing power, conducting demand: Reconfiguring social practices for the smart grid
10 October 2013	Video	National knowledge sharing event highlights video
14 October 2013	Internal	Training for Northern Powergrid Control Engineers on the GUS Active Network Management platform
16 October 2013	Industry Conference	IET Power in Unity conference
18 October 2013	Internal	Training for Northern Powergrid field operations engineers on on-load tap changers, includes site visit
21 October 2013	External media	Capacity crowd hears latest findings from £54m smart grid project (national event)
22 October 2013	Stakeholder Engagement	Major Energy Users Council conference
22 October 2013	Stakeholder Engagement	WebEx broadcast and presentation on CLNR to GE's global office network
23 October 2013	External media	Newcastle Journal newspaper article entitled 'A smarter way to help slash energy bills in the North East'
24 October 2013	Policy & Regulation	Ofgem's smart demand (WS6) forum, presentation of CLNR customer trial results
29 October 2013	Internal	Training for Northern Powergrid field ops engineers on OLTC, includes site visit
30 October 2013	CLNR Report	Social science interim report
30 October 2013	Email Campaign	Dissemination of social science report findings
01 November 2013	External media	Energy World magazine, article entitled 'How will domestic consumers react to smart systems?'
06 November 2013	Knowledge Sharing	Manchester Electrical Energy and Power Systems (MEEPS) workshop
07 November 2013	MarComms	CLNR Autumn Newsletter

DATE	ACTIVITY TYPE	DESCRIPTION
11 November 2013	External media	Article in the Major Energy Users Council (MEUC) members magazine on CLNR DSR trials
13 November 2013	Industry Conference	ENA LCNF Conference, Brighton, UK
15 November 2013	Internal	Northern Powergrid training for Control Engineers on GUS
18 November 2013	Knowledge Sharing	Workshop on modelling social energy practices, University of Surrey, UK
19 November 2013	Internal	Training for Northern Powergrid field operations engineers on OLTC, included site visit
20 November 2013	Internal	Training for Northern Powergrid field operations engineers on electrical energy storage, included site visit
30 November 2013	External media	Channel 4 website, article entitled 'Power to the people, smart meters, lower energy bills?'
02 December 2013	SDRC	DNO knowledge sharing event, Darlington, UK
02 December 2013	External media	Northeast leading the way in energy innovation (LCNF conference)
06 December 2013	External media	Utility Week opinion piece, Prof Harriet Bulkeley of Durham University which discusses findings from CLNR's social science study concerning the relationship consumers perceptions of their relationship with the grid
11 December 2013	Internal	Presentation at Northern Powergrid end of year Management conference
17 December 2013	Internal	Presentation at Northern Powergrid end of year Regulation conference
18 December 2013	Policy & Regulation	CLNR time of use data replicated and CLNR referenced in DECC's second annual report on the smart metering implementation programme (p24)
18 December 2013	External media	Energy Engineering magazine, article on Active Network Management
19 December 2013	Video	DNO knowledge sharing event highlights
20 December 2013	CLNR Report	Progress Report 6
21 December 2013	External media	CLNR shares network technology trials insights with peers
09 January 2014	External media	Utility Week opinion piece by Ian Lloyd, Northern Powergrid on electrical energy storage
17 January 2014	External media	The Financial Times, article entitled 'UK's CLNR tests low carbon grids'
20 January 2014	External media	Bdaily, article entitled 'North East's smart grid project stages energy industry event'
22 January 2014	External media	Newcastle Journal, article entitled 'Network operators visit pioneering Northern Powergrid site'
05 February 2014	Stakeholder Engagement	Smart model demonstration and presentation to Baroness Prosser on CLNR
07 February 2014	External media	The Telegraph, smart grid article from Siemens referencing CLNR
12 February 2014	Industry Conference	E-World Energy & Water Congress, presentation on the GUS platform by Siemens

DATE	ACTIVITY TYPE	DESCRIPTION
13 February 2014	Stakeholder Engagement	Northern Powergrid's annual stakeholder engagement report, CLNR case study
07 February 2014	Academic Conference	Spatial Variations in Energy Use, University of Westminster, UK Prospecting for flexibility? Socio-technical capital and smart electricity demand management
14 February 2014	Academic Publication	Integrating electrical energy storage into coordinated voltage control schemes for distribution networks' as published by IEEE Transactions on Smart Grids journal
27 February 2014	External media	Putting electrical energy storage to the test
27 February 2014	Knowledge Sharing	CLNR customer engagement strategy presented at SSEPD's Solent Achieving Value from Efficiency (SAVE) kick-off event.
28 February 2014	Email Campaign	First CLNR monthly e-news bulletin sent to *ca.* 900 opt-in mailing list subscribers
04 March 2014	Policy & Regulation	Presentation to DECC's benefits monitoring and review group, London, UK
04 March 2014	External media	Renewables Focus magazine, article entitled 'Northern Powergrid puts electrical energy storage to the test'
10 March 2014	External media	Metering.com 'UK begins largest energy storage trial'
18 March 2014	Stakeholder Engagement	Northern Powergrid annual stakeholder engagement report launch, Newcastle upon Tyne, UK
20 March 2014	Knowledge Sharing	Lecture by Professor Phil Taylor 'MicroGrids; niche application or fundamental to future energy systems? Institution of Mechanical Engineers
20 March 2014	Knowledge Sharing	Launch of the Energy Storage Operators Forum (ESOF) good practice guide which extensively references CLNR trials.
24 March 2014	Stakeholder Engagement	Northern Powergrid annual stakeholder engagement report launch, Leeds, UK
24 March 2014	Stakeholder Engagement	HSE site visit and tour of electrical energy storage sites
27 March 2014	External media	Utility Week opinion piece Dave Miller, Northern Powergrid on Active Network Management
28 March 2014	Policy & Regulation	Information sent to the National Audit Offices Climate Change & Sustainability department with links to CLNR reports
28 March 2014	Email Campaign	Monthly e-news bulletin
03 April 2014	Video	'Smarter homes' video
04 April 2014	External media	Transmission & Distribution World magazine, article entitled 'England's Northern Powergrid tests energy storage'
10 April 2014	Academic Conference	Smart Grids and the Social Sciences conference, Trondheim, Norway
16 April 2014	MarComms	CLNR Spring Newsletter
18 April 2014	Video	Engaging consumers in the smart grid
18 April 2014	Video	CLNR smart appliance trials
18 April 2014	Video	CLNR trials with heat pump customers

DATE	ACTIVITY TYPE	DESCRIPTION
18 April 2014	Video	CLNR trials with solar PV users
18 April 2014	Video	CLNR and National Energy Action
21 April 2014	External media	Newcastle Journal NESCO supplement; Energy past, present and future
23 April 2014	External media	Newcastle Journal, article entitled 'North east project testing effectiveness of energy storage'
24 April 2014	CLNR Report	Social science report
24 April 2014	Email Campaign	Dissemination of social science report findings
29 April 2014	Stakeholder Engagement	Northern Powergrid community energy event, Leeds, UK
30 April 2014	Stakeholder Engagement	Northern Powergrid community energy event, Newcastle upon Tyne, UK
30 April 2014	Email Campaign	Monthly e-news bulletin
01 May 2014	External media	Energy Management Magazine
01 May 2014	Stakeholder Engagement	Presentation on CLNR together with Newcastle City Council to ETI
01 May 2014	Stakeholder Engagement	Presentation on CLNR with local authority to ETI - Newcastle upon Tyne
06 May 2014	Stakeholder Engagement	Presentation on CLNR trials with Hull local authority to ETI
07 May 2014	Policy & Regulation	NECC roundtable with Chris Hulme MP: The energy debate, balancing the energy mix
08 May 2014	Stakeholder Engagement	CLNR presentation as part of the Energy Live Event, Drax Power Station, North Yorkshire, UK
13 May 2014	Stakeholder Engagement	PRASEG reception: Electricity storage in the future vision for a lower cost sustainable electricity system
14 May 2014	Email Campaign	Monthly e-news bulletin
19 May 2014	Stakeholder Engagement	Presentation on CLNR with local authority to ETI - Sheffield
20 May 2014	Industry Conference	British Gas presentation on CLNR and their smart meter roll out at the Next Generation Utilities Summit, Berlin, Germany
01 June 2014	External media	Customers will change routines in return for lower electricity bills
01 June 2014	External media	Newcastle Chronicle, article entitled 'Families willing to change daily routines if it cuts bills, North East study shows'
02 June 2014	External media	Bdaily magazine article entitled 'Consumers demonstrate changeable habits in North East smart grid project'
02 June 2014	External media	Solar Power Portal, article entitled 'UK PV owners have a greater understanding of how they consume energy'
10 April 2014	Academic Paper	Smart Grids and the Social Sciences conference Understanding evening peak electricity use in the UK, a socio technical approach
03 June 2014	Academic Conference	Joint workshop between Durham University and Lund University, Sweden, 'What makes the smart grid social?'

DATE	ACTIVITY TYPE	DESCRIPTION
05 June 2014	External media	Electrical Engineering magazine, article entitled 'CLNR at the forefront of research into how UK electricity networks can rise to the challenge of cutting UK carbon emissions.'
11 June 2014	Academic Conference	CIRED Workshop 2014, Rome, Italy
17 June 2014	Knowledge Sharing	IPPR roundtable discussing Demand Side Response measures with Shadow Energy Minister Tom Greatrex MP
17 June 2014	Knowledge Sharing	Power 2020 debate: Does the UK have the skills & innovation to deliver an energy revolution?'
19 June 2014	Knowledge Sharing	Presentation to DNO Stakeholder Managers on low carbon knowledge sharing and communication; using CLNR as an example of best practice.
20 June 2014	CLNR Report	Progress Report 7
27 June 2014	Video	Energy storage and its place in the low carbon future video
27 June 2014	Email Campaign	Monthly e-news bulletin
01 July 2014	Website	Refresh and re-launch of the CLNR website featuring an improved project learning library
03 July 2014	Stakeholder Engagement	NEA Fuel Poverty Forum, presenting key findings from CLNR customer trials
06 July 2014	External media	Modern Power Systems magazine, article entitled 'Battery storage on trial in the North East'
07 July 2014	Academic Paper	Peak electricity demand and the flexibility of everyday life' as published by the Geoforum journal
07 July 2014	Academic Conference	13th International conference on probabilistic methods applied to power systems, hosted by Durham University and discussing findings from CLNR
09 July 2014	External media	Could energy storage help meet UK decarbonisation targets?
09 July 2014	Academic Paper	DEI briefing note: Smart grids in the city
22 July 2014	Stakeholder Engagement	International engineering students from Newcastle University tour our EES sites
27 July 2014	Academic Conference	IEEE Power & Energy Society general meeting, Washington, USA.
31 July 2014	Email Campaign	Monthly e-news bulletin
31 July 2014	External media	GUS goes live on CLNR test networks
13 August 2014	External media	Case Study: CLNR solar PV user trialling automatic in-premises balancing
15 August 2014	Industry Conference	NEA Annual Conference, Scarborough, UK
23 August 2014	Industry Conference	IMechE Conference: Energy storage, an integrated approach
29 August 2014	SDRC	Use description
29 August 2014	Email Campaign	Dissemination of customer load and generation profiles, meeting the SDRC criteria
02 September 2014	Policy & Regulation	Phil Jones, CEO of Northern Powergrid, gives evidence to the Energy & Climate Change Committee on electricity demand-side measures, referencing CLNR trials

DATE	ACTIVITY TYPE	DESCRIPTION
11 September 2014	Internal	Northern Powergrid internal roadshows; visiting sites to talk to all staff about what we've learnt through the CLNR project and how it could affect future business practices
16 September 2014	Industry Conference	ENA Licenced Network Operators (LNO) knowledge sharing day
16 September 2014	External media	Are solar owners in the dark about the value of their generated power?
22 September 2014	External media	Solar PV Magazine: Solar customers may be better off using self generated power
22 September 2014	Internal	Northern Powergrid internal CLNR roadshow
29 September 2014	External media	Smart grid project releases important new data on consumers energy consumption
29 September 2014	Internal	Northern Powergrid internal CLNR roadshow
30 September 2014	Email Campaign	Monthly e-news bulletin
01 October 2014	External media	Renewable Energy Installer magazine, article entitled 'In the dark on self consumption?'
06 October 2014	External media	Utility Week, article entitled 'New data highlights future energy needs from network operators'
07 October 2014	External media	Newcastle Journal, article entitled 'Energy efficiency will be the priority for future UK governments'
10 October 2014	External media	Filming for a CLNR feature to be aired on Bloomburg News
26 August 2014	Academic Conference	Royal Geographical Society AGM, London, UK - Smart grid data cultures
31 August 2014	Academic Conference	European Association of Social Anthropologists, Tallin, Estonia - Household relations and domestic demand side reponse
12 October 2014	Academic Paper	Design and analysis of electrical energy storage demonstration projects on UK distribution networks, as published by the Applied Energy Journal
13 October 2014	Policy & Regulation	Ofgem's smart grid forum (WS6), sharing findings from CLNR domestic DSR trials
14 October 2014	Stakeholder Engagement	Major Energy Users Council conference, Bradford, UK
16 October 2014	Policy & Regulation	Ofgem's smart grid forum (WS6), sharing findings from CLNR industrial & commercial DSR trials
20 October 2014	Industry Conference	ENA LCNI conference (LCNI), Aberdeen, Scotland
25 October 2014	Video	Electrical energy storage installation time lapse video
30 October 2014	Academic Paper	Defining and evaluating the capacity value of distributed generation' as published by IEEE Transactions on Power Systems
30 October 2014	External media	Smartmeters.com, article entitled 'UK smart grid project publishes new consumer data'
31 October 2014	Email Campaign	Dissemination of network trial datasets and publication of network planning standards report
31 October 2014	SDRC	Publication of network technology trials datasets (match SDRC description)
03 November 2014	External media	New results and recommendations from the CLNR project

DATE	ACTIVITY TYPE	DESCRIPTION
11 November 2014	External media	Could energy storage prove to be a 'silver bullet'?
18 November 2014	Internal	NPADDS user group close out meeting
18 November 2014	Video	Voltage control for smart grids
27 November 2014	Email Campaign	Monthly e-news bulletin
02 December 2014	Industry Conference	Smart Meter Forum 2014: Delivering a successful rollout: engagement, installation and technology strategies
03 December 2014	Industry Conference	IET Manchester power technical group on energy storage
09 December 2014	External media	The Guardian: smart meters and smart grids, spearheading the energy revolution, CLNR article
09 December 2014	Knowledge Sharing	ESOF Forum White Paper: State of charge of GB
21 December 2014	SDRC	Match the SDRC description
Forthcoming	Academic Paper	'A probabilistic approach to combining smart meter & electric vehicle charging data to investigate distribution network impacts'. Submitted for a special edition of Applied Energy on clean transport, due for publication Sept 15
Forthcoming	Academic Paper	What's in a Peak? Rhythms of energy use across home and infrastructure'. Submitted for peer review, publication expected 2015.

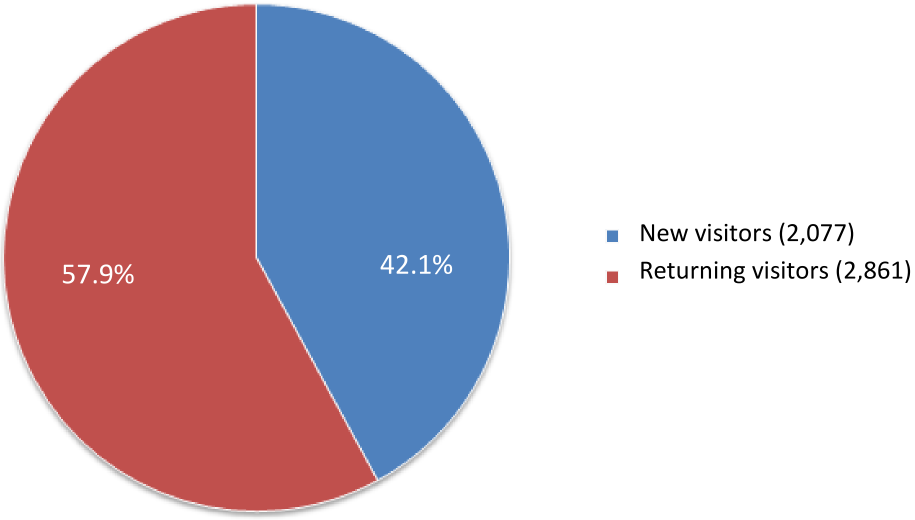
The Customer-Led Network Revolution website

The CLNR project website was launched early in the project in 2011, satisfying the Successful Delivery Reward Criteria (SDRC) as set out in the project bid. We recognised however, that as a key part of the enduring legacy of the project and most people's first port of call for information on CLNR, the website would require regular updates and improvements to its functionality. In July 2014, we completed a major refresh and relaunch of the website to improve the visitor experience and to support the sharing of knowledge with our stakeholders. The major upgrades we made were as follows;

- A new content management system (CMS) allowed us to perform document uploads and content updates in-house, instead of relying on external suppliers. This proved particularly important in the latter stages of the project when it became necessary to upload multiple project outputs and we would recommend any future projects take this into account when designing their websites.
- A new and improved project library allowed users to search and filter documents, share them via email and social media channels and access any related reports or video content.
- The website was made responsive across all platforms meaning it could be accessed on the move from laptops, tablets and mobile phones.
- It is estimated that up to 11 million people in the UK have some form of disability or impairment which makes it difficult to read websites. To make the site accessible to all and meet international web accessibility standards we implemented an innovative solution called Recite on our website. Recite enables the user to customise the site to make it work for them. It allows them to change the font size and colour (useful for anyone with a visual imparement), features text-to-speech functionality which reads the website content aloud and a translation tool for non-UK visitors or anyone with English as a second language.

Since the website relaunch on 1 July 2014, there have been 4,938 visitors to the site and 28,282[20] unique page visits. The website analytics show a near equal split between new and returning visitors (see figure A9.1) which suggests that our communications efforts have been succesful in driving new visitors to the site and that existing users found enough new interesting content and updates to return regularly.

Figure A9.1: Website Analytics – New vs returning visitors (July 2014-Dec 2014)



Homepage http://www.networkrevolution.co.uk/	3,927 visits
Project Library http://www.networkrevolution.co.uk/resources/project-library/	2,445 visits
The Project http://www.networkrevolution.co.uk/the-project/	1,700 visits
Resources http://www.networkrevolution.co.uk/resources/	1,343 visits
News and Events http://www.networkrevolution.co.uk/news-and-events/	809 visits
Network Technology Trials http://www.networkrevolution.co.uk/technology/	691 visits
Smart Grids http://www.networkrevolution.co.uk/smart-grid/	630 visits
Customer Trials http://www.networkrevolution.co.uk/customers/	622 visits
Project Library (List View) http://www.networkrevolution.co.uk/resources/project-library/	543 visits
Why are we doing this? http://www.networkrevolution.co.uk/the-project/why-are-we-doing-this/	368 visits

Table A9.2 Website page visits (July 2014 – Dec 2014)

[20] Figures correct as of 15 December 2014

Table A9.2 shows the most visited pages on the CLNR website. Unsurprisingly, the project library is amongst the most popular pages, indicating this important resource is being regularly used.

Email campaigns

Email, as a cost-effective method of mass communication, became our primary tool for disseminating learning and engaging with our stakeholders. From the outset we began to grow a list of opt-in mailing list subscribers, which reached 900+ by the close of the project. Individuals were invited to subcribe via a sign-up button on the CLNR website or by contacting the project team. Once registered they received priority updates on the release of any new project outputs and later, a monthly e-news bulletin which kept them up to date with the latest project news.

In November 2013, we began using new software that enabled us to create and send email campaigns in-house. This gave us more flexibility and proved much more cost-effective than outsourcing the work. We would recommend that future projects consider this when developing their own communications strategies.

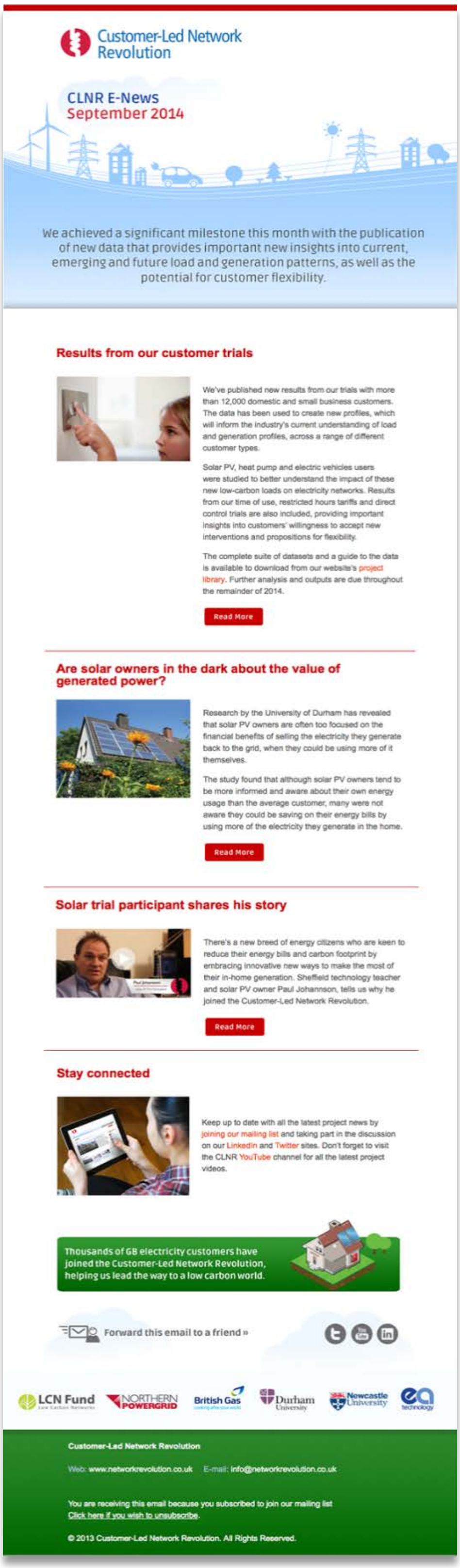
Email proved an effective means of communication and proved popular with our stakeholders (see examples in figure A9.2). On average CLNR email campaigns were opened by 25% of respondents, representing a good response rate for this type of marketing communications activity. Table A9.3 below enables a comparison of typical open rates with other selected industries.

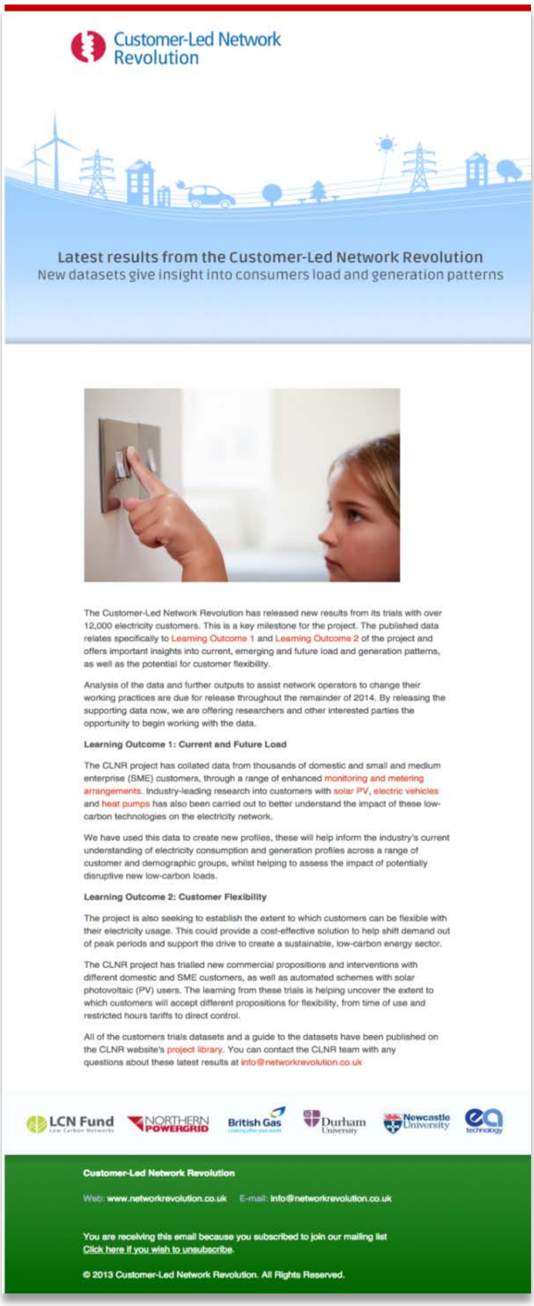
Table A9.3: Average email campaign stats by industry[21]

Industry	Average % open rate
Architecture and Construction	25.38%
Business and Finance	20.68%
Computers and Electronics	24.65%
Consulting	18.78%
Daily Deals/E-Coupons	13.20%
e-Commerce	17.35%
Gambling	18.72%
Government	25.69%
Insurance	19.72%
Marketing and Advertising	18.81%
Mobile	23.32%
Non-Profit	25.12%
Public Relations	19.98%
Recruitment and Staffing	20.77%
Retail	23.16%
Social Networks and Online Communities	21.98%
Telecommunications	19.77%
Travel and Transportation	20.00%

[21] Source: http://mailchimp.com/resources/research/email-marketing-benchmarks/

Figure A9.2. Email campaign examples



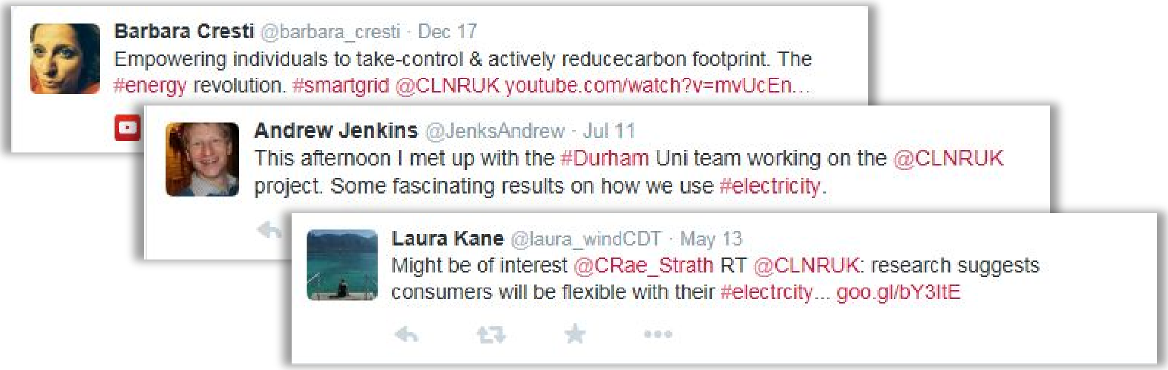


Social media

In January 2013, we launched our Twitter, LinkedIn and YouTube channels which have been well received and have enabled us to:

- significantly increase the visibility and reach of the project;
- engage with a wide range of relevant stakeholders & individuals;
- align with and support high profile national campaigns (see Energy Saving Week and DECC's British Energy Challenge for example); and
- communicate high level messaging about the project in a concise 140 characters.

Most importantly social media has given our followers a medium to disseminate learning on our behalf (see examples below). At the point of writing, our CLNR Twitter channel had 564 followers, our LinkedIn group consisted of 243 members and the videos on our YouTube channel had been viewed 14,454 times. Although social media did not form part of the original CLNR communications strategy, we would recommend it to future projects as a cost-effective means of reaching and engaging with potential stakeholders.



External media

In November 2012 we employed the services of a communications agency who have worked closely with the team throughout the project.

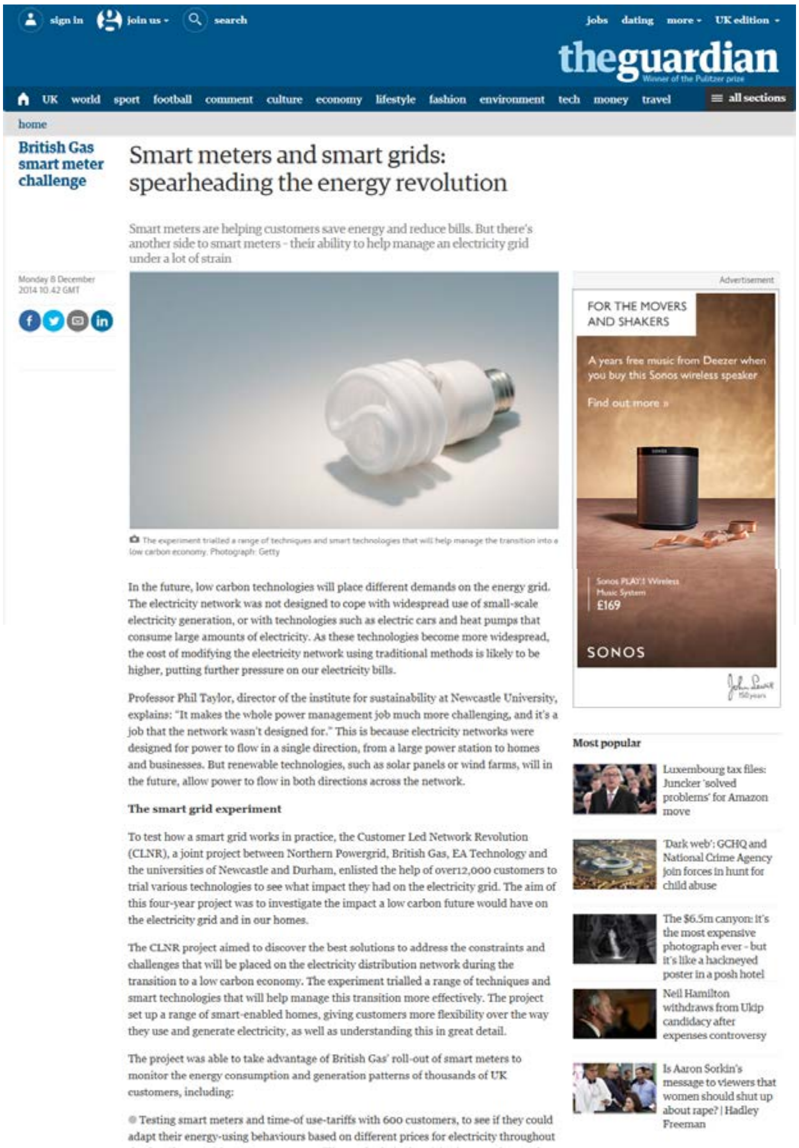
Initially, the agency helped us to raise awareness about the project by identifying and building relationships with key regional, national and trade media contacts. In the later stages of the project, they have helped us to communicate the all important 'so what' facts from our extensive list of project outputs and to articulate these into key messages for the general public and industry stakeholder groups. We estimate that we have reached over 11 million readers over the two years that we have been active.

It is worth noting that on the CLNR project we did not pay for media opportunities as we did not consider this an appropriate use of customers' money. Any media coverage we generated was PR, which we deemed to be more valuable as readers will typically engage more with editorial copy than they do with advertorial.

Examples of national media coverage

The Guardian – 8 December 2014

http://www.theguardian.com/british-gas-smart-meter-challenge/2014/dec/08/smart-meters-and-smart-grids-spearheading-the-energy-revolution



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British Gas smart meter challenge

Smart meters and smart grids: spearheading the energy revolution

Smart meters are helping customers save energy and reduce bills. But there's another side to smart meters - their ability to help manage an electricity grid under a lot of strain

Monday 8 December 2014 10.42 GMT

The experiment trialled a range of techniques and smart technologies that will help manage the transition into a low carbon economy. Photograph: Getty

In the future, low carbon technologies will place different demands on the energy grid. The electricity network was not designed to cope with widespread use of small-scale electricity generation, or with technologies such as electric cars and heat pumps that consume large amounts of electricity. As these technologies become more widespread, the cost of modifying the electricity network using traditional methods is likely to be higher, putting further pressure on our electricity bills.

Professor Phil Taylor, director of the institute for sustainability at Newcastle University, explains: "It makes the whole power management job much more challenging, and it's a job that the network wasn't designed for." This is because electricity networks were designed for power to flow in a single direction, from a large power station to homes and businesses. But renewable technologies, such as solar panels or wind farms, will in the future, allow power to flow in both directions across the network.

The smart grid experiment

To test how a smart grid works in practice, the Customer Led Network Revolution (CLNR), a joint project between Northern Powergrid, British Gas, EA Technology and the universities of Newcastle and Durham, enlisted the help of over12,000 customers to trial various technologies to see what impact they had on the electricity grid. The aim of this four-year project was to investigate the impact a low carbon future would have on the electricity grid and in our homes.

The CLNR project aimed to discover the best solutions to address the constraints and challenges that will be placed on the electricity distribution network during the transition to a low carbon economy. The experiment trialled a range of techniques and smart technologies that will help manage this transition more effectively. The project set up a range of smart-enabled homes, giving customers more flexibility over the way they use and generate electricity, as well as understanding this in great detail.

The project was able to take advantage of British Gas' roll-out of smart meters to monitor the energy consumption and generation patterns of thousands of UK customers, including:

- Testing smart meters and time-of use-tariffs with 600 customers, to see if they could adapt their energy-using behaviours based on different prices for electricity throughout

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Is Aaron Sorkin's message to viewers that women should shut up about rape? | Hadley Freeman

Channel 4 News – 30 November 2013
http://www.channel4.com/news/energy-prices-smart-meters-revolution-british-gas-eon

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SATURDAY | 30 NOVEMBER 2013 | UK

Power to the people - smart meters, lower energy bills?

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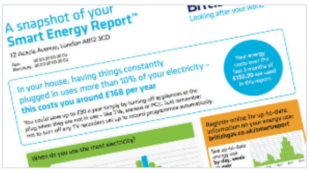
Even though the price of your next energy bills may shock you, will you spend any time at all doing something about it?



Faced with above-inflation hikes in energy costs, the government has advised customers to try switching to save money.

But a recent study by Accenture concluded that the average customer spends only nine minutes year interacting with their energy provider, typically on matters relating to billing, credit or supply issues.

So if high prices don't prompt us to act, what will? Social scientists believe they know.

Customer engagement

Users get a monthly smart energy report online or on paper, detailing where energy is used and where their money goes.

Remember that Accenture statistic about our interaction with our suppliers? (Just nine minutes a year on average)

British Gas says that 30 per cent of smart meter households spend an average of 18 minutes looking at their monthly energy reports - not once, but five times a year.

But that's not all.

The energy industry hopes that smart meters could be a step on the path to smart houses.

In the North East and Yorkshire a £54m research project called the Customer-led Network Revolution (CLNR) is underway. Engineers and social scientists are working to find out how customers can reduce energy costs and carbon emissions in the years to come.

Financial Times – 17 January 2014

http://www.ft.com/cms/s/2/274f6c1e-7158-11e3-8f92-00144feabdc0.html#axzz3LdO3cXLp

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January 17, 2014 2:15 pm

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UK's CLNR tests low-carbon power grids

By Chris Tighe

Electric cars being charged in London: a UK study is preparing for more widespread use of low-carbon technology

While this may seem an extreme example of the potential challenges posed by the shift to low-carbon technology, the changes occurring in energy consumption and generation have wide-ranging implications.

Microgeneration from devices such as solar panels could at certain times feed so much electricity into the grid that it would raise the network voltage to unacceptable levels, beyond those for which household appliances are designed. To mitigate such voltage rises, costly investment might be necessary – precisely what consumers who install solar panels to reduce their energy bills are anxious to avoid.

Low-carbon technologies are at the heart of the UK government's target of reducing carbon emissions by 80 per cent by 2050. But the upheaval in the power sector is putting pressure on the "network to customer" model, based on large power stations feeding the grid. This has characterised the UK's electricity distribution since the 1950s, following the electricity industry's nationalisation in 1947.

Interest is now focusing on smart grids – modernised electrical infrastructure which makes the most of information and communications technology to improve the efficiency, economy, reliability and sustainability of electrical power supply.

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IN INNOVATION IN ENERGY

Examples of regional media coverage

Newcastle Journal - 23 October 2013

http://www.thejournal.co.uk/business/business-news/smarter-way-help-slash-energy-6226699

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A smarter way to help slash energy bills in the North East

Oct 23, 2013 13:08 By Peter McCusker

With rising electricity bills at the top of the political agenda Peter McCusker reports on a £54m North East project aimed at helping business and domestic customers to use energy in a smarter way

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British Gas's energy monitor, the 'pebble'

Free electricity on a Saturday and cheaper energy during off-peak periods are just some of the benefits hundreds of North East households are enjoying in an on-going trial.

Launched in 2011 the Customer-Led Network Revolution (CLNR) – the largest of its kind in the UK - is now producing results which will shape how we power and heat our homes, offices and factories in the future.

A joint initiative between Northern Powergrid, British Gas, Durham and Newcastle

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Port of Sunderland

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Newcastle Chronicle Newspaper – 1 June 2014

http://www.chroniclelive.co.uk/news/families-willing-change-daily-routine-7198717

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News > British Gas

Families willing to change daily routine if it cuts bills, North East study shows

Jun 01, 2014 06:30 By Michael Brown

Thousands of homes changed when they did chores like laundry in exchange for cheaper electricity, Durham University researchers found

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Familes are willing to change their household habits if it means making a saving on their energy bills, a major North study has proved.

Bdaily Business News – 2 June 2014

https://bdaily.co.uk/environment/02-06-2014/consumers-demonstrate-changeable-habits-in-north-east-smart-grid-project/

One of the UK's largest smart grid projects is happening in the North East

Consumers demonstrate changeable habits in North East 'smart grid' project

Tom Keighley

02 JUN 2014 ENVIRONMENT

Householders taking part in one of the UK's largest 'smart grid' projects, here in the North East, have shown their willingness to adapt their consumption of electricity.

Newcastle Journal – 7 October 2014

http://www.thejournal.co.uk/business/business-news/energy-efficiency-priority-future-uk-7895193

Oct 07, 2014 19:00 By Peter McCusker

With prices continuing to rise and demand set to double households and businesses are being encouraged to using energy in a more efficient way

Over the last decade the UK has used 10% less energy than the previous 10 years, while GDP has returned to its 2004 levels despite the financial crash which wiped 7% off national wealth.

This is particularly impressive as the number of households is 6% higher than 2004 – and is a trend that has been mirrored across the first world.

Experts attribute some of the falls in energy use a raft of households energy efficiency measures such as; better insulation and boilers and incandescent light bulbs – although there is still a long way to go (see panel).

policy makers and grid operators.

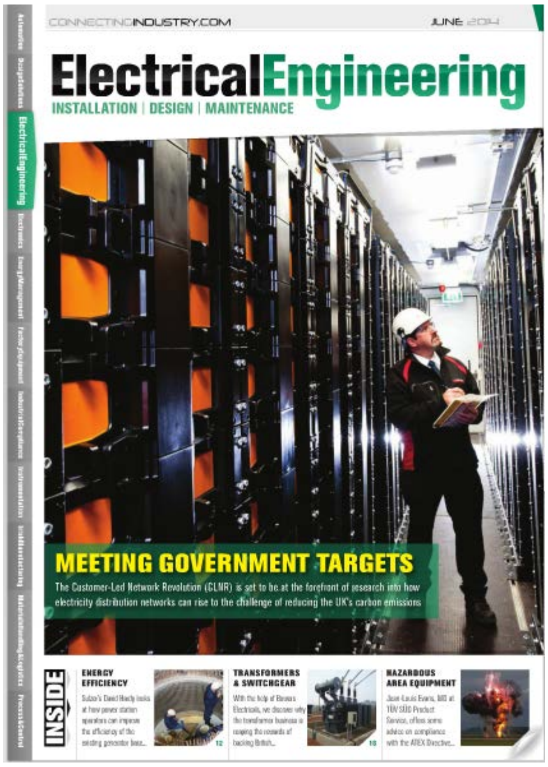
Here in the North East a world-leading trial aimed at supporting the transition to a smarter renewable electricity system is coming to an end.

Launched in 2011 the £54m Customer-Led Network Revolution (CLNR) is a joint initiative between Northern Powergrid, British Gas, Durham and Newcastle Universities and National Energy Action.

Examples of trade press coverage

Electrical Engineering Magazine – 5 June 2014

http://content.yudu.com/A2w6ee/EEJune2014/resources/index.htm?referrerUrl=http://www.connectingindustry.com/electricalengineering/default.aspx



Utility Week Magazine – 06 October 2014

http://www.utilityweek.co.uk/news/new-data-highlights-future-energy-needs-from-network-operators/1058782

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New data highlights future energy needs from network operators

06/10/2014 Share:

Data showing the electricity usage of more than 12,000 UK consumers has been released by Customer-Led Network Revolution (CLNR) to understand the use of electricity by consumers.

By releasing the findings the CLNR, which is part-funded by Ofgem's Low Carbon Networks (LCN) Fund, hopes to help electricity network operators better understand the consumption and generation patterns of consumers and what it means in terms of future energy requirements from them.

Of the participating consumers, thousands had smart meters, which provided updated information on their electricity usage every half hour. Many of the customers had used low carbon technologies such as solar panels,

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Project Videos

During the course of the project we produced a number of high quality videos which added a new dimension and value to our dissemination efforts.

The original thought process behind using this particular medium was that it would allow us to capture the operational experience and lessons learned during the installation of innovative network technologies as it happened, thus creating a valuable reference for other DNOs and future innovation projects. We have since produced a series of network technology and customer trial specific videos which have been helpful in raising the profile of the project and effectively communicating its size, scope and relevance.

These videos have been well received by our DNO and industry colleagues and form an important part of the project's learning legacy. We would recommend that future projects consider using the medium of video as an effective way of sharing knowledge and experiences from LCN Fund projects.

Figure A9.3: You Tube CLNR video views

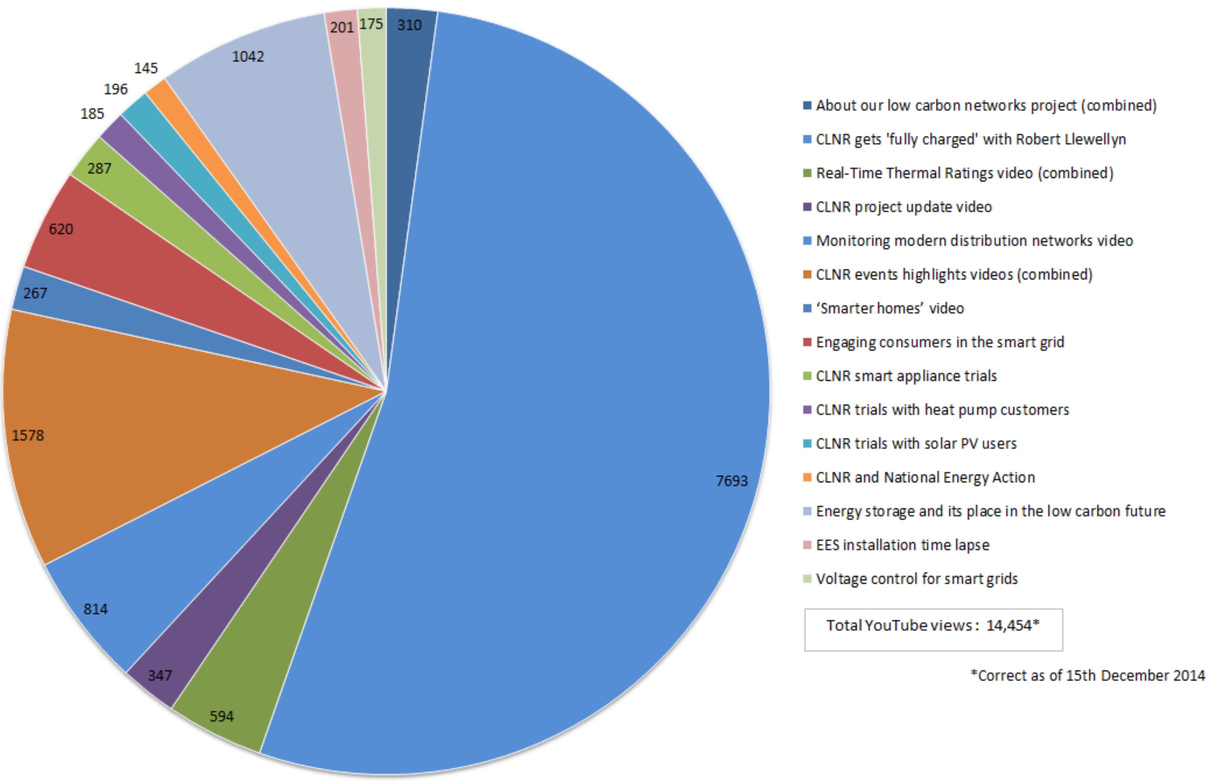

Table A9.4: You Tube CLNR video views

About our low carbon networks project	310 views
CLNR gets 'fully charged' with Robert Llewellyn	7,693 views
Real-Time Thermal Ratings video	594 views
CLNR project update video	347 views
Monitoring modern distribution networks video	814 views
CLNR events highlights videos	1,578 views
‘Smarter homes’ video	267 views
Engaging consumers in the smart grid	620 views
CLNR smart appliance trials	287 views
CLNR trials with heat pump customers	185 views
CLNR trials with solar PV users	196 views
CLNR and National Energy Action	145 views
Energy storage and its place in the low carbon future	1,042 views
EES installation time lapse	201 views
Voltage control for smart grids	175 views

APPENDIX 10: Revised business case

Executive summary

This appendix presents an updated business case for the CLNR Project conducted by EA Technology. The original business case for the project was presented as Optional Appendix 6 of the project bid document. The learning from the project has been used to update the original business case. In particular the costs and benefits of the technologies have been assessed using the Transform™ model in place of the relatively simple, bespoke cost benefit assessment model which was used to prepare the business case for the bid. Transform™ is the industry standard approach to forecasting benefits and costs of changes to distribution networks to accommodate Low Carbon Technologies. It is used by Ofgem and all DNOs. We have not recalculated the avoided costs associated with reducing peak generation requirements, which were included in the original business case.

On the assumption that the project learning is adopted nationally (where the learning is replicable), it is estimated that the project will deliver, to consumers over the period 2020 – 2050, a present value (i.e. discounted to 2014 value) of between £4.87bn and £25.6bn of net financial benefits (including value from between 10.8MtCO_2 and 32.5MtCO_2 emission savings). This can be compared with the benefit estimate in the previous business case of £6.3bn (present value in 2014), noting that the previous business case also included avoided peak generation benefit, which is not included in this business case. These benefits, dependent on the uptake rate of LCTs, are built up from the following high level benefit areas:

- Between £3.25bn and £17.7bn network capital cost savings – from avoided costs associated with reinforcing the electricity distribution networks to support additional load and increased variability of supply and demand;
- Between £1.3bn and £7bn direct customer benefit – from payments to I&C customers associated with DSR flexibility; and
- Between £0.32bn and £0.94bn carbon emission savings – carbon savings relating to acceleration of the connection of LCTs.

The extreme values of these ranges correspond to the lowest and highest scenarios for future penetration rates from the latest DECC LCT Growth Projections.

The previous business case, which was prepared in 2010, predicted a total net benefit of £5.52bn (2010 discounted figures), which is equivalent to £6.3bn in 2014 pounds. The benefits comprised undiscounted values of: £5.3bn network capital cost savings; £0.82bn direct customer benefit; £6bn carbon emission savings; and £2.18bn generation capital cost saving.

Comparing the financial benefits accruing from the CLNR project, which were estimated at bid stage, with those calculated for this business case, it can be seen that:

- the network capital cost savings from this business case range from slightly below to significantly greater than the previous value;
- the direct customer benefits from this business case range from higher to significantly greater than the previous value; and
- the carbon emission savings benefits range from significantly lower to lower than the previous value. This is predominantly due to the change in forecast uptake of solar PV from 2038 onwards.

The CLNR project has successfully purchased, commissioned and tested a wide range of smart solutions for distribution networks. For all of these technologies, the costs and benefits have been carefully monitored and assessed and network cost benefits based on the actual installed costs and monitored performance of the smart solutions have been calculated for each ED period and from 2020 to 2050 using the Transform Model. The technologies and learning assessed were:

- Enhanced Automatic Voltage Control;
- Real Time Thermal Rating (RTTR) of transformers, underground cables and overhead lines;
- Enhanced Automatic Voltage Control;
- Demand Side Response (DSR);
- Electrical Energy Storage; and
- New LCT load profiles.

The calculations and our learning from installing these technologies show that CLNR has been a major success in identifying potential improvements to current “business as usual” practices. The major findings are as follows:

1. For the time period from 2020 - 2050, the full suite of CLNR smart technologies is predicted to reduce distribution network reinforcement costs by between £3.25bn and £17.7bn dependent on the uptake rate of LCTs.
2. A possible further reduction of at least £500m from 2020- 2050 based on better load profile data for LCTs has been identified. This learning will be added into the Transform Model governance process for further consideration by the DNOs.
3. Between 2020 and 2050, payments associated with DSR flexibility of between £1.3bn and £7bn are predicted to be made by DNOs to I&C customers.
4. Over the time period 2020 to 2050, a reduction in emissions of between 10.8MtCO2 and 32.5MtCO_2 is predicted.
5. The major smart grid technologies which appear most likely to succeed include:
    a. EAVC HV Regulator;
    b. EAVC Distribution OLTC;
    c. DSR for I&C customers;
    d. RTTR for primary and secondary Transformers; and
    e. RTTR for EHV and HV Overhead Lines.

6. Energy storage remains an expensive technology for DNOs but could become competitive for an Energy Service Company in a few years' time.
7. There is further scope for substantial savings from the learning of this project in some areas, this will require further work. These areas include:
    a. A review of Engineering Recommendation P27 where we are recommending new rating values for OHLs on redundant circuits.
    b. Time of Use Tariffs for DSR for domestic customers, this will require further research, development and regulatory review.
8. In addition to the network benefits, resulting from capital investment savings quantified above, the CLNR project has helped to keep the UK in the vanguard of smart technology development and this will undoubtedly lead to opportunities for job creation and carbon reduction.

1 Introduction

This document provides an overview of the:

- Net financial benefits the project will provide to existing and future customers;
- Net carbon savings the project expects to deliver;
- Approach and methodology that the project has taken in assessing financial and carbon benefits; and
- Key assumptions that underpin the project's business case.

The aim of this report is to estimate the overall cost and benefits to the UK economy achieved through implementation of the CLNR programme through the period 2015 - 2050. Although the original project business case recognised that there would be benefits accruing from the project in the period from 2015 to 2020, it was recognised that, at the time the project bid was prepared, the method used to model the clustering effects of LCT take up was insufficiently sophisticated to provide a credible quantitative assessment of this benefit. Consequently the original business case only gave benefits from 2020 -2050.

The original GB-wide Cost-Benefit Analysis (CBA) for CLNR was calculated using a simple spreadsheet methodology. Since submission of the original bid, this spreadsheet methodology has evolved and has been developed into a sophisticated computer model for assessing the network cost benefit of Smart Grid technologies. This model, now known as Transform, is used by all the GB DNOs to calculate projected smart grid costs and network benefits versus 'business as usual' (BAU).

This updated business case has used the Transform model to generalise the findings of the project to all of GB. Transform models clustering effects significantly better than the original cost benefit assessment model. Therefore, as well as calculating the benefits from 2020 – 2050, benefits gained from 2015 – 2020 have also been assessed and have been used to calculate benefits within ED1. Also, in addition to assessing the overall impact of the programme, when all the technologies are implemented simultaneously, the project cost benefit assessment[22] also identified the economic cost benefit of each individual smart technology installed in the CLNR trials.

Whilst summary details of the cost benefit analysis is given here, this report is not intended to be a detailed discussion of the benefits of the smart technologies tested. For in depth discussion of the performance of these technologies and implications for the costs and benefits thereof, reference should be made to the CLNR-L144: Cost Benefit Assessment Report, the CLNR-L248: Optimal Solutions Report and the VEEEG reports produced by Newcastle University.

The network capital cost benefits and the net carbon savings have been assessed assuming future scenarios for electricity use as laid down by DECC to satisfy the 4th Carbon Budget.

1.1 The Transform™ Model

The Transform Model was developed by EA Technology with inputs from a number of project partners and with the full engagement of all British DNOs. It is now licensed to the DNOs, Ofgem, DECC and National Grid and is being used as part of all DNOs' business plans for the next regulatory period (RIIO-ED1). The model uses DECCs fourth Carbon Budget scenarios to look at the potential costs associated with the proliferation of new low carbon technologies such as EVs, PV and Heat Pumps.

The Transform Model was originally produced for the GB Smart Grid Forum. It considers the entire GB network at 33kV and below. It does this by using a number of representative network elements that can be replicated in the appropriate proportions to give an overall network that is a reasonable approximation to the GB distribution network.

The model considers the impact of low carbon technologies (LCTs) on the representative networks. Technology uptake forecasts which are aligned to Government (DECC) scenarios are modelled for Heat Pumps (residential, business and public); Electric Vehicles; Photovoltaics; and Distributed Generation (taken from National Grid scenarios). Conventional load growth is also taken into account within the model alongside load growth attributed to the uptake of low carbon technologies

The model determines the "headroom" in terms of capacity of each representative network element. It then models the change in headroom with the uptake of Low Carbon Technologies, including distributed generation, and load growth. The model identifies the point at which headroom is consumed and investment is required. It considers many solutions (both conventional and "smart") that could be applied to produce the additional headroom required. A "merit order stack" of solutions is defined in the model. This represents the relative merits of each solution in

[22] CLNR-L144: Cost Benefit Analysis of the CLNR Project

terms of its cost, the headroom it releases and any second order benefits or costs. All solutions are dynamically ranked for all network types annually to 2050.

For our work to calculate the cost benefit we have developed new solution templates based on the work of the Transform Model but populated using real data from the CLNR trials. These can be found in Appendix B of the CLNR Cost Benefit Assessment report. Subsequently the solutions have been configured into the Transform Model in order to analyse the impacts of the acquired knowledge and lessons learnt from the CLNR outputs. These solutions describe the benefit in terms of the increased headroom or legroom available within statutory limits that the solutions can provide.

1.2 Comparison of Transform™ and the original cost benefit analysis spreadsheet model

Both Transform and the original CBA spreadsheet model use the concept of “headroom” of network feeders. Both model the change in headroom with the uptake of Low Carbon Technologies, including distributed generation, and load growth. Both identify the point at which headroom is consumed and investment is required. Both produce a “merit order stack” of solutions (both conventional and “smart”) that could be applied to produce the additional headroom required, based on the headroom released and the cost of the solution.

Although the approach used by the models is the same (Transform evolved from the CBA approach used for CLNR), Transform is significantly more sophisticated than the original spreadsheet model in five respects:

a) Representation of Network

The original model represents LV networks using two generic types: one urban LV network and one rural LV network. Transform represents LV networks using 19 representative LV feeders. The original model did not consider variants of HV network, except to recognise that a proportion of HV networks are interconnected and that the model would not apply to these networks. Transform has 7 representative HV feeders. The original model did not consider EHV networks at all, whereas Transform has 6 variants of EHV network. There are approximately 100 realistic combinations, with 10 subsets of these combinations to reflect clustering (more than 1000 combinations in total). The characteristics of each representative feeder has been considered at length and agreed by members of the Smart Grid Forum Workstream 3, which includes authoritative representatives of each GB DNO.

b) Solution variants

The original model has five variants of smart solution and three variants of conventional solution. Transform has the ability to consider around 100 variants of 15 representative smart solution families and 5 types of conventional solution; although for CLNR smart solutions and 5 types of conventional solutions were considered. Split feeder, New feeder, New Transformer, minor works and major works.

c) Representation of headroom

The original model represented headroom by the % of possible LCT connection points, assuming a specific characteristic for PV, EV and HP. This was because these values were outputs from a Windebut study for the STP. The STP study considered only two representative LV networks, one rural and one urban, which is why the original model used only two types of LV networks to represent all LV networks. Transform uses % voltage headroom and leg-room, also % thermal headroom. This provides a better representation of the capacity of network feeders and enables LCTs with different characteristics to be assessed. It also enables more accurate assessment of a wider range of solutions which directly impact on the voltage profile of circuits and the power that is carried by a circuit.

The original model used a single scenario for installed capacity of PVs, EVs and HPs each year to 2050, for each technology a middle estimate was derived from a range of sources. For the cost benefit analysis which underpins this business case, Transform uses future scenarios for electricity use as laid down by DECC to satisfy the 4th Carbon Budget.

d) Clustering

The original model used a simple clustering model: 50% of each technology installed in 20% of the network, with 50% of each technology installed in the remaining 80%. Transform uses 10 groups, each group has a different proportion of total LCTs connected to a different proportion of the network, ranging from 5% of LCT on 1% of network to 7% on 40% of network. These values are derived from the latest FIT report.

The spreadsheet model that was used to produce the original cost benefit estimate for the project was sound in concept and appropriate for the bid document. The cost benefit analysis produced using the findings of the CLNR project and Transform is significantly more robust and reliable.

1.3 Methodology and assumptions

1.3.1 Network capital cost savings

To calculate estimates of network costs and benefits from the CLNR programme it is necessary to have detailed forecasts of current and likely future costs of the technologies investigated plus a detailed understanding of the technical benefits released

Over the course of the CLNR programme, all expenditure on the Smart Grid Technologies investigated was carefully recorded and these can be found in Appendix A of the CLNR Cost Benefit Analysis Report. The costs identified for each technology were revisited with the following methodology:

1. Estimate how much the technology cost and how this might change next time
2. How much of the installation cost was incurred as first in class or for experimental reasons and would not need to be spent again

3. How much was spent on site specific issues (e.g. asbestos removal) which would not form part of a generic unit cost for modelling purposes.

Following this analysis a final estimate for how much each technology would cost to be installed (and to be operated) next year was made. The full costings for each technology can be found in Appendix A of the CLNR Cost Benefit Analysis Report.

The outputs of the VEEEG analysis of CLNR trial results provided an understanding of both the impact of LCTs on representative networks and the benefits of each solution. This benefit was expressed as % increase in voltage headroom, voltage legroom and thermal headroom. This information entered into Transform in the form of “solution templates”. These solution templates are presented in Appendix B of the CLNR Cost Benefit Analysis Report.

Solution templates were produced for each of the individual smart technologies and learning found in CLNR. The technologies can be grouped into a number of generic types:

- Enhanced Automatic Voltage Control – six variants
- Real Time Thermal Rating (RTTR) of transformers, underground cables and overhead lines – five variants
- Demand Side Response (DSR) – only costs and benefits of DSR contracts for Industrial and Commercial (I&C) customers
- Electrical Energy Storage - three variants
- New LCT load profiles

The identified benefits were modelled against a Business As Usual counterfactual for the four DECC scenarios for both ED1 and out to 2050. Each of the variants in each group can be used to address similar network problems. Modelling using Transform identified optimum combinations of the technologies in each type, year by year, to produce a GB wide benefit and cost for each generic type of technology. It should be noted that the benefits from the modelling of each individual generic type are not cumulative because different types of solution can be used to address similar issues. Therefore a degree of “double counting” of benefits would result from a simple sum of benefits. Transform can calculate the optimum combination across all solutions, provided all are modelled together. Therefore all the solutions, combined with the ANM system (GUS) were modelled to provide an overall benefit estimate for CLNR based on the interaction of all these solutions.

All the benefits estimated using the Transform™ Model for this business case only considered LCT driven load growth and are presented as a range of potential benefits for the four DECC LCT growth scenarios. Only scenario 4 was used as the basis for benefits in ED1, as in reality the DNOs are tracking most closely to scenario 4 in ED1. The savings for ED1 are versus BAU and since the DNOs have been using the Transform™ Model to estimate ED1 savings, these savings are already captured in DNOs’ current business plans for ED1.

The key assumptions underlying this Business Case are:

- Future penetration levels of LCT are correctly predicted by the DECC LCT Growth Projections
- Penetration levels of LCT at which network constraints occur are correctly predicted by the methodology used.
- The Transform™ Model is sufficiently representative of GB networks to be used to extrapolate the specific findings of the CLNR project to GB wide applicability.

Transform uses a simplified representation of GB networks based on a number of assumptions. It is outside of the scope of this document to describe and consider the implications of these assumptions. The reader is referred to REF which gives a detailed description of Transform™.

1.3.2 Carbon Emissions Savings

The original business case for the CLNR bid advocated that project success will not in itself bring about the acceptance and use of key carbon reducing technologies. For these the technology trajectories are already established and are likely to be achieved without a successful outcome of the project.

The carbon case methodology was based on an assessment of the change in overall carbon emitted as a result of the project outcomes bringing forward the implementation of such technologies such as photovoltaic micro-generation (PV), heat pumps (HP) and replacement of fossil fuelled vehicles with electric vehicles (EV).

We consider that this remains the most appropriate method to assess the potential carbon benefits of the CLNR project. The methodology is:

For each technology for each year a comparison can be made of the number of installations of that technology that would be expected across the whole UK, according to current predictions against the number that would be expected if the take-up curve was bought forward due to successful project delivery. This comparison gives a carbon benefit for each year as a result of this accelerated technology take up. Total carbon benefit has then calculated by aggregating across the individual technologies for each year. It is then been converted into monetary values using the 2014 UK Government published traded carbon prices for modelling purposes for 2015 to 2035. Unlike the 2009 and 2010 Carbon Pricing in UK Policy Appraisal documents, the 2014 document does not have values for 2036 to 2050. In the absence of revised numbers the 2010 UK Government published traded carbon prices are used for the remaining period.

Carbon benefits have been calculated for both the highest and lowest scenario for future penetration rates from the latest DECC LCT Growth Projections.

All other assumptions are the same as used in the carbon benefit assessment of the original Business Case, including choice of a one year improvement in take up to estimate the aggregate benefit across the technologies for the purposes of this analysis.

1.4 DECC LCT Growth Projections

The Transform Model uses DECC's fourth carbon budget scenarios to project out to 2050, the amount of reinforcement required to the UK distribution network to accommodate the growth of Low Carbon electrical technologies such as heat pumps, PV and electric vehicles. The UK Government has implemented a carbon budget which places a restriction on the total amount of greenhouse gases the UK can emit over a 5-year period. Under a system of carbon budgets, every tonne of greenhouse gases emitted between now and 2050 will count. The Government has set the first 4 carbon budgets in law, covering the period from 2008 to 2027 and have committed to halving UK emissions relative to 1990 during the fourth carbon budget period (2023 to 2027). In order to meet the 4th Carbon Budget the Government has laid out four possible scenarios:

1. High Abatement in Heat (i.e. significant uptake of Heat Pumps)
2. High Abatement in Transport (i.e. significant uptake of electric cars)
3. High Abatement in Heat and Transport
4. Carbon Credit Purchase

These four scenarios of electricity growth have been used in the following analysis to predict the requirement for smart technologies to accommodate LCT driven load growth to 2050.

The scenario that DNOs are predicting for ED1 based on their consultations of stakeholders is now known to be closest to scenario 4. It is however different to scenario 4 in that higher levels of PV uptake are predicted. Therefore expenditure will be likely to be higher than scenario 4 but closer to scenario 4 than any of the other scenarios. Thus when presenting the estimated benefits of a technology we consider this to be closest to the actual savings for ED1 although we should not expect a precise match. Beyond ED1 and out to 2050 it is equally likely that any of the four scenarios given by DECC could be followed, so for our savings estimates out to 2050 we provide a range estimate based on all four scenarios.

2 Cost Benefit of CLNR

Financial benefits in this section are expressed as 2014 Present Values. The Social Time Preference Rate (STPR), defined by DECC has been used to discount future values.

2.1 Network capital cost savings

The savings predicted versus a conventional reinforcement counterfactual scenario are as follows:

DECC Scenario	ED1	ED2	ED3	ED4[23]	2020-2050
Scenario 1	£503m	£5,476m	£3,539m	£5,012m	£15,600m
Scenario 2	£687m	£2,601m	£4,042m	£4,995m	£14,700m
Scenario 3	£384m	£5,528m	£4,268m	£4,976m	£17,700m
Scenario 4	£441m	£349m	£850m	£664m	£3,250m

Table A10.1: Discounted Totex Savings by Scenario

The total benefit in discounted total expenditure predicted by the Transform Model lies in the range £3.25bn to £17.7bn over the period 2015 – 2050.

For ED1, including all CLNR benefits produces a cost saving of £441m compared with the counterfactual of conventional reinforcement costs. This saving is comparable to the saving from adoption of smart solutions which is recognised in the DNOs' ED1 business plans[24].

The total benefit was estimated by modelling in Transform all of the technologies together with the highly sophisticated area control scheme known within CLNR as the Grand Unified Control Scheme (GUS). This approach includes the costs and the additional benefits gained from using GUS. It should be noted that the CLNR project has learned that simpler techniques can address simpler problems nearly as effectively as can be achieved using GUS to coordinate the solutions, except where the issue is intrinsically complex. Therefore it is unlikely that widespread coordinated control will be deployed across British Gas. As a consequence the overall cost benefit reported in this section, which includes costs of GUS, scaled to application across GB, are conservative estimates.

One of the outputs of CLNR has been to provide a much better understanding of the load profiles exhibited by each of the LCTs trialled in the programme. These profiles are shown in detail in our associated paper CLNR-L185: Review of distribution network planning & design standards for future low carbon electricity systems. By gaining better data on Heat Pump, PV and EV profiles, better estimates of the future impact of LCT growth can be made. By comparing current profiles in the Transform Model to the CLNR data we find that predicted spend falls by around £75m in ED1 and by between £500m and £3 billion out to 2050.

[23] Note ED1 to ED4 runs 2015 to 2046 so these values do not sum

[24] The actual expenditure of DNOs in ED1 for LCT reinforcement is forecast to be around £500m. This is larger than the £385m figure from the Transform Model as it is known that the DNOs have used a higher proliferation rate for PV than in scenario 4. Unfortunately exact DNO scenario data is not available but the comparison looks sensible.

If these load profiles are agreed by the DNOs in their peer review process and accepted through Governance into the Transform Model there would therefore be a reduction in predicted spend. These values will therefore be passed through to Transform Governance for further review.

2.1.1 Benefit by Technology

2.1.1.1 Voltage Control

The total benefit provided by Enhanced Automatic Voltage Control solutions to 2050 is estimated by Transform to be between £1.4bn to £10bn dependent on LCT growth scenario.

The precise split of solutions employed will depend heavily on the growth of LCTs and the impact of clustering and these values should be seen as indicative only.

2.1.1.2 Thermal Ratings

The total benefit provided by Thermal Rating solutions to 2050, when compared against other smart solutions is estimated by the Transform Model to be between £0.3bn to £2.2bn dependent on LCT growth scenario.

CLNR has identified three different categories of benefits from changing thermal ratings compared to current Engineering Recommendations P15 Transformers, P17 Underground Cables and P27 Overhead Lines:

1. Possible uplift to generic network ratings
2. Use of a thermal rating assessment tool and local measurement data to calculate additional available uplift for specific assets
3. Use of RTTR equipment combined with controls to provide additional benefits such as enhancing DSR, EES etc. (by reducing calls)

The above recommendations are now being subjected to further validation.

2.1.1.3 DSR

The total benefit provided by I&C DSR to 2050 is estimated by Transform is between £60m and £700m dependent on LCT uptake scenario assuming 100% uptake of DSR contracts offered.

The learning for Demand Side Response (DSR) within CLNR has come from the use of DSR contracts for Industrial and Commercial (I&C) customers and the use of Time of Use Tariffs for domestic customers. Whilst the learning from the domestic studies is promising, it was insufficiently certain to attribute a reliable financial benefit for DNOs.

Our learning suggests that I&C DSR will be available from the marketplace at a cost of up to £2,190/MWh. Our proposed policy for use of DSR is that the market should be tested whenever a network constraint falls below this price point. This means the price paid for DSR will vary up to this price. The Transform™ Model was used to identify the number of times DSR would be offered to the market, rather than the number of times it would be implemented. A price of at least £1,000/MWh was used as the threshold price.

At this cost, the Transform Model suggests DSR that at 100 % take up by the market I&C DSR can offer savings of around £160m in ED1 against business as usual in scenario 4.

More learning is required to determine how often DSR will be applied. The figures for DSR should therefore be regarded as a range estimate at this stage.

2.1.1.4 Storage

For a 2.5MVA storage unit deployed in CLNR to be economically competitive as a DNO owned solution the cost would have to fall significantly to be competitive. However a third party storage unit owner, generating income from trading energy or providing other services such as frequency response, could offer a service to the DNO. This contracted service is essentially the same as I&C DSR. Therefore no explicit benefits from storage are included in this business case.

2.2 Direct Customer Benefit from DSR

In addition to providing benefits to DNOs as capital savings compared to conventional reinforcement, DSR also provides benefit directly to customers in the form of DNO payments to the DSR service provider. Modelling with Transform as described above forecasts that over the period 2020 to 2050 the value of payments to I&C DSR service providers is between £1.3bn and £7bn. The table A10.2 below additionally shows the range of value of these payments in ED1, ED2, ED3 & ED4.

	ED1	ED2	ED3	ED4	2020-2050
DSR Contract Values	£30m	£70m - £250m	£250m - £3bn	£1bn - £4bn	£1.3bn - £7bn

Table A10.2: Value of payments to I&C customers for DSR services

2.3 Carbon Emissions Savings

The following table A10.3 shows the annual savings in carbon emissions from Electric Vehicles, Heat Pumps and Photovoltaic Generators from 2015 to 2050, using the **lowest** DECC scenario. Some 10.7MtCO2 emissions are predicted to be saved. The forecast financial value of these savings is also shown in the table. The aggregate discounted value of these savings is £0.32bn.

The value of carbon is taken from:

- 2015 to 2035 Updated short-term traded carbon values used for modelling purposes, DECC, 2014
- 2036 to 2050 Carbon Pricing in UK Policy Appraisal, DECC, 2009, updated 2010

	Annual Carbon Saving				Carbon Value		Carbon Value
Year	**EV**	**HP**	**PV**	**Total**	**£/tonne**		**£**
2015	11,399	11,196	278,240	**300,835**	£4.6		£1,371,808
2016	16,625	11,196	256,203	**284,023**	£4.7		£1,323,547
2017	24,575	11,195	216,259	**252,029**	£4.8		£1,204,698
2018	36,767	81,203	207,069	**325,039**	£5.0		£1,615,445
2019	55,547	133,649	223,406	**412,603**	£5.2		£2,129,031
2020	64,950	22,116	166,781	**253,847**	£5.4		£1,358,083
2021	72,673	22,228	113,654	**208,554**	£5.6		£1,157,476
2022	96,273	22,544	92,515	**211,332**	£5.8		£1,215,158
2023	116,351	22,509	71,400	**210,260**	£6.0		£1,255,252
2024	130,728	22,359	70,313	**223,400**	£6.2		£1,382,846
2025	144,688	24,870	43,216	**212,774**	£6.4		£1,366,008
2026	167,131	24,350	27,812	**219,293**	£6.7		£1,460,491
2027	182,641	24,642	24,499	**231,782**	£6.9		£1,601,616
2028	193,581	26,057	24,639	**244,276**	£7.2		£1,749,019
2029	217,024	26,201	24,957	**268,182**	£7.4		£1,992,590
2030	226,549	35,033	32,425	**294,007**	£7.7		£2,266,794
2031	239,929	37,342	32,749	**310,020**	£13.5		£4,188,375
2032	249,050	39,830	33,077	**321,957**	£22.5		£7,250,461
2033	252,979	42,511	33,407	**328,898**	£33.5		£11,027,940
2034	260,406	45,401	33,741	**339,548**	£49.0		£16,634,465
2035	263,598	48,515	34,079	**346,193**	£69.9		£24,188,476
2036	258,295	51,874	34,420	**344,589**	£109.0		£37,560,191
2037	253,097	55,496	34,764	**343,356**	£115.5		£39,657,659
2038	243,751	59,402	35,111	**338,265**	£122.0		£41,268,293
2039	226,143	63,616	35,463	**325,222**	£128.5		£41,790,967
2040	222,264	68,162	35,817	**326,244**	£135.0		£44,042,902
2041	216,455	73,069	36,175	**325,699**	£141.5		£46,086,395
2042	209,730	78,365	36,537	**324,632**	£148.0		£48,045,482
2043	206,559	84,081	36,903	**327,542**	£154.5		£50,605,311
2044	208,937	90,254	37,272	**336,462**	£161.0		£54,170,393
2045	194,061	96,919	37,644	**328,624**	£167.5		£55,044,488
2046	182,977	104,118	38,021	**325,115**	£174.0		£56,570,060
2047	175,011	111,894	38,401	**325,306**	£180.5		£58,717,705
2048	161,908	120,296	38,785	**320,988**	£187.0		£60,024,799
2049	152,112	129,375	39,173	**320,659**	£193.5		£62,047,582
2050	152,112	129,375	39,564	**321,051**	£200.0		£64,210,213
			Total	**10,732,606**	tonnes	**Total**	**£847,582,019**
			Discount rate:		3.50%	**NPV**	**£315,577,065**

Table A10.3: Carbon emissions savings from Electric Vehicles, Heat Pumps and Photovoltaic Generators from 2015 to 2050, using the **lowest** DECC scenario

The following table A10.4 shows the annual savings in carbon emissions from Electric Vehicles, Heat Pumps and Photovoltaic Generators from 2015 to 2050, using the **highest** DECC scenario. Some 32.5MtCO2 emissions are predicted to be saved. The forecast financial value of these savings is also shown in the table. The aggregate discounted value of these savings is £0.94bn.

	Annual Carbon Saving				**Carbon Value**		**Carbon Value**
Year	**EV**	**HP**	**PV**	**Total**	**£/tonne**		**£**
2015	90,556	11,196	640,015	**741,766**	£4.6		£3,382,453
2016	117,177	11,196	629,241	**757,614**	£4.7		£3,530,481
2017	143,734	11,195	601,200	**756,129**	£4.8		£3,614,298
2018	170,225	81,203	614,623	**866,051**	£5.0		£4,304,276
2019	196,654	133,649	685,088	**1,015,392**	£5.2		£5,239,422
2020	256,849	128,651	362,242	**747,742**	£5.4		£4,000,418
2021	313,010	164,652	225,743	**703,405**	£5.6		£3,903,899
2022	369,161	214,255	175,381	**758,796**	£5.8		£4,363,078
2023	405,084	300,203	122,362	**827,649**	£6.0		£4,941,066
2024	434,905	321,529	122,040	**878,474**	£6.2		£5,437,751
2025	472,240	347,540	78,218	**897,998**	£6.4		£5,765,147
2026	510,549	352,301	63,164	**926,014**	£6.7		£6,167,251
2027	549,896	357,299	60,205	**967,400**	£6.9		£6,684,731
2028	590,339	359,806	60,701	**1,010,846**	£7.2		£7,237,657
2029	631,955	350,753	61,380	**1,044,087**	£7.4		£7,757,569
2030	587,324	115,573	69,212	**772,109**	£7.7		£5,952,957
2031	555,042	119,617	69,904	**744,563**	£13.5		£10,059,053
2032	537,437	123,816	70,603	**731,857**	£22.5		£16,481,410
2033	537,278	128,178	71,310	**736,766**	£33.5		£24,703,762
2034	557,877	132,708	72,023	**762,607**	£49.0		£37,360,121
2035	599,164	137,412	72,743	**809,319**	£69.9		£56,547,092
2036	668,807	142,299	73,470	**884,576**	£109.0		£96,418,788
2037	772,353	147,374	74,205	**993,932**	£115.5		£114,799,156
2038	916,427	152,646	74,947	**1,144,020**	£122.0		£139,570,481
2039	1,108,937	158,122	75,697	**1,342,756**	£128.5		£172,544,138
2040	1,100,420	163,811	76,453	**1,340,685**	£135.0		£180,992,470
2041	1,079,695	169,721	77,218	**1,326,635**	£141.5		£187,718,799
2042	1,044,437	175,861	77,990	**1,298,288**	£148.0		£192,146,662
2043	991,867	182,240	78,770	**1,252,877**	£154.5		£193,569,497
2044	918,678	188,868	79,558	**1,187,104**	£161.0		£191,123,717
2045	820,926	195,754	80,353	**1,097,034**	£167.5		£183,753,194
2046	693,907	202,910	81,157	**977,974**	£174.0		£170,167,430
2047	532,014	210,345	81,968	**824,327**	£180.5		£148,791,038
2048	328,554	218,072	82,788	**629,414**	£187.0		£117,700,402
2049	75,551	226,101	83,616	**385,268**	£193.5		£74,549,283
2050	0	226,101	84,452	**310,553**	£200.0		£62,110,617
				Total **32,452,026**	tonnes	**Total**	**£2,453,389,564**
				Discount rate:	3.50%	**NPV**	**£937,618,772**

Table A10.4: Carbon emissions savings from Electric Vehicles, Heat Pumps and Photovoltaic Generators from 2015 to 2050, using the **highest** DECC scenario

The following tables show the annual carbon saving calculations for each technology.

Year	No of Vehicles Low-Range	Mid-Range	High-Range
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	4,016.00	0	10,637.10
2013	10,263.00	0	28,656.31
2014	22,603.00	0	94,477.25
2015	37,224.00	128,516	219,807.48
2016	59,593.00	228,550	397,507.36
2017	92,216.00	359,832	627,447.33
2018	140,440.00	524,970	909,499.14
2019	212,589.00	728,063	1,243,536.44
2020	321,590.00	975,513	1,629,435.39
2021	449,043.00	1,291,249	2,133,455.46
2022	591,651.00	1,669,667	2,747,682.72
2023	780,569.00	2,126,332	3,472,095.14
2024	1,008,887.00	2,637,944	4,267,001.40
2025	1,265,418.00	3,192,922	5,120,426.52
2026	1,549,343.00	3,798,229	6,047,114.63
2027	1,877,308.00	4,463,142	7,048,975.94
2028	2,235,708.00	5,181,879	8,128,049.16
2029	2,615,576.00	5,951,030	9,286,484.81
2030	3,041,448.00	6,784,016	10,526,584.22
2031	3,486,010.00	7,582,557	11,679,103.22
2032	3,956,828.00	8,362,552	12,768,275.89
2033	4,445,544.00	9,134,222	13,822,900.50
2034	4,941,971.00	9,909,593	14,877,214.67
2035	5,452,972.00	10,712,461	15,971,949.46
2036	5,970,237.00	11,558,970	17,147,702.19
2037	6,477,096.00	12,468,607	18,460,118.21
2038	6,973,754.00	13,474,739	19,975,724.84
2039	7,452,073.00	14,613,062	21,774,051.67
2040	7,895,839.00	15,922,992	23,950,144.85
2041	8,331,993.00	17,220,759	26,109,525.12
2042	8,756,747.00	18,492,492	28,228,236.46
2043	9,168,305.00	19,723,032	30,277,759.31
2044	9,573,640.00	20,898,881	32,224,122.48
2045	9,983,642.00	22,005,254	34,026,865.99
2046	10,364,452.00	23,001,120	35,637,788.87
2047	10,723,512.00	23,861,485	36,999,458.94
2048	11,066,940.00	24,555,191	38,043,441.54
2049	11,384,655.00	25,036,413	38,688,171.17
2050	11,683,148.00	25,259,787	38,836,426.05

Scenarios where a successful project implementation bring forward EV implementation by 1 year

Scenario Low-Range	Δ EVs	Δ CO2 (tonnes)
59,593	22,369	11,399
92,216	32,623	16,625
140,440	48,224	24,575
212,589	72,149	36,767
321,590	109,001	55,547
449,043	127,453	64,950
591,651	142,608	72,673
780,569	188,918	96,273
1,008,887	228,318	116,351
1,265,418	256,531	130,728
1,549,343	283,925	144,688
1,877,308	327,965	167,131
2,235,708	358,400	182,641
2,615,576	379,868	193,581
3,041,448	425,872	217,024
3,486,010	444,562	226,549
3,956,828	470,818	239,929
4,445,544	488,716	249,050
4,941,971	496,427	252,979
5,452,972	511,001	260,406
5,970,237	517,265	263,598
6,477,096	506,859	258,295
6,973,754	496,658	253,097
7,452,073	478,319	243,751
7,895,839	443,766	226,143
8,331,993	436,154	222,264
8,756,747	424,754	216,455
9,168,305	411,558	209,730
9,573,640	405,335	206,559
9,983,642	410,002	208,937
10,364,452	380,810	194,061
10,723,512	359,060	182,977
11,066,940	343,428	175,011
11,384,655	317,715	161,908
11,683,148	298,493	152,112
11,981,641	298,493	152,112
	Total Saving	6,086,875 t

Scenario High-Range	Δ EVs	Δ CO2 (tonnes)
397,507	177,700	90,556
627,447	229,940	117,177
909,499	282,052	143,734
1,243,536	334,037	170,225
1,629,435	385,899	196,654
2,133,455	504,020	256,849
2,747,683	614,227	313,010
3,472,095	724,412	369,161
4,267,001	794,906	405,084
5,120,427	853,425	434,905
6,047,115	926,688	472,240
7,048,976	1,001,861	510,549
8,128,049	1,079,073	549,896
9,286,485	1,158,436	590,339
10,526,584	1,240,099	631,955
11,679,103	1,152,519	587,324
12,768,276	1,089,173	555,042
13,822,901	1,054,625	537,437
14,877,215	1,054,314	537,278
15,971,949	1,094,735	557,877
17,147,702	1,175,753	599,164
18,460,118	1,312,416	668,807
19,975,725	1,515,607	772,353
21,774,052	1,798,327	916,427
23,950,145	2,176,093	1,108,937
26,109,525	2,159,380	1,100,420
28,228,236	2,118,711	1,079,695
30,277,759	2,049,523	1,044,437
32,224,122	1,946,363	991,867
34,026,866	1,802,744	918,678
35,637,789	1,610,923	820,926
36,999,459	1,361,670	693,907
38,043,442	1,043,983	532,014
38,688,171	644,730	328,554
38,836,426	148,255	75,551
38,836,426	0	0
	Total Saving	19,679,029 t

No of HP installations

Year	Low-Range	Mid-Range	High-Range
2007		0	
2008		**4,014**	
2009		**8,028**	
2010		**18,564**	
2011		**35,122**	
2012	52,683	**52,683**	52,683
2013	65,945	**65,945**	65,945
2014	81,204	**81,204**	81,204
2015	108,885	**108,885**	108,885
2016	136,564	**136,564**	136,564
2017	164,243	**164,243**	164,243
2018	191,921	**191,921**	191,921
2019	392,680	**392,680**	392,680
2020	723,103	**723,103**	723,103
2021	777781	**909,474**	1041168
2022	832734.5	**1,140,486**	1448238
2023	888471.5	**1,433,207**	1977942
2024	944121.7	**1,832,129**	2720136
2025	999400.7	**2,257,227**	3515054
2026	1060887	**2,717,584**	4374281
2027	1121088	**3,183,183**	5245278
2028	1182011	**3,655,322**	6128632
2029	1246432	**4,132,308**	7018183
2030	1311209	**4,598,281**	7885353
2031	1397822	**4,784,453**	8171085
2032	1490144	**4,978,479**	8466814
2033	1588617	**5,180,772**	8772926
2034	1693717	**5,391,770**	9089822
2035	1805962	**5,611,939**	9417916
2036	1925907	**5,841,774**	9757642
2037	2054155	**6,081,802**	10109448
2038	2191358	**6,332,580**	10473802
2039	2338218	**6,594,704**	10851190
2040	2495496	**6,868,807**	11242118
2041	2664014	**7,155,562**	11647110
2042	2844663	**7,455,688**	12066714
2043	3038405	**7,769,951**	12501497
2044	3246279	**8,099,166**	12952052
2045	3469414	**8,444,203**	13418992
2046	3709027	**8,805,992**	13902957
2047	3966438	**9,185,526**	14404613
2048	4243075	**9,583,863**	14924651
2049	4540484	**10,002,138**	15463792
2050	4860338	**10,441,561**	16022783

Scenarios where a successful project implementation bring forward HP implementation by 1 yea

Scenario Low-Range	Δ HPs	Δ CO2 (tonnes)
136,564	27,679	11,196
164,243	27,679	11,196
191,921	27,678	11,195
392,680	200,759	81,203
723,103	330,423	133,649
777,781	54,678	22,116
832,735	54,954	22,228
888,471	55,737	22,544
944,122	55,650	22,509
999,401	55,279	22,359
1,060,887	61,487	24,870
1,121,088	60,200	24,350
1,182,011	60,924	24,642
1,246,432	64,421	26,057
1,311,209	64,776	26,201
1,397,822	86,613	35,033
1,490,144	92,322	37,342
1,588,617	98,473	39,830
1,693,717	105,101	42,511
1,805,962	112,244	45,401
1,925,907	119,945	48,515
2,054,155	128,248	51,874
2,191,358	137,202	55,496
2,338,218	146,860	59,402
2,495,496	157,278	63,616
2,664,014	168,519	68,162
2,844,663	180,649	73,069
3,038,405	193,741	78,365
3,246,279	207,875	84,081
3,469,414	223,135	90,254
3,709,027	239,613	96,919
3,966,438	257,411	104,118
4,243,075	276,637	111,894
4,540,484	297,408	120,296
4,860,338	319,854	129,375
5,180,192	319,854	129,375

Total Saving 2,051,242 t

Scenario High-Range	Δ HPs	Δ CO2 (tonnes)
136,564	27,679	11,196
164,243	27,679	11,196
191,921	27,678	11,195
392,680	200,759	81,203
723,103	330,423	133,649
1,041,168	318,065	128,651
1,448,238	407,070	164,652
1,977,942	529,704	214,255
2,720,136	742,194	300,203
3,515,054	794,918	321,529
4,374,281	859,227	347,540
5,245,278	870,997	352,301
6,128,632	883,354	357,299
7,018,183	889,552	359,806
7,885,353	867,170	350,753
8,171,085	285,731	115,573
8,466,814	295,729	119,617
8,772,926	306,113	123,816
9,089,822	316,896	128,178
9,417,916	328,094	132,708
9,757,642	339,726	137,412
10,109,448	351,806	142,299
10,473,802	364,354	147,374
10,851,190	377,388	152,646
11,242,118	390,927	158,122
11,647,110	404,992	163,811
12,066,714	419,604	169,721
12,501,497	434,783	175,861
12,952,052	450,554	182,240
13,418,992	466,940	188,868
13,902,957	483,965	195,754
14,404,613	501,656	202,910
14,924,651	520,038	210,345
15,463,792	539,140	218,072
16,022,783	558,992	226,101
16,581,775	558,992	226,101

Total Saving 6,662,955 t

PV installed capacity **TWh**

Year	Low-Range	Mid-Range	High-Range
2007			
2008			
2009			
2010			
2011			
2012			
2013			
2014			
2015	3.489852	4.76	6.024974
2016	4.182682	5.90	7.618636
2017	4.820637	7.00	9.185471
2018	5.35913	8.02	10.68248
2019	5.87474	9.04	12.21292
2020	6.431031	10.17	13.91882
2021	6.846322	10.83	14.82081
2022	7.129325	11.26	15.38292
2023	7.35969	11.59	15.81963
2024	7.537478	11.83	16.12432
2025	7.712559	12.07	16.4282
2026	7.820168	12.22	16.62297
2027	7.889421	12.33	16.78025
2028	7.950425	12.44	16.93016
2029	8.011776	12.55	17.08131
2030	8.073919	12.65	17.23415
2031	8.15	12.78	17.41
2032	8.24	12.91	17.58
2033	8.32	13.04	17.76
2034	8.40	13.17	17.93
2035	8.49	13.30	18.11
2036	8.57	13.43	18.29
2037	8.66	13.57	18.48
2038	8.74	13.70	18.66
2039	8.83	13.84	18.85
2040	8.92	13.98	19.04
2041	9.01	14.12	19.23
2042	9.10	14.26	19.42
2043	9.19	14.40	19.61
2044	9.28	14.55	19.81
2045	9.37	14.69	20.01
2046	9.47	14.84	20.21
2047	9.56	14.99	20.41
2048	9.66	15.14	20.61
2049	9.75	15.29	20.82
2050	9.85	15.44	21.03

Scenarios where a successful project implementation bring forward PV implementation by 1 year

Scenario Low-Range	Δ PVs	Δ CO2 (tonnes)
4.18	0.69	278,240
4.82	0.64	256,203
5.36	0.54	216,259
5.87	0.52	207,069
6.43	0.56	223,406
6.85	0.42	166,781
7.13	0.28	113,654
7.36	0.23	92,515
7.54	0.18	71,400
7.71	0.18	70,313
7.82	0.11	43,216
7.89	0.07	27,812
7.95	0.06	24,499
8.01	0.06	24,639
8.07	0.06	24,957
8.15	0.08	32,425
8.24	0.08	32,749
8.32	0.08	33,077
8.40	0.08	33,407
8.49	0.08	33,741
8.57	0.08	34,079
8.66	0.09	34,420
8.74	0.09	34,764
8.83	0.09	35,111
8.92	0.09	35,463
9.01	0.09	35,817
9.10	0.09	36,175
9.19	0.09	36,537
9.28	0.09	36,903
9.37	0.09	37,272
9.47	0.09	37,644
9.56	0.09	38,021
9.66	0.10	38,401
9.75	0.10	38,785
9.85	0.10	39,173
9.95	0.10	39,564
	Total Saving	2,594,489 t

Scenario High-Range	Δ PVs	Δ CO2 (tonnes)
7.62	1.59	640,015
9.19	1.57	629,241
10.68	1.50	601,200
12.21	1.53	614,623
13.92	1.71	685,088
14.82	0.90	362,242
15.38	0.56	225,743
15.82	0.44	175,381
16.12	0.30	122,362
16.43	0.30	122,040
16.62	0.19	78,218
16.78	0.16	63,164
16.93	0.15	60,205
17.08	0.15	60,701
17.23	0.15	61,380
17.41	0.17	69,212
17.58	0.17	69,904
17.76	0.18	70,603
17.93	0.18	71,310
18.11	0.18	72,023
18.29	0.18	72,743
18.48	0.18	73,470
18.66	0.18	74,205
18.85	0.19	74,947
19.04	0.19	75,697
19.23	0.19	76,453
19.42	0.19	77,218
19.61	0.19	77,990
19.81	0.20	78,770
20.01	0.20	79,558
20.21	0.20	80,353
20.41	0.20	81,157
20.61	0.20	81,968
20.82	0.21	82,788
21.03	0.21	83,616
21.24	0.21	84,452
	Total Saving	6,110,042 t

3 Conclusions

Estimating the future impact of the learning of CLNR out to 2050 is, by necessity, imprecise. In an unprecedented era for the UK, where electricity use is currently falling year on year, current levels of spend on distribution network reinforcement are low. Yet if the Government wishes to meet its long term carbon reduction targets it seems likely that electricity will be the fuel of choice for an increasing proportion of the country's needs for both transportation and heat. The Government has produced scenarios for the future showing a range of options of how this might be achieved and these have been used to model the potential savings which CLNR has delivered.

The previous business case, which was prepared for the CLNR bid in 2010, predicted a total net benefit of £5.52bn (2010 discounted figures, which is equivalent to £6.3bn in 2014 pounds (calculated from average RPI in 2010 of 223.6 and Northern Powergrid forecast outturn RPI for 2014 of 256.4, i.e. inflation of 14.7%). Our most recent calculations show, using the Government projections for future electricity demand growth, that the learning from CLNR may provide eventual benefit from 2020 to 2050 of between £4.87bn and £25.6bn of discounted total expenditure from DNO capital investment savings, direct payments for DSR services and the financial value of reductions in carbon emissions. The realisation of these benefits is dependent on the rate of proliferation of Low Carbon Technologies

Equally important is that the development and implementation of projects like CLNR under the LCN Fund banner not only produce tangible cost benefits for the DNOs but also that they keep the UK at the forefront of the development of smart technologies which delivers not only these direct cost savings but also economic development opportunities for the UK and the delivery of opportunities for carbon emission reduction. These benefits are difficult to quantify but are undoubtedly substantial.

APPENDIX 11: Key project learning documents

The following table lists the key project documents. The documents are published on the CLNR website's project library with a brief synopsis so that the reader can judge whether or not the document will be of use to them.

Summary learning reports[25]		
CLNR-L246	23 Jan 2015	Developing the smarter grid: the role of domestic and small and medium enterprise customers
CLNR-L247	23 Jan 2015	Developing the smarter grid: the role of industrial & commercial and distributed generation customers
CLNR-L248	23 Jan 2015	Optimal solutions for smarter distribution systems
6 monthly progress reports		
	June 2011	Progress report 1
	Dec 2011	Progress report 2
CLNR-G013	June 2012	Progress report 3
CLNR-G014	Dec 2012	Progress report 4
CLNR-G016	June 2013	Progress report 5
CLNR-G018	Dec 2013	Progress report 6
CLNR-G020	June 2014	Progress report 7
CLNR-G024	Dec 2014	Progress report 8
Detailed reports from the customers trials		
CLNR-L006	1 June 2012	Domestic and SME tariff development for the CLNR project
CLNR-L015	30 April 2013	Initial Time of Use Tariff Trial Analysis Report
CLNR-L014	30 April 2013	Initial report on Industrial and Commercial (I&C) demand side response trials
CLNR-L036	24 Jul 2014	Project lessons learned from trial recruitment
CLNR-L052	30 April 2014	Social Science Report April 2014

[25] Draft for consultation

CLNR-L086	17 Nov 2014	Report on enhanced profiling of domestic customers with Micro-CHP
CLNR-L087	18 Dec 2014	April 2010 Tariff Reform Analysis; Introduction to the Common Distribution Charging Methodology (CDCM)
CLNR-L090	23 Jan 2015	Insight Report: Domestic Solar PV
CLNR-L091	23 Jan 2015	Insight Report: Domestic Heat Pumps
CLNR-L092	23 Jan 2015	Insight Report: Electric Vehicles
CLNR-L093	23 Jan 2015	Insight Report: Domestic time of use tariff
CLNR-L094	23 Jan 2015	Insight Report: Enhanced Domestic Monitoring
CLNR-L098	18 Dec 2014	Report on CLNR Industrial & Commercial customer demand side response trials
CLNR-L099	23 Jan 2015	Insight Report: Small and Medium Enterprises (SMEs)
CLNR-L104	11 Dec 2014	Heat Pump Survey Results
CLNR-L106	11 Dec 2014	Driving the Electric Vehicle! Survey Data Visualisation
CLNR-L242	23 Jan 2015	High Level Summary of Learning: Domestic Smart Meter Customers
CLNR-L243	23 Jan 2015	High Level Summary of Learning: Domestic Smart Meter Customers on Time of Use Tariffs
CLNR-L244	23 Jan 2015	High Level Summary of Learning: Domestic Solar PV Customers
CLNR-L245	23 Jan 2015	High Level Summary of Learning: Heat Pump Customers
CLNR-L254	23 Jan 2015	High Level Summary of Learning: Electric Vehicle Users
Learning from the network trials		
CLNR-L220	24 Dec 2014	Overview of Network Flexibility Trial Design for CLNR
CLNR-L163	15 Dec 2014	Lessons Learned Report: Electrical Energy Storage
CLNR-L164	17 Dec 2014	Lessons Learned Report: Real Time Thermal Rating
CLNR-L165	17 Dec 2014	Lessons Learned Report: Enhanced Automatic Voltage Control
CLNR-L232	29 Dec 2104	Enhanced Network Monitoring Report
CLNR-L167	15 Dec 2014	Lessons Learned Report: Grand Unified Scheme

Reports on the optimal solutions		
CLNR-L185	31 Oct 2014	Review of the distribution network planning & design standards for the future low carbon electricity system
CLNR-L144	23 Jan 2015	CLNR Cost Benefit Assessment
CLNR-L145	23 Jan 2015	CLNR Commercial Arrangements Report – Phase 2
Outputs for DNOs for implementation into business as usual		
CLNR-L032	17 Jun 2013	CLNR commercial arrangements study: review of existing commercial arrangements and emerging practice
CLNR-L147	19 Dec 2014	Technical recommendation for the purchase of Electrical Energy Storage systems
CLNR-L149	19 Dec 2014	Technical recommendation for the purchase of overhead line Real Time Thermal Rating systems
CLNR-L150	19 Dec 2014	Technical recommendation for the purchase of Real Time Thermal Rating for transformers
CLNR-L151	19 Dec 2014	Technical recommendation for the purchase of underground cable Real Time Thermal Rating systems
CLNR-L209	19 Dec 214	Technical recommendation for the purchase of Enhanced Automatic Voltage Control for HV systems
CLNR-L210	19 Dec 2014	Technical recommendation for the purchase of Enhanced Automatic Voltage Control for HV-LV systems
CLNR-L154	19 Dec 2014	Technical recommendation for the purchase of an Active Network Management systems
CLNR-L155	23 Dec 2014	NPADDS Enduring Specification
CLNR-L255	23 Dec 2014	NPADDS Prototype Functionality and Benefits Case
CLNR-L156	22 Dec 2014	Operational Guidance and Training Requirements: Electrical Energy Storage Systems
CLNR-L157	18 Dec 2014	OHL Real Time Thermal Rating Installation Guide
CLNR-L158	22 Dec 2014	Operational Guidance and Training Requirements: Trials of Secondary Transformers with Integral OLTC
CLNR-L160	19 Dec 2014	Application Guide: CLNR Demand Side Response Trials

CLNR-L161	22 Dec 2014	Operational Guidance and Training Requirements: Grand Unified Scheme (GUS)
CLNR-L233	15 Dec 2014	A guide to the CLNR Training Packages
CLNR-L168	15 Dec 2014	Training Package: Electrical Energy Storage
CLNR-L204	15 Dec 2014	Training Package: Real Time Thermal Rating for overhead lines
CLNR-L205	15 Dec 2014	Training Package: Real Time Thermal Rating for underground cables
CLNR-L206	15 Dec 2014	Training Package: Real Time Thermal Rating for transformers
CLNR-L170	15 Dec 2014	Training Package: Enhanced Automatic Voltage Control
CLNR-L172	15 Dec 2014	Training Package: Active Network Management
CLNR-L173	15 Dec 2014	Training Package: Demand Side Response
CLNR-L220	24 Dec 2014	Overview of Network Flexibility Trial Design for CLNR

APPENDIX 12: Closedown consultation

This appendix will support section 12 by providing more detail on the outcome of the closedown consultation i.e. the nature of feedback and how we have taken these into account in the final closedown report.

Customer-Led Network Revolution

For enquires about the project
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