CUSTOMER-LED NETWORK REVOLUTION

SECOND TIER REWARD APPLICATION

- **Internationally renowned landmark project** – this seminal work is now being used to transform the electrical, heat and transport sectors in the UK and internationally
- **£6.6bn to £20.3bn of GB net financial benefits** and up to 34m tonnes of CO_2 emissions avoided to 2050 through a proven evolutionary roll-out of smart grid solutions
- **Informed business changes even before project closedown** – customer load assumptions, asset ratings, voltage settings changed and comprehensive £83m Northern Powergrid deployment of smart grid enablers commenced
- **'Whole system' learning** benefitting customers by informing the development of smart and flexible energy policy and **boosting the UK economy through new sales and services**
- **Created a collaborative innovation culture and confidence** that has secured lead roles in numerous follow-on competitively funded projects totalling £106m
- **Developed a cohort of *ca.* 50 smart grid experts**, encompassing and combining social, technical, commercial and regulatory knowledge who now work across the industry putting into practice the skills and knowledge gained through this ground breaking project

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1 Executive summary

1. Northern Powergrid's (NPg's) Customer-Led Network Revolution (CLNR) was a ground-breaking and unique programme of work that successfully delivered a step change in the understanding and momentum necessary to support the decarbonisation of the energy system in the period to 2050. This £31m four-year smart grid demonstration project brought together the key stakeholders in the electricity system to develop, integrate and trial customer and network flexibility techniques to deliver increased network capacity at least cost to customers. CLNR leaves a comprehensive legacy: a rich body of research and learning with GB net benefits estimated as £6.6bn in the period to 2050 and 21m tonnes CO_2 emissions avoided– rising to £20.3bn and 34m tonnes respectively if low carbon technology (LCT) take-up grows faster than projected.
2. The socio-technical trials combined customer energy practices insight with state of the art technology to integrate and compare customer and network flexibility solutions. By trialling with real customers on real networks, the outcomes have provided understanding of customer diversity in the use of electricity; with rigorous modelling that enables us to look ahead and work out how to manage the network congestion that could result from much higher concentrations of local generation, charging of electric vehicles and heat pumps.
3. CLNR was a 'whole system' project that preceded the popular use of that term. As such, its benefits have also benefitted customers by informing the development of energy policy. This landmark project informed many of the judgements in the Smart Systems and Flexibility Plan and, years after formal closure, the evidence base created is still being used – most recently to inform Ofgem's Targeted Charging Review. The project data that we curated and made available has been downloaded by 100 organisations in 20 different countries; and not just by those in the energy sector. Website visits to access the learning library have exceeded 10,000.
4. The project has international reach that is benefitting UK economic development. The knowledge created has stimulated sustained international interest and has enabled sales of products and services. Closer to home, the learning has shaped follow-on projects by NPg, our partners and others in the industry. These have been informed by the specific learning as well as the confidence that the project has given to the sector. Siemens funded a centre for excellence for smart grids following the success of CLNR, cementing the region's reputation. The project's scale, scope and ambition has had a defining impact on Northern Powergrid's culture, where collaborative innovation - always engaging stakeholders – is now the way we do things.
5. The project drove change in NPg even before it finished; and this has continued. New voltage settings in our primary substations have already created additional headroom for solar panels at minimal cost. The detailed customer observations have provided evidence for reviews of national standards that benefit all GB customers. But perhaps most importantly it promoted the evolutionary development of power systems; where 'incremental smartening' captures option value and avoids unnecessary expenditure ahead of need.
6. CLNR significantly impacted smart grid benefits in the 2015-23 price control period. Specifically, CLNR results have shaped NPg's £83m smart grid enablers program that is creating an upgraded communications and control platform upon which smart solutions will be integrated to service new flexibility markets to accommodate new customer uses such as the charging of electric vehicles. At the price control review, GB-wide benefit was locked in by Ofgem's development and use of the Transform model to compare and benchmark all distribution network operators' (DNOs') plans. That model was an evolution of the bid stage benefits model created in CLNR and populated with predicted results from CLNR that were largely confirmed by the trials.
7. The exceptional value of CLNR has been widely recognised. In conducting its review of network innovation for Ofgem, Poyry[1] provided an overall rating for CLNR of 95%. An independent Hubnet study[2] identified CLNR evidence as robust. CLNR academic papers have been published in top quartile peer reviewed journals, providing external validation that the work was of international 'archival' quality. Finally, the knowledge gained through CLNR established the partners as national and international leaders in the field of smart grids and energy systems; evidenced by competitively secured further funding and lead roles in the £20m Engineering and Physical Sciences Research Council (EPSRC) national Centre for Energy System Integration (CESI), £11m Supergen energy networks research hub, Faraday Institution (£65m) and e4Future vehicle to grid (£10m) projects.
8. In short, CLNR has:
   - one of the *most extensive integrated trials of network and customer smart grid technology* with the most advanced wide area control system in Europe.
   - the *most comprehensive study of customer energy practices* undertaken in GB; and
   - delivered *unrivalled benefits* through reach, replicability and quality of learning - backed up by datasets, validated models and new generalised smart grid methodologies.
9. This challenging project is delivering outstanding benefits for customers because it was both ambitious and well-managed. The success of the project demands that the at-risk element of funding provided by NPg is recognised and rewarded.

2 Description of project and alignment of evidence with each reward criterion

Tier 2 project name	**Customer-Led Network Revolution (CLNR)**
Licensee	Northern Powergrid (NPg)
Project summary (2 sentences)	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.
Tier 2 funding (£k)*	27,930
Licensee compulsory contribution (£k)	3,103
Other contributions (£k) *	3,750
Link to closedown report	http://www.networkrevolution.co.uk/project-library/project-closedown-report-2/

**Nominal prices*

2.1 Project description

10. CLNR set out to find out whether customers could be flexible in the ways they use and generate electricity and how DNOs could contribute to reducing customers' energy costs and carbon footprint. It was designed to predict future loading patterns as the UK moves towards a low carbon future and to develop novel network and commercial tools and techniques and to establish how they can be integrated with novel control techniques to accommodate the growth of low carbon technologies in the most efficient manner. The project used new network monitoring techniques to measure power flow, voltage and harmonics, trialling alternative smarter solutions that employ active network management (ANM) and customer engagement to increase network capacity and modulate load patterns.

11. While network management and demand response technologies already existed to CLNR, they had not previously been deployed at distribution level in a market with the degree of vertical separation in GB. CLNR created an integrated programme of bringing together the knowledge and resources need to bridge this gap. CLNR success in bringing NPg (a 'wires only' DNO) the largest national unaffiliated energy supplier (British Gas), together with a multi-disciplinary academic team from Durham University and Newcastle University and network consultants EA Technology.

12. More than 13,000 domestic, SME, industrial and commercial (I&C) customers and distributed generators took part in the project which operated between 2010 and 2014. The trials involved a range of customer-side solutions (innovative tariffs and load control incentives in association with different LCTs) and network-side technology (including voltage control, real time thermal rating (RTTR) and energy storage). A state of the art wide area control system was developed to integrate the customer and network trials to optimise across the whole energy system. The trials were designed to be applicable to a high percentage of GB networks and demographic groups.

13. The trials were designed to address the following:
    - **Learning outcome 1:** understanding of current, emerging and possible future customer (load and generation) characteristics;
    - **Learning outcome 2**: to what extent are customers flexible in their load and generation, and what is the cost of this flexibility?
    - **Learning outcome 3**: to what extent is the network flexible and what is the cost of this flexibility?
    - **Learning outcome 4:** what is the optimum solution to resolve network constraints driven by the transition to a low carbon economy?
    - **Learning outcome 5:** what are the most effective means to deliver optimal solutions between customer, supplier and distributor?

2.2 Alignment of evidence with each reward criterion

2.2.1 Criterion A – Exceptional performance against the detailed time, cost and quality criteria

A1: Facilitate the Carbon Plan and/or Clean Growth Strategy

14. CLNR is an internationally renowned landmark project that is transforming the electrical, heat and transport sectors in the UK and internationally. We quantify here how it is contributing at least 21 million tonnes CO_2 emissions avoided. Further, we detail the wider group of GB and international stakeholders that are using the learning generated from CLNR. Stakeholder testimonials demonstrate the delivery of environmental, economic and societal benefits – on a local, national and international scale.

A2: Releasing network capacity

15. We have used the Transform quantification and modelling tool to demonstrate the 0.4GW to 1.7GW of GB capacity released in 2050 from CLNR solutions. We also identify capacity released by specific NPg projects. Our related work on voltage reduction has the potential to release an additional 10.6GW of capacity (see section A8).

A3: Delivering financial benefits

16. We estimate that the value to GB of CLNR will be at least £5.2bn of which the network capital cost savings are the largest share at £4.3bn. In this section we explain how we have modelled this impact. In addition to specific smart grid solutions we have estimated a value for the wider benefits of CLNR and its influence on other innovation work – at less than 5% of the total this is significant in terms of the platform provided by CLNR for wider energy system innovation.

A4: Rollout across the DNOs' systems and across GB

17. Rollout commenced and benefit was locked in for all GB customers prior even before the project concluded. We outline in this section how CLNR solutions are being rolled out into business as usual, providing examples of roll out in NPg and the wider industry in term of assets operating on the network, policies and standards, and tools for planning and design. In more detail we set out what the roll-out has achieved to date in NPg and the next steps planned. Our examples include the £83m smart grid enablers programme and the new smart solutions being used in place of reinforcement to accommodate low carbon technologies.

A5: Value for money to customers

18. Project funding was used to achieve the best value outcome for present and future customers. We evidence how we maximised value for money during the project by minimising the delivery cost through our approach to sourcing resources, leveraging customer Low Carbon Networks Fund (LCNF) contributions through external funds, and by refining the detailed design of some of the trials. Finally we describe actions taken post-project to achieve further value for money by redeploying equipment.

A6: Relevance and timing of project

19. The emerging conclusions from CLNR and the toolkit to model benefits enabled Ofgem to lock in around £800m of benefits for all customers in the ED1 price control review. Exceptional effort was made to address externalities that we outline here in order that we could still achieve the project outcomes.

A7: Methodology robustness and project readiness

20. CLNR learning is high quality and diverse. We provide independent evidence of the robustness of the project methodology and then describe how we delivered additional learning at no additional cost. Our approach to combining modelling in addition to the physical trials is discussed, along with the measures taken to mitigate delays.

A8: Other benefits

21. In this section we describe how CLNR thinking and learning and equipment has flowed to other initiatives and organisations, leveraging even greater benefit and value for money from the LCNF customer contributions.

2.2.2 Criterion B – To invest the DNO's money to enable the project to be delivered

B1: Details and significance of DNO's additional contribution

22. We have quantified over £5.75m of additional contributions across four areas of external funding and additional contributions by the project partners. These funds were used to ensure successful high quality delivery of the project either because the original route to the learning was not possible or they were used to enhance learning.

B2: Issues that justified the additional contribution

23. The delay to the renewable heat incentive meant that there were insufficient heat pumps available for the project to deliver the planned learning without the injection of an £2.2m additional funding; and £1m of project partner resources was required to ensure that the project delivered.

B3: Demonstrable benefit to customers

24. We explain how the extra funding provided clear outcomes that were valuable to customers in terms of the learning from the project.

2.2.3 Criterion C – To undertake exceptional effort to ensure the project exceeds the expected delivery outcomes and the learning is maximised for the good of all DNO customers

C1: Demonstrate where the project has delivered more learning than was expected

25. CLNR produced much additional learning that was delivered from following the methodology and extracting more learning or being alert to opportunities to capture knowledge that was tangential to the main intent. Both are explained here.

C2: Additional learning as a result of exceptional effort of the DNO

26. The scope, scale and ambition of CLNR was ground breaking. Not only was the committed learning delivered but exceptional effort also enabled additional learning to be created from this seminal work on both the network technology and customer technology trials.

C3: Exceptional capture and dissemination of learning in a way that maximises value for all customers

27. CLNR set new standards for the capture and exchange of knowledge with DNOs and other interested parties. We describe firstly how we delivered learning in a way that would be relevant and accessible to a range of stakeholders, how we used the project website and social media to disseminate information and how we approached dissemination of the disaggregated datasets to maximise their impact. We then go on to present evidence of the effectiveness of our approach and dissemination metrics to demonstrate reach.

3 Description and evidence of project compliance with the reward criteria

3.1 Reward criterion A

Sources of evidence

28. In providing evidence against each criterion, we have drawn on third party sources where possible – most notably Poyry's report for Ofgem as part of the Network Innovation Review and post-project research by Durham University into the impact of CLNR. Unless indicated otherwise, quotations in this document are from the Durham University research. We have also drawn on and updated previously published material, notably the Project Closedown Report and the Successful Delivery Reward Application[3]. Modelling of benefits has been conducted using the industry standard cost forecasting tool (Transform).

29. Independent evaluations of LCNF projects have assessed CLNR as having delivering robust evidence (Hubnet), and of being well designed and well run: Poyry awarded CLNR a weighted total score of 95 out of 100 and the scoring against each of its criteria are shown below.

Criteria	Score	Justification
Accelerates the development of a low carbon energy sector	5	• The project clearly facilitates the connection of low carbon generation or demand. • The carbon benefits are credible and quantified.

Criteria	Score	Justification
Has the potential to deliver net financial benefits to future and/or existing customers	-	• Compelling evidence that the project is highly likely to deliver significant financial benefits in the long term (ED2 and beyond) to the majority of customers.
Generates knowledge that can be shared amongst all DNOs	5	• Specific replication report(s) exist. These cover the main technical / commercial / stakeholder aspects as applicable. A learning dissemination event or webinar was held.
Involvement of other partners and external funding	5	• The project involved a wide range of external partners covering the main technical /commercial / stakeholder aspects as applicable. • External funding for > 10% of the project was obtained.
Relevance and timing	4	• The project has been /is ready to roll out into BAU. The project has a high likelihood of being replicated by other DNOs.
Effective project methodology, and effectiveness of implementation	5	• The project achieved all its successful delivery reward criteria (SDRC) and the variance was <10%.

30. The interest in CLNR learning is key to its impact on the low carbon energy sector and can be evidenced by the number of visits to webpages which is provided in C3.

31. The quality of the learning is assured by the peer review process for publication in academic journals, and the impact can be demonstrated through the number of times that these have been cited in further published work. At the time of project closedown a total of 12 papers had already been published in peer reviewed academic journals, with five identified as 'archival' quality and over 80% in the top half of the rankings. Seven further papers have been published more recently as research drawing on CLNR continues.

32. Academic citations demonstrate the importance of the work in progressing understanding of GB energy systems. The three most popular papers have today reached over 150 citations from the international community in peer reviewed papers on topics of peak electricity demand and the link to consumers' flexibility, integrating electrical energy storage (EES) into coordinated voltage control schemes and combining smart meter and EV charging data to investigate distribution network impacts.

Approach to identifying benefits

33. CLNR was designed to develop solutions in advance of need, with deployment of those solutions increasing as LCT uptake increases. The figures we present here for the associated benefits of CLNR start from 2016/17 (i.e. we have concentrated on calculating the significant benefits (A1 to A3) that is being delivered by deploying these solutions from 2016/17 through to 2050. This is instead of quantifying the relatively small benefits delivered up to 2015/16, as LCT adoption rates to date have been low compared to what we may have expected; the need to deploy the CLNR solution set described in the closedown report (planned implementation table) has also therefore been relatively low to date, and wide-scale adoption of CLNR solutions would not realistically be expected to start before the 2014 project completion date.

34. To calculate the GB-scale costs and benefits of the CLNR solutions we have used the industry standard forecasting tool – Transform. This takes each smart solution that was proven to work in CLNR and then forecasts the benefits and costs of changes to distribution networks to accommodate low carbon technologies. We have used the same methodology as we did at the project closedown, but we have refreshed the calculations so that they are based on what we consider currently to be a more realistic base case scenario for LCT growth rates. The base case is based on the growth rate assumptions in our ED1 business plan, except that we have increased the growth rate for EVs from low to medium to reflect the government's more recent policy position. To demonstrate the sensitivity of benefits to LCT growth rates, we have also included the results of the modelling for the low and high scenarios presented in the closedown report.

	Assumed LCT growth rate (DECC scenarios)		
Scenario	HP	EV	PV
CLNR modelling 'Low' case	Low	Low	Low
Northern Powergrid ED1 business plan assumption	Low	Low	Medium
CLNR modelling 'Base' case	Low	Medium	Medium
CLNR modelling 'High' case	High	High	High

35. As well as the CLNR solution suite, the project delivered a wider range of additional learning and we have identified other initiatives which have drawn on CLNR learning. These initiatives are described, and, where possible, the benefits are quantified in this section A.

3.1.1 A1: Aspects of the Carbon Plan and/or Clean Growth Strategy that have been facilitated

36. CLNR provides the opportunity to save 19 million tonnes of CO_2 by 2050 under the expected LCT growth rates, rising to 32 million tonnes if growth rates are higher.

37. In this section we provide an overview of the UK's Carbon Plan and Clean Growth Strategy and then discuss the outputs from CLNR and how they advance the low carbon transition, quantifying this in terms the reduction in CO_2 emissions as a result of implementing the CLNR solutions GB-wide. We then discuss the wider impact of CLNR and how this is contributing to the low carbon transition through a range of actions being taken by industry and academia. Finally, we set out evidence of the quality of CLNR learning and its wider impact.

38. Informed by CLNR, we have developed other initiatives that reduce carbon emissions and these are described in A8, including a quantification of the associated carbon emissions saving where possible.

Overview of Carbon Plan and Clean Growth Strategy

39. Through CLNR, we investigated potential solutions to a range of specific network issues and the project has provided the country with effective outputs and demonstration to support the central objective of clean growth that will support the a growing economy while reducing carbon emissions.

40. Both the Carbon Plan (2011) and Clean Growth Strategy (2017) require an increase in low carbon electricity generation and the decarbonisation of heating and transport, with electricity being a key way of achieving this decarbonisation.

41. Electrification of heating and transport and the rise in micro-generation are placing new demands on electricity networks. It is essential that we learn how to design and operate networks in a way that can accommodate the new challenges presented by this transition in the most economical way; capture new opportunities presented by the new solutions, and minimise the need for significant network investment. CLNR has successfully demonstrated the opportunities and challenges associated with different solutions to increase the numbers of photo-voltaic (PV) installations, heat pumps and EVs being connected to electricity distribution networks.

42. However the Clean Growth Strategy is about more than achieving UK decarbonisation at the right price. CLNR has led to wider benefits. For example, by helping to cut transport emissions there is an improvement in air quality, which has a positive impact on public health, the economy, and the environment. Our country also benefits economically and in terms of reputation from the selling of UK goods and expertise around the world and benefitting from subsequent international carbon reduction.

CLNR outputs and how they advance the low carbon transition

43. CLNR has advanced the low carbon transition by:

- providing information to inform network planning on new customer demands;
- showing how advanced voltage control, thermal ratings and storage may be integrated to enable more low-carbon technologies to be accepted on the network;
- new evidence on the contribution of real generators to system security;
- by developing a prototype decision support tool for network planning and design (NPADDS); and
- by providing a better understanding of the fundamentals of how customers and networks behave.

44. These routes by which CLNR outputs are making a significant contribution to the low carbon transition are set out in more detail here:

- **New customer demands for network planning**: we have provided network designers with more accurate information about customers' behaviour and LCT demand profiles, enabling them to deliver low voltage (LV) designs that better reflect emerging and future load and generation profiles. This will enable DNOs to better support and enable the low carbon transition and growth of LCTs connected to distribution networks. We published network design coefficients for domestic customers with high, medium and low annual consumption, and new sets of design coefficients in an industry standard format suitable for existing industry standard tools to represent LCTs such as EVs, heat pumps and PV. Given existing industry modelling standards did not consider LCTs, this work provided and recommended a new set of generic load and generation curves representative of the operating regime of LCTs.
- **Integration of advanced voltage control, thermal ratings and storage to enable more LCTs to be accepted on the network:** CLNR's 'Optimal solutions for smarter network businesses' report[4] is a generic smart grid

safety case, backed up by detailed documents for the installation, operation and maintenance of each new technology deployed.

- EES has proven to be an effective form of demand side management alongside customer flexibility – assisting to alleviate upstream network constraints.
- We have validated that the existing engineering thermal ratings are not overly conservative - with 10-15% headroom on some overhead lines and conversely some cable networks requiring de-rating by *ca.* 10%.
- We have demonstrated how to control voltage better - with the optimal devices being an in-line regulator on rural high voltage (HV) networks and an on-load tap-changer (OLTC) on secondary transformers in urban networks.
- We have developed detailed specifications for all the CLNR solutions. Together these form a rich DNO toolkit (see A4), providing 'how to' guidance on the application of novel network technologies.

- We reviewed **the contribution of real generators to system security** and recommended the review and update of F-factors to support DNOs to better recognise the contribution that distribution generation (DG) makes to system security and therefore to comply with the security requirements of Engineering Recommendation P2/6. This approach seeks to use customer flexibility solutions to contribute to security of supply as an alternative to building more networks.
- For day-to-day application, the prototype **Network Planning and Design Decision Support** (NPADDS) tool enables analysis of PV, EV and heat pumps on a network. It also illustrates a process of ranking, design and analysis of example headroom solutions that were trialled by the CLNR project, within the context of the Smart Grid Forum Workstream 3 solutions. NPADDS is a case-specific tool, not one that uses generic rules to make sweeping statements. It brings in network data from host systems using the Common Information Model, and applies customer demands using the coefficients developed for the key customer groups in CLNR, to carry out a bespoke, bottom-up, power flow analysis across LV and HV networks.
- **A better understanding of fundamentals of how customers and networks behave**: we have developed new tools for systematic analysis of each, including:
  - development of a socio-technical framework for understanding the implementation of energy services;
  - a validation, extension, extrapolation, enhancement and generalisation (VEEEG) framework to specify, prioritise and analyse field trials of new methods (available for others to use in the future); and
  - new metrics to define network response, including Diversified Voltage Sensitivity Factors and Feeder Voltage Diversity Factors. These are aimed at academic and high-end policy work.

45. The reductions in CO_2 emissions that the CLNR solutions could ultimately deliver are based upon the conservative assumption that the deployment of CLNR solutions will accelerate the future take-up of LCTs by just one year. This is the same method of calculation as was used in the closedown report.

46. For each of the scenarios described above, the carbon emissions saved by the GB rollout of CLNR solutions are:

GB wide benefits from rollout of CLNR solutions Carbon emission savings – million tonnes CO_2 cumulative						
LCT growth scenario	**2015**	**2016**	**2020**	**2030**	**2040**	**2050**
Low case	0.30	0.58	1.83	4.15	7.48	10.73
Base case	0.52	1.04	3.31	7.55	13.51	19.33
High case	0.74	1.50	4.88	13.67	23.16	32.45

47. Independent confirmation that CLNR facilitates the Carbon Plan and Clean Growth Strategy is provided by the Poyry assessment of LCNF projects which scored the CLNR project as 5 out of 5 against the criteria 'Accelerates the development of a low carbon energy sector'.

Wider impact of CLNR

48. Since project closedown, we have been able to trace how the learning from CLNR has been used by other parties, demonstrating the significance of CLNR and the additional ways in which the legacy of CLNR continues to actively facilitate the low carbon transition. These are grouped under a number of themes, with further information in C3 on the dissemination that has enabled this impact.

Research and development expertise and strategic learning

49. As one of the very first smart grid projects, CLNR has influenced many similar and subsequent projects that have since been undertaken by other DNOs. These have been funded through the LCNF fund, and more recently the Network Innovation Competition (NIC), the Network Innovation Allowance (NIA). It was always the intention that CLNR should provide a platform for further developments that would accelerate the implementation of LCTs and

this has proven to be the case. We have interviewed those DNOs undertaking these new projects that build on CLNR and develop its insight further. These include

- Control systems from CLNR grand unified scheme (GUS) - Smart Street and Network Equilibrium;
- Electric vehicles - Electric Nation, Car Connect and My Electric Avenue; and
- Customer engagement – SAVE and FREEDOM.

50. The sheer scale of CLNR, of trialling and joining up various innovation threads is understood to be of particular significance throughout the industry. CLNR was described as a '*high profile project*' (respondent from PassivSystems) that '*broke the mould'* (respondent from Sustainability First, ex-NPg employee). Understood by manufacturers and consultants generally to be more significant in technology demonstration and system integration than specific technology development, CLNR has conferred confidence on DNOs specifically, but also across the industry. It has also opened doors to future R&D:

- *'The amount of R&D and innovation projects we do has grown significantly…it's all kind of a logical extension of CLNR….CLNR gave us a very good foundation on which to extend and do other things'* (respondent from PassivSystems).
- *'The main impact of the CLNR project comes from the meta findings in multiple new technology areas that have gone on to shape the industry…a lot of the findings were medium to long term focused and were not directly deployed at project close but are becoming more relevant to the on-going energy system transition'* (Respondent from Smarter Grid Solutions)
- *'CLNR is still something people will refer to in the energy research community'* (Newcastle University)

Technology systems and market development

51. CLNR has influenced the wider industry transition to flexibility services from both the technical and commercial learning. It has proved the market and capabilities for numerous technologies such that we are now seeing commercial business-as-usual (BAU) deployments in various areas:

- **NECES**, the supplier of battery units in CLNR (formerly operating as A123) were introduced to the UK EES market as a result of their involvement in CLNR, increasing competition and innovation in the market.

  'When we were bidding on some of the EFR [Enhanced Frequency Response] projects, some customers wanted to know some real examples of lessons learnt from past projects and improvements and so we referred back to our track record of projects in the UK that we successfully deployed' (NEC).
- Aggregator **Kiwi Power** trade from the battery asset at Rise Carr that was deployed from CLNR:

  'Without CLNR we wouldn't be doing what we're doing right now, simple as that' (Kiwi Power).
- **Siemens** control system product 'Spectrum Power' was further developed under CLNR (and subsequently termed GUS). The development of this technology has been significant for the organisation, creating a centre in Northeast for smart grids, winning two internal awards (Best Smart Grid Project 2013 and Best Global Customer Project 2013) and acting as an international case study attracting visits from Turkish regulators and the Japanese government:

  'Digitalisation (software application and related digital services) is breaking new boundaries in many organisations, Siemens are investing heavily and it forms a key aspect of our future strategy that can be read more if you search industry 4.0 (fourth Industrial revolution). CLNR played a part in revolutionising secondary substation digital control and creating a relatively low cost solution to smart grid coordination.' (Siemens).
- **Other DNOs** have gone on to use GUS/Spectrum Power such as WPD in their Network Equilibrium project and ENW have used it on their 'Smart Street' project trialling voltage control.

52. A number of the CLNR project partners have competing effectively to secure £106m of follow-on funding and continue the development of understanding using the proven tools, techniques and working relationships:

- **Centre for Energy Systems Integration (CESI),** Newcastle University: a £20m centre funded by public and private funding from the EPSRC and Siemens, bringing together academic (Newcastle, Heriot-Watt, Sussex, Edinburgh, Durham) and industry partners. Experience gained and capability demonstrated on CLNR was key to winning this work:

  'The Centre for Energy Systems Integration is, I think, unmistakably shaped by the experience of CLNR in that it's a socio-technical, integrative energy centre.' (respondent, Newcastle University).
- The £11m **Supergen energy networks research hub:** a consortium of academic researchers tasked with coordinating research in energy networks in the UK. It is led by Newcastle University with industrial collaboration input from NPg and Siemens.

- The £65m **Faraday Institution:** the UK's independent centre for electrochemical energy storage science and technology, supporting research, training, and analysis. Newcastle University is one of the founding universities, examining system integration of battery systems with an initial focus on the automotive sector; additional projects include those related to battery recycling and reuse and battery degradation.
- The **e4Future vehicle to grid project:** £9.8m funding by Innovate UK in 2018. A consortium led by Nissan and including NPg and Newcastle University is carrying out a widespread demonstration and deployment of vehicle to grid systems.

53. Further, the partnership has taken forward additional projects as follows:

- **'FrESH', Newcastle University:** Described as *'the formalisation of a set of collaborations'* (respondent Newcastle University). In part developed through CLNR, regional organisations have come together to consider challenges of the city region under the transition to a low-carbon economy.
- **Integrel**: A £30m gas and electricity system demonstrator that is exploring optimised whole energy systems at a Northern Gas Networks site with a number of CLNR collaborating partners and providing a practical test bed to complement CESI and work with regional, national and international innovators.
- **Sustainable Multi-Storey Communities project:** This was described as *'an offspring of CLNR…almost like a mini-CLNR trial' (respondent Newcastle University).* This project considers the need to re-bundle the value chain by being creative and bringing together housing providers, EV charging companies and the NHS.

54. More broadly, academics are taking forward other projects and collaborations related to CLNR:

- **'Smart Energy Network Demonstrator', Keele University**: SEND is part funded through the European Regional Development Fund (ERDF) and part funded by the Department of Business, Energy and Industrial Strategy (BEIS). The project is a large 'living laboratory' that models various technologies including the Siemens Spectrum system and microgrid controllers.
- Demand Response in Blocks of Buildings (DR-BOB)**, Teesside University:** an international Horizon 2020 European Commission funded project demonstrating economic and environmental benefits of demand side response (DSR). Project representatives from Sustainability First were invited to be involved because of their CLNR expertise.
- **Smart City Australia, Durham University:** Professor Bulkeley worked on a smart grid project in Australia with Professor Pauline McGuirk and Professor Robyn Dowling ("Making a Smart City for the Smart Grid? The urban material politics of actualising smart electricity networks". *Environment and Planning A*. 2016)[5] *'That was informed by the CLNR project…and then Pauline and Robyn have gone on to do work on smart buildings in Australia as well, which is then, also obviously informed by that work'' (Professor Harriet Bulkeley, Durham University).*

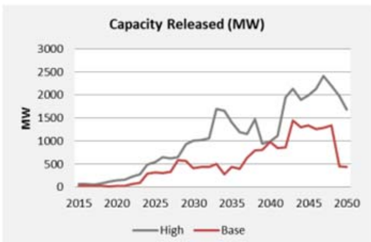
3.1.2 A2: Releasing network capacity

55. Our Transform modelling of the base case LCT growth scenario demonstrates that at GB-scale CLNR solutions have the potential to release up to 1.4GW of capacity in the early 2040s compared to using traditional or alterative smart solutions to accommodate LCTs. Under a higher LCT growth rate, the capacity released is higher, reaching up to 2.4GW in the late 2040s. Much of this benefit is from 2030 onwards. Separately, we have identified specific NPg projects where actual deployments are already starting to release benefits.

Network capacity released – GB wide

56. We have used Transform modelling to quantify the capacity released through a GB-wide rollout out of CLNR solutions compared to the counterfactual scenario (i.e. using only traditional methods).

LCT growth scenario MW	2015	2016	2020	2030	2040	2050
Base case	24.4	25.6	21.7	411.1	981.8	437.6
High case	58.9	66.6	147.0	1,007.7	993.38	1,685.0



Network capacity released – Northern Powergrid networks

57. Further, we have already started to deploy the CLNR solutions on the Northern Powergrid network, and the capacity released from these schemes is set out in the table below. The projects are described in section A4.

58. There is clear overlap between these specific examples of capacity release and those modelled at a GB-scale above. As such, they should not be summated to estimate total beneficial impact.

Benefits from Northern Powergrid actual rollout to date of CLNR solutions Capacity released MW	
Additional voltage control - Stow regulator	9.0
Additional voltage control - Hunmanby regulators	9.0
Additional voltage control – Seghill load drop compensator	9.0
Active network management – Driffield	22.3
Total	49.3

3.1.3 A3: Delivering Financial Benefits

59. The GB financial benefit of the CLNR solutions to 2050 is estimated as £5.2bn of which the network capital cost savings are the largest share at £4.3bn. Under the higher LCT adoption rate scenario, the network capital cost savings are estimated to be £14.1bn.

60. Further, we have estimated the value of CLNR to other DNO in that there has been transfer of data, knowledge and methods. Our estimate is £220m. Finally, we describe other, unquantified, financial benefits arising from the CLNR project where there are three examples of more value being sought from CLNR outputs.

Costs and financial benefits from deployment of CLNR solutions GB-wide

61. There are three areas of GB financial benefit that we have quantified:

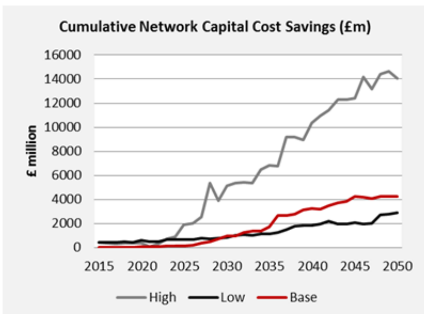
	Benefits accrue to	
	DNO	**Customers**
Network capital cost savings from avoided costs associated with reinforcing the electricity distribution networks to support additional load and increased variability of supply and demand	Directly	Indirectly
Direct customer benefit from payments to I&C customers associated with DSR flexibility	-	Directly
Generation capital cost savings from avoided costs associated with reducing peak generation requirements.	-	Indirectly

62. We have used Transform to model the *network capital costs* to meet the base case LCT growth scenario firstly when using the CLNR solutions and secondly without using the CLNR solutions.

GB wide rollout: base case Network capital costs £m - cumulative costs NPV 2017/18 prices	**2015**	**2016**	**2020**	**2030**	**2040**	**2050**
Using CLNR solutions	41.1	58.8	446.6	1,321.6	2,484.3	4,136.1
Without CLNR solutions	65.4	89.3	508.0	2,264.8	5,744.8	8,398.0
Savings from CLNR solutions	24.3	30.6	61.4	943.2	3,260.6	4,261.9

63. This Transform modelling has also quantified the *direct customer benefits* and *generation capital cost savings* that would be realised in future by deploying CLNR solutions instead of traditional methods and other smart solutions under the base case LCT growth scenario. Adding this to the savings in network capital costs by deploying the CLNR solutions (above), we quantify the total savings from a GB-wide rollout of CLNR solutions.

GB wide rollout: base case Financial benefits £m - cumulative savings NPV 2017/18 prices	**2015**	**2016**	**2020**	**2030**	**2040**	**2050**
Network capital cost savings	24.3	30.6	61.4	943.2	3,260.6	4,261.9
Direct customer benefit	0.9	1.7	4.8	40.3	557.2	861.2
Generation capital cost saving	-	-	-	-	3.5	51.0
Total savings	**25.1**	**32.3**	**66.2**	**983.5**	**3,821.3**	**5,174.1**



Sensitivity of the network capital cost savings to LCT growth scenario

64. The table above demonstrates that the largest element of savings from deploying CLNR solutions is the reduction in network capital costs. The chart below shows the sensitivity of those savings to the LCT growth scenario with savings to 2050 increasing to £14.1bn under the high LCT adoption scenario.

Financial benefits from deployment of CLNR solutions on Northern Powergrid networks

65. As described in section A4, we have already started to deploy the CLNR solutions on the Northern Powergrid network, and the financial savings avoided network investment from these schemes is set out in the table below.

Benefits from Northern Powergrid actual rollout to date of CLNR solutions Financial benefits £m - cumulative costs NPV 2017/18 money						
	2015	2016	2020	2030	2040	2050
Additional voltage control – Stow regulator			0.77			
Additional voltage control - Hunmanby regulators			0.80			
Additional voltage control – Seghill load drop compensators	Included in voltage reduction					
Active network management - Driffield			10.10			
Total			11.67			

Quantification of CLNR benefits delivered through other DNOs' projects

66. We explain in section A1 how CLNR had a fundamental and far reaching effect on the nature of collaborative innovation within not only NPg but also in the other DNOs. Our estimate of this benefit is £220m.

67. The data, knowledge and methods have been re-used and provided benefit to many other DNO projects. It is almost impossible to place a value on this hard to measure benefit. In this section we identify several of the projects where we can see that CLNR had an impact. Conservatively we have chosen 1% of the stated benefits of other related projects that followed CLNR. There is of course double counting such that we view this as a guide figure that should not be added to the benefits we have modelled.

68. We have only applied this to seven projects where other DNOs have stated to us that there is such an influence on their project design (see section A1 for details).

69. The stated potential benefit of these projects is in excess of £20bn to 2050 and we have therefore estimated the CLNR contribution to be approximately £220m.

Other benefits

70. There are a number of other additional, potential, but less certain benefits in addition to the projected benefits quantified above:

- A possible further reduction of at least £500m has been identified for the period from 2020 to 2050 based on better load profile data for LCTs. .
- Time of Use (ToU) Tariffs for DSR for domestic customers, which will require further research and development to identify a tariff more certain to reduce peak loading on the day of greatest network peak demand and a regulatory review of requirements for energy suppliers to pass on the tariff signals to customers.

3.1.4 A4: Rollout across the DNO's system and across GB

71. A huge amount of learning from CLNR has already been applied to our own network and we have been proactive in the dissemination of the findings to facilitate wider take up of the CLNR learning and solutions by other DNOs. As explained at the start of section A, independent assessment of LCNF projects by Poyry supports this too. Poyry scored CLNR 5 out of 5 against the criterion 'Generates knowledge that can be shared amongst all DNOs'.

72. As we have described in sections A2 and A3 above, as the standard GB DNO tool for planning network investments, Transform evidences that the CLNR solutions are appropriate and cost effective for addressing the issues associated with LCT uptake, and are selected by Transform over 97% of the time in preference to traditional reinforcement or other smart solutions (see para 86). Significantly, information on the costs and benefits of the CLNR solutions and on the new customer demands were provided in Transform template format. These have been adopted through the Transform governance process, meaning that learning from CLNR is now

firmly embedded in the BAU planning processes of GB DNOs. This demonstrates that the CLNR solutions are widely applicable and that we can therefore be confident that the GB wide rollout of CLNR solutions, which has already started, will continue in future and deliver the benefits set out in sections A1 to A3 above.

73. NPg has had no other projects trialling similar solutions, so there has been no double counting of benefits.

How the rollout is proceeding

74. **New designs for network planning**: We have embedded this learning about customer demands into by BAU in NPg by updating the design demands used in our LV designs in our network design policy and by including PV diversity in our generator connection policy. This CLNR learning has been made available to other DNOs by the incorporation of this information in issue 6 of the industry guidance document Engineering Recommendation P5 "Design of low voltage underground networks for new housing estates". The revised ADMs from CLNR are also being built into NPg's new 'AutoDesign' system (see A8).

75. We have fed the learning on the contribution of real generators to system security into the industry review of ER P2 via the **Distribution Code Review Panel**. The panel has just consulted on ER P2/7 which lays down the policy for relying on generation, storage and DSR for security contribution. In parallel with that change to P2/7, Ofgem has requested more prescriptive guidance in ETR130 and we will feed CLNR learning on F-factors into that too.

76. **Time of use tariffs**: From our trials with domestic customers, we consider that ToU tariffs, enabled by smart meters, could deliver value in the next 10 years, when delivered in conjunction with energy suppliers. Half hourly metered customers at NPg are already on ToU DUoS tariffs and we have developed ToU DuoS tariffs for all customer classes, including domestic customers. Take-up by suppliers will be dictated by the roll-out of smart meters and how our price signals are built into the offerings from electricity suppliers, the extent to which suppliers promote these tariffs and the response by customers.

77. **Demand side management (DSM) comprising EES, DSR, GSR generation sides response):** In line with our stated intentions at the end of CLNR, we have developed a capability to identify DSR potential and to market and manage DSR contracts. I&C DSR and GSR are fit for business as usual today so we have developed a standard contract for procurement of these services I&C customers and will start to roll this out when there is a need (due to characteristics of network loading, some other DNOs have progressed more quickly). We have fed our learning on EES into the first good practice guide (alongside learning from other DNO projects), produced by EA Technology (2014) in collaboration with Energy Storage Operators' Forum (ESOF); 'A Good Practice Guide of Electrical Energy Storage'[6]. We fed learning on DSR into the Energy Networks Association's Open Networks project and National Grid's Power Responsive programme to facilitate wider take up.

78. **EES (battery storage)** is increasingly popular with customers, and in 2016/17 we quoted 7.3GW of new connections to the NPg network, and a further 24.1GW in 2017/18. Volumes for future years are expected to be much higher. The learning from CLNR has allowed us to facilitate the connection of storage by providing guidance to our customers. Further, we are re-using the CLNR 2.5MVA battery unit to value stack services through the services of a commercial aggregator. In this way we are building 'informed seller' knowledge such that we may become an 'informed buyer' as part of the transition to Distribution System Operator (DSO).

79. **Enhanced Ratings**: We have reviewed and updated our underground cable ratings policy following CLNR, to take account of bespoke ratings and are training our design engineers in applying these. A transformer ratings policy has also been introduced, and the overhead line ratings policy is in the process of being updated. Enhanced ratings could potentially apply to all assets operating above 20kV and rollout will be driven by demand growth, which is driven by customer behaviour. We have deployed enhanced ratings at several locations so far, as set out in the quantification of benefits to date.

80. We have included **RTTR** in our ED1 investment plan and recognise that some DSR is needed to maximise the benefit from this technology. Although we have not yet deployed RTTR due to a lack of need so far, we have a clear approach for its deployment when needed. For DG connection customers on a potential thermal constraint we will offer RTTR on overhead lines and on transformers to optimise the commercial viability of the developers' schemes; RTTR will also be used on circuits that have DSM support to be used as a means of triggering the DSM response; we will make full-blown RTTR available across the higher voltage network, but we expect take-up to be in single figures through 2015-2023.

81. **Enhanced Voltage Control**: We revised NPg voltage control policy to apply the CLNR learning and specified a new automatic voltage control scheme to enable enhanced load-drop compensation, reactive power control and remote indication and control of the scheme at every primary. We are now rolling this out and will complete by 2023.

82. **Additional Voltage Control**: Take-up of the secondary OLTC and HV regulators depends upon how competitive they are with respect to other solutions. Voltage reduction has largely addressed the present issues on

underground networks and secondary OLTC is now expected to be associated with the mass roll out of EV charging. We are bringing forward the projects currently - Stow and Humanby being the first two instances.

83. **Network Planning & Design Decision Support (NPADDS) system**: NPADDS was a prototype software system developed under CLNR to support network designers and the learning on this was disseminated widely. This learning is being used as a basis for our £1.1m AutoDesign NIA project, which is seeking to build an automated budget design tool for LV connections in advance of the expected boom in electric vehicle charging applications. AutoDesign will take NPADDS and the revised after diversity maximum demand (ADMD) figures from CLNR (also disseminated widely) into a production ready tool which can be rolled out in DNOs across the country, enabling DNOs to deliver the CO_2, capacity and financial benefits of these design methods with a higher degree of automation (maximising consistency and efficiency).

84. **Smart remote terminal units (RTU)** are an enabler to DSM. CLNR produced a specification for network monitoring equipment (and disseminated this widely. We have taken this specification into BAU and we are rolling out network monitoring as part of our £83m smart grid enablers programme in ED1, providing the foundations for a smart grid and enabling £400m of benefits by 2031 (by accommodating high levels of growth in LCTs beyond 2023). We have produced a specification for a new RTU roll-out during RIIO-ED1 and we will deploy the smarter characteristics of these RTUs to manage the use of DSM to off-load primary substations under n-1 fault conditions during constrained periods. This lays the foundations of a smart grid in three important areas - substation control units (to make them compatible with a modern digital communication system), primary communications network and transformer control units.

85. **Area Control**: Northern Powergrid currently has over 700MW of ANM operational, all of which was offered to the customer as an alternative to straightforward, but more expensive, upgrades to circuits or transformers. The customer made the choice on which option to pursue. We are currently implementing a standardised replicable ANM solution in the Driffield area of East Yorkshire and four customers have accepted offers for connection to this scheme with completion scheduled for November 2018. This is a good example of synthesising knowledge from CLNR control system trials, with our existing BAU early deployments of ANM, and innovation projects carried out by other DNOs to develop and deploy a new design. This new scheme is using distributed intelligence and control to despatch multiple local generators according to changing network conditions, thus enabling materially more low carbon generators to be accommodated than would have been otherwise possible.

Evidence of the current use of the project on the DNO's system and across GB

Actual deployment		
Solution	**DNO**	**Scheme**
Additional voltage control	NPg	Stow regulator
Additional voltage control	NPg	Hunmanby regulators
Additional voltage control	NPg	Seghill load drop compensators
Active network management	NPg	Driffield

Assessment of the future use of the project on the DNO's system and across GB

86. Assessment of likely smart solutions by Transform modelling, shows that between 97% and 99% of smart solutions deployed GB-wide will be techniques or assets trialled under CLNR. This peaks in percentage terms between 2023 and 2038, and in absolute terms after 2038.

	Cumulative smart deployments based on techniques or assets trialled under CLNR	**Cumulative smart deployments based on techniques or assets not trialled under CLNR**	**Percentage of deployments trialled under CLNR**
Up to 2022	19,006	493	97%
Up to 2030	106,107	1,090	99%
Up to 2038	199,621	2,631	99%
Up to 2046	493,493	11,163	98%

Exceptional approach to knowledge dissemination

87. While the closedown report is fully compliant with the specification, we also recognised that there are a diverse range of stakeholders with different interests 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. Therefore, in addition to the closedown report, we delivered three 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.

88. The closedown report and three key learning reports set out the implications of our findings and these draw on the other preceding high quality outputs where more detail can be found. We undertook a period of consultation to ensure that our stakeholders, in particular DNOs, had the opportunity to explore, absorb and give feedback on our findings through written feedback and the opportunity to participate in face-to-face feedback at a consultation event. This was well attended and included delegates from all DNOs, Ofgem, the Department of Energy & Climate Change, academics, consultants and other industry parties. In addition, UKPN undertook a formal peer review of the closedown report (part of a collaboration that also saw us jointly present to the Gas and Electricity Markets Authority board meeting). Our reports were accepted with no major changes, demonstrating the quality of the reports written and disseminated.

89. The ‘Optimal solutions for smarter network businesses’ report[7] is a generic smart grid safety case. To enable CLNR solutions to be rolled out by other DNOs, we considered it essential to develop and share a ‘DNO toolkit’ that would enable them to benefit from experience of procuring, installing and operating network equipment. The toolkit comprises 16 detailed documents for each new technology deployed by CLNR encompassing operational guidance, lessons learned, network monitoring, technical recommendations for purchasing equipment and systems, and training materials. More information on our dissemination is provided in C3.

3.1.5 A5: Value for money to customers

90. In this section we describe first how project funding was used to achieve the greatest outcome for present and future customers. We then evidence how we maximised value for money during the project by minimising the cost of delivering the project through our approach to sourcing the resources required, by leveraging external funding to ensure that LCNF funding was used efficiently, and by refining the detailed design of some of the customer trials to ensure the funding was used most effectively. Finally we describe actions taken post-project to achieve further value for money by re-deploying equipment purchased by the project.

91. Poyry’s assessment of LCNF projects scored CLNR as 5/5 against the criteria ‘Involvement of other partners and external funding’, providing and independent assessment of CLNR’s exceptional performance in terms of value for money for customers.

How project funding was used to achieve the greatest outcome for present and future customers

92. We successfully delivered an ambitious programme of work over a four-year period as confirmed in Ofgem’s Successful Delivery Reward decision letter “We are satisfied that the evidence supplied demonstrates that NPg delivered its SDRCs to at least a satisfactory quality, in a timely and cost effective way”, the output from the project has more than fulfilled the commitments made and it was delivered on budget, despite an extra year being required to manage the impact of a few significant externalities.

93. The ratio of aggregate benefits to LCNF funding is 197:1. This figure represents the ratio of the NPV of the combined financial benefits, developed up to 2050 across the entirety of the GB distribution network under the base case LCT growth scenario i.e. £6.6bn benefits to the LCNF funds deployed, £33.5m in 2017/18 prices. If LCT growth rate is higher, the NPV of the combined financial benefits would be up to £20.3bn, giving a benefits to funding ratio of 608:1.

Minimising the cost of delivering the project through a value for money approach to sourcing the resources required

94. The process for delivering value for money and the areas of high value project expenditure for CLNR can be broken down and evidenced as follows:

- **Systems Integration:** The key objective of the CLNR project was 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 it delivered better value for money than contracting a single large supplier and system integrator.
- **Customer LCT and metering installations:** CLNR leveraged existing PV installations (valued at £8.90m), British Gas’s smart metering programme (£2.30m) and Department of Energy and Climate Change (DECC) funded heat pumps (£2.20m), representing equipment valued at a total of £13.40m that CLNR had access to without financial support from LCNF.
- **Project Manager:** This cost line had a budget of £2.54m, 8.2% of the total budget. Our strategy for maintaining cost control and driving efficiencies was to predominantly use direct employees over

consultants, to monitor costs via monthly financial reviews with the project accountant, and to report regularly on project budget to the Project Board & Executive Board.

- **Electrical Energy Storage:** The combined budget for all the EES units was £5.83m, 18.8% of the total budget. Our strategy was to carry out a full-market competitive tender at the initial procurement stage, selecting the most competitive commercial and technically compliant supplier. As with other cost lines we followed our established financial and project management routines. In addition we secured the personal engagement of both NPg's Field Operations Director and Director of Safety and Environment to provide expertise and access to skilled and scarce resources during the commissioning, training and operation phase of this novel equipment on our live network.
- **Control Interfaces:** This cost line had a budget of £3.37m, 10.9% of the total budget. Our strategy was again to carry out a full-market competitive tender as with the storage devices. As with other cost lines we followed our established financial and project management routines and with this equipment we again had the personal engagement of the Field Operations Director providing expertise and skilled and scarce resources for this smart grid state estimation control system which was a first of its kind in Europe.
- **British Gas:** This cost line had a budget of £3.87m, 12.5% of the total budget. Our strategy was to predominantly use British Gas' direct employees over consultants, to closely monitor costs via the project routines described above and, when appropriate, to reduce resources through flexible deployment onto other projects, such as internal British Gas projects and for example UKPN's Vulnerable Customers and Energy project.
- **EA Technology:** This cost line had a budget of £4.09m, 13.2% of the total budget. Our strategy was to predominantly use EA Technology's direct employees over sub-contractors, to closely monitor costs via the project routines described above and only to pay for EA Technology employees when deployed on work. When work stopped, then so did the charges, with those employees deployed onto other projects.
- **Durham University**: This cost line had a budget of £3.64m, 11.7% of the total budget. Our strategy was to closely monitor the workload / work-flow liaison and review processes, deploying the NPg workstream managers and the technical architect into both Durham University and Newcastle University. Through this method we maintained a clear view on scope and by checking the analysis work whilst it was still in progress during Q3 and Q4 2014. We also closely monitored costs via the project routines described above.

Efficient use of LCNF funding by leveraging external funding

95. We have set out above how CLNR accessed customer LCT and metering installations valued at a total of £13.40m without financial support from LCNF. In B1 we have quantified £5.75m of additional contributions from external funding and from the project partners. Together these total £19.15m of value leveraged from the £30.65m LCNF funding demonstrating a highly efficient use of LCNF funding.

Efficient use of LCNF funding by flexing the detailed design of customer trials

96. We refined the detailed design of some of the customer trials in three ways to ensure funding was used effectively
    - The EV test cells were cancelled because we found that variable rate tariffs for EV customers were increasingly becoming the norm, so trialling a range of interventions in CLNR would have added little value.
    - We changed the commercial proposition for within-premises balancing for PV customers when we found that the current feed-in tariff arrangement distorts price signals to customers, such that it was not necessary to provide a tariff discount to customers for balancing, and indeed to do so would have incurred unnecessary cost.
    - We implemented a three time-band ToU tariff - even though we identified the merits of trialling a four time-band tariff we did not implement this as it would have required major changes to British Gas's billing systems which would have added significant cost and delay.

Further value for money through re-use of CLNR equipment

97. We took the opportunity to reuse some of the decommissioned residential customer monitoring devices which we re-deployed at no cost to two projects. The first is UKPN's Vulnerable Customers and Energy Efficiency project where UKPN have avoided up to £170k of expenditure on monitoring equipment. The second is South Kesteven district council who were introduced to us by WPD and who are monitoring temperature in *ca.* 200 off-gas households in rural Lincolnshire, in order to size heat pump installations pre-installation.
98. We have re-deployed CLNR batteries to capture additional value from the sunk investment cost and bring further benefits to customers:

- The large battery is being used to provide services to National Grid and the income is being used to fund other innovation projects.
- Three of the batteries are being used in our 'Microresilience' project (see A8).

99. The servers used by CLNR to collect network monitoring data during have since been redeployed for network monitoring in BAU.

3.1.6 A6: Relevance and timing of project

100. In this section we describe first the relevance and timing of the project in relation to the low carbon transition and DNOs' long term business planning cycles. We then talk about the exceptional efforts that we took to address issues that we encountered in order that we could still achieve the project outcomes, these issues being mainly related to the lower than expected rollout of LCTs at the time of the project and difficulties sourcing the required technologies. Finally we discuss how these outcomes have been used in future business planning and in our day to day activities.

Relevance and timing

101. CLNR addressed the challenges relating to the increasing amount of LCTs, particularly at the domestic level and particularly in local concentrations, on the electricity network. This is a national issue and with the number of LCTs predicted to increase, these challenges will only increase. CLNR was therefore both relevant and timely, seeking to deliver learning outcomes that are relevant to all GB DNOs and to do this largely in advance of need. The learning outcomes have been turned into engineering guidelines and codes of practice for use more widely by the engineering design community. As part of the revised LV design manual, the results have informed system planning and hence future business plan submissions. Equally important is the impact on the price to customers of new and amended connections.

102. At the time of the project bid in 2010, the key consideration on timeliness was whether or not the CLNR project would produce learning in time to inform distribution investment plans prior to need for the 2015-23 ED1 period and beyond. The industry uses the Transform model that is itself a development of the CBA model developed in preparing the 2010 CLNR bid. The first version of Transform included solution templates with parameters taken from the original estimates of CLNR solution performance. These original estimates formed the basis of the inputs into DNO business planning for ED1 and the findings from CLNR have to a large extent validated these earlier assumptions.

103. In addition to the Transform model templates, the project was producing and sharing high quality peer reviewed outputs through the period of ED1 DNO business plan production.. In their business plan submissions, four of the DNOs, including NPg, quantified the smart grid benefits to be realised in the ED1 period as more than £300m. It is learning from projects such as CLNR that gave DNOs the confidence to support the forecasts from the Transform model and offer these benefits to customers in the ED1 period and beyond. Ofgem itself identified that smart grid benefits totalling *ca.* £800m were included in the ED1 price control review outcome. This value was locked in to prices for customer for the period 2015-23.

104. Poyry's assessment of 2nd tier LCNF projects against criteria 'Relevance and timing' scored CLNR 4 out of 5 providing an independent assessment of CLNR's strong performance in this regard.

Exceptional efforts to achieve the outcomes of the project

105. In the September 2010 bid, we set out what we would deliver in each learning outcome and the method to do this. We 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 a timely manner and made exceptional efforts to do this. In some cases this meant modifying our approach although the trial methodology remained fundamentally unchanged.

106. The original project plan was based around recruiting British Gas customers within the NPg area. However, we found **a scarcity of customers with heat pumps and EVs** and we had to take exceptional efforts and time to ensure sufficient numbers to proceed with the trials:

- we recruited non-British Gas customers which entailed more complex monitoring systems to be designed and installed, revision of the Customer Engagement Plan and Data Protection Strategy, and engagement with other energy suppliers and their agents to fit an isolation switch on the customer side of the meter for non-BG customers (under the Meter Operation Code of Practice Agreement, BG is precluded from pulling the fuse for customers it does not supply);

- we extended recruitment to include customers from outside the NPg region to attract more participants for the scarce LCTs which required revision of the Customer Engagement Plan and Data Protection Strategy;
- we sourced an additional £2.2m DECC funding to achieve heat pump installations; and
- we entered into an arrangement with Charge Your Car to recruit EV customers which also required us to revise the Customer Engagement Plan and Data Protection Strategy.

107. We found **low rates of fixed line broadband in social housing** and this affected the heat pumps trials since most of those trial participants lived in social housing. This significantly limited the number of homes where we were able to install broadband enabled communication hub devices. Given the scarcity of heat pump households and the additional importance of monitoring each heat pump installed as part of the conditions of the £2.2m grant from DECC, we decided to pay for one year's subscription of broadband and also to provide assistance in setting up the account and hardware. This enabled us to monitor over 380 heat pumps, which we believe to be the largest heat pump dataset ever recorded in the UK.

108. **Rent-a-roof PV providers not agreeing to the necessary monitoring**, requiring the recruitment of additional customers. British Gas recruited over 400 of its existing customers onto the PV trials and found that approximately half of these customers were on rent-a-roof schemes, of which 85% are with one provider i.e. approximately 170 out of the total recruited. For such customers to participate in the trials would have required hard wiring of monitoring equipment into assets belonging to the provider. The major provider was seeking to make an agreement to connect this monitoring equipment contingent upon Northern Powergrid providing, on an exclusive basis, full addresses for G83 notifications of PV installations. This was refused so that Northern Powergrid could maintain the confidentiality of customer data and to avoid any discriminatory behaviour. Therefore, no agreement was entered in to with this provider and a large number of potential trial participants could not take part in the trials. We then needed to spend additional time seeking alternative routes to customers. To overcome this, we decided to recruit additional trial participants from non-BG customers, but before we could do this we had to amend our CLNR Data Protection Strategy and Customer Engagement Plan and seek approval of these changes before we could commence recruitment, and also to fit isolation switches as described above.

109. 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. Although we had held discussions with GE at the bid stage about its smart appliances and their suitability for the CLNR trials, GE subsequently decided not to market smart appliances in the UK market at that time. We therefore sought out alternative suppliers of smart appliances and of the demand-side management solution. This change in commercial strategy by a major supplier and the sourcing of alternative products caused delay to the trials that involve demand response by residential general load customers. We were ultimately successful in developing the technical solution with new vendors: Indesit for the smart appliance and Greencom for the demand-side management solution.

110. We found that there was no version of smart meter available at the time that would have made it possible **to retrieve data from smart meters with the frequency required** for real-time network operation and control. An alternative approach was taken based on LV network monitoring. We worked with the suppliers of the monitoring equipment to specify enhanced functionality to provide information at the frequency required for real-time applications. We then installed extra LV monitoring, to the enhanced specification, at the trial network locations and these readings weresupplemented by modelling to provide the data for additional points along the feeder. This innovation enabled us to overcome the limitations of the current versions of smart meters. Without this new solution it would not have been possible to trial enhanced automatic voltage control (EAVC).

111. Despite these difficult external circumstances described above, we took exceptional efforts to recruit sufficient customers to allow each customer type, each technology type and each type of commercial proposition to be trialled. We are proud that due to our exceptional efforts we have delivered quality learning at the same overall cost, despite the increased length of the project while at the same time we were able to exceed the methodology (see A7) and deliver other additional learning (see C1 and C2).

112. **The procurement and manufacture of novel network technology took longer than planned**, due to a variety of external factors:

- **Electrical energy storage vendor entering bankruptcy protection proceedings**: A123 Systems Inc., the supplier of the EES systems, entered Chapter 11 bankruptcy protection proceedings in the US in October 2012 following financial difficulties related to a product recall in its EVs division. Business relations were maintained and contract terms were modified in favour of the supplier in order to safeguard the initial payment made and to fund completion of system manufacture and shipping. The intervention was successful in that the contract was honoured following the acceptance by the US bankruptcy court of the modified payment terms and early transfer of title to Northern Powergrid. The battery units were all ultimately supplied at the original contracted price.

- **Scarcity of HV transformer with on-load tap changer (OLTC) for EAVC**: Investigations at project bid stage identified a manufacturer who could supply the required technology. However, post-bid, further investigation revealed operational problems with the equipment. An alternative solution of fitting a regulator to the existing transformer was discounted as the equipment's footprint meant that it would not have been possible to install in the space available. However, further investigation identified that an alternative manufacturer, Maschinenfabrik Reinhausen, had a suitable operational prototype, and following a full technical assessment of both the supplier and the product, the transformer with OLTC was purchased from them.
- **No market-ready solution available for RTTR for underground cables**: No retro-fit market-ready solution was available. We designed our own prototype solution based upon EA Technology's cable rating design tool, 'Crater'. Having to develop, rather than purchase, the solution introduced a delay but has developed an innovative product.
- **Company takeover of vendor for HV and EHV overhead line RTTR**: We initially engaged with a niche manufacturer for the purchase of the overhead line RTTR but the purchase of FMC-Tech by GE delayed the procurement of this equipment. Aiming to avoid this delay, we looked for alternative solutions. Although three other manufacturers offered similar solutions, closer investigation revealed that each had technical features or limitations which made them unsuitable. For example, an Australian solution was designed for operation in conditions of higher solar intensity. We therefore remained with GE which involved having to accept this delay.
- **Scarcity of vendor of full specification of RTTR monitoring equipment for primary transformers**: Time and effort was invested in engaging with two potential suppliers of transformer monitoring equipment until it became clear that the equipment would not provide one of the necessary parameters - ampacity. To address this we adopted an alternative approach: we specified and purchased the monitoring equipment for the primary transformers and agreed an enhancement to the GUS control system to incorporate algorithms to generate ampacity.
- **Component and sub system delays adversely impacting the control system integration**: The date for completing the implementation of the GUS control system was adversely affected by the network technology delays since the full design specification of the GUS was dependent upon the specification of all the network technologies with which it interfaces.

113. Ofgem's Successful Delivery Reward decision letter confirms that we these exceptional efforts were successful in enabling us to deliver the outcomes of the project *"We are satisfied that the evidence supplied demonstrates that NPg delivered its SDRCs to at least a satisfactory quality, in a timely and cost-effective way".*

How the project outcomes are being used in future business planning in order to resolve issues identified in project scope

114. CLNR has informed an approach to the evolutionary development of power systems; with 'incremental smartening' retaining option value and avoiding expenditure until needed by customers. The toolkit of options has increased the number of solutions open to our business as we seek optimum solutions for customers.

How the project outcomes are being used in our day to day activities

115. The project outcomes are being used on a day to day basis in the following ways:

- Design processes – our designers are now using different assumptions on a daily basis, in particular on diversity.
- Network development planning – the opportunities for smart solutions are now understood. These are being reflected in our financial and technical planning.
- Policy engagement – CLNR outputs and knowledge continue to be reflected in the industry and policy maker fora where evidence is sought to justify policy. For instance, most recently, Ofgem's consultants on the Targeted Charging Review have used CLNR evidence. A broader example is the evidence that was provided by Professor Phil Taylor of Newcastle University provided evidence at the planning permission appeal for a coal mine[8], outlining the case for the suitability of LCTs to replace coal, drawing on CLNR findings. This was a high profile case, positioned as a major indicator of the government's commitment to move away from reliance on coal towards a low carbon future. The refusal is particularly significant because it is the first UK case in which climate change has been explicitly used as a reason to call-in and to refuse a planning application.

- Innovation projects – ongoing projects and future collaborations are using the 'how to do such projects' knowledge gained on CLNR.
- Wider uses – the reach of the CLNR data downloads by 100 organisations in 20 different countries has been extensive. It is not possible for us to identify all the daily uses to which the data is being applied.

3.1.7 A7: Methodology robustness and project readiness

116. In this section we provide independent evidence of the robustness of the project methodology and then describe how we evolved the methodology to enhance and extend the planned learning to deliver additional learning, all at no additional cost. As required by the guidance, evidence on how this additional learning has been used is covered in C1.

117. Many of these instances of methodology evolution provide an insight into the 'how' and 'why' and 'so what' of customer behaviours alongside the 'who' 'what' and 'when' questions answered by the quantitative results of the trials. We also exceeded the methodology by using modelling to extend the planned learning on network solutions in normal conditions to deliver learning on these network solutions in fault conditions too. In the final part of this section we discuss project readiness, the impact of the external circumstances that caused delay the measures we took to ensure delay was minimised, and the one year extension to the project.

Methodology robustness

118. The trial methodology for CLNR was robust as it enabled us to deliver all the planned learning outcomes, and also to exceed it (as described below), despite the issues that we encountered. External assessments have delivered a firm endorsement of the trial methodology. Poyry assessed LCNF projects against criteria 'Effective project methodology and effectiveness of implementation' and scored CLNR 5 out of 5. Further, Hubnet assessed projects in terms of the robustness of the evidence generated and also whether the innovation can be considered as a BAU option ready for deployment when required. Hubnet confirmed that CLNR had in particular produced robust evidence for I&C DSR, enhanced network monitoring and residential appliance control. This assessment is evidence that the trials had good experimental design and were well implemented with results well disseminated.

Evolution of the methodology to exceed the specification in the Full Submission

Planned learning outcome 1: understanding of current, emerging and possible future customer (load and generation) characteristics

119. Learning outcome 1 (LO1) was scoped to deliver quantitative data on load and generation profiles**. We went beyond this by delivering insight** into the benefits and issues associated with the main LCTs trialled in CLNR, and by developing insights into how and why energy use takes particular patterns for groups and individuals.

- **Low carbon technology insight**: We produced additional outputs by LCT type that compared monitoring (LO1) results to those involving customer participation (LO2) and the behavioural studies, delivering better learning and dissemination at minimal incremental cost in the form of 'insight reports' for PV[9], for heat pumps[10], and for EVs[11].
- **Customer insight, social science behavioural learning**: This qualitative research answers the 'why', 'how' and 'so what' questions alongside the 'who' 'what' and 'when' questions answered by the quantitative research, providing a greater depth and richness of learning into energy practices that have provided more value than originally scoped. The country's foremost social scientists were 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 was additional to our bid commitment and was at minimal cost. Further, there were more than twice as many academic conference/journal papers than originally envisaged and the value of the social insight gained was 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.

120. We also exceeded the planned methodology in the enhanced profiling of domestic smart meter customers: The original bid intention was to pick out six 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 were: cooking; space & water heating; cold & wet appliances; consumer electronics, home computing and lighting. We produced a rich data set from this test cell

and there has been significant interest from 3rd parties in this learning .Planned learning outcome 2: to what extent are customers flexible in their load and generation, and what is the cost of this flexibility?

121. The planned deliverables for learning outcome 2 (LO2) was quantitative data on customer flexibility and the cost of flexibility. As with learning outcome 1, we went beyond this to research customers appetite for and barriers to providing flexibility, and drew together our qualitative research findings with the quantitative research into a socio-technical synthesis which has provided **a fuller understanding of the opportunities and limitations on customer flexibility**.

- **ToU insight**: We produced an output that compared monitoring (LO1) results to those involving customer participation (LO2) and the behavioural studies, delivering insight into domestic customers experience of ToU tariffs (see Insight Report: Domestic Time of Use Tariff[12])
- **Small and medium enterprises (SME) flexibility**: *more social studies in order to understand in more detail the barriers to them offering greater flexibility to network operators.* This was necessary as we had found that this customer group were unable to offer the flexibility services we were seeking and they were also found to be particularly diverse. See 'SME Customers: Energy Practices and Flexibility'[13].
- **Larger (I&C) business customers' appetite for DSR:** ***w****e also undertook an additional qualitative survey for this customer group*. This was necessary better to understand the reasons behind the difficulties in attracting customers to contract with us for their flexibility. Subsequently, learning from this aspect of our trials has been shared with numerous industry fora including the NGC Power Responsive initiative where we have been working with the system operator to seek to grow the resource base. (See 'Report on CLNR Industrial & Commercial Demand Side Response Trials'[14].)
- ***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 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 for customers with the: smart meters[15], ToU Tariffs[16], PV[17], heat pump[18] and EV[19]

122. We identified the opportunity to generate additional learning which will become increasingly relevant in the move towards higher uptake of heat pumps, exceeding the planned methodology in three ways:

- **Heat pumps with storage:** The methodology specified in the bid involved only one type of heat pump for our DSR trials but following on from detailed design reports that we had commissioned, we identified that the intended air-source heat pumps (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 therefore introduced a DSR trial for heat pumps with thermal stores in addition to the planned trials with just regular ASHPs.
- We also went beyond just monitoring heat pump consumption profiles and flexibility to **explore customers' attitudes to the operation and performance of heat pumps**. The benefit of this has been a wider understanding of issues which need to be addressed (e.g. to educate in operation and gain 'buy-in') if heat pumps are to become a more active part of the energy system. This was achieved at minimal incremental cost. See Heat Pump Survey Results[20] and the report on interviews with domestic customers with air source heat pumps[21].
- We also studied **the effect of heat pumps on power quality**, both individually in clusters, in order to consider the concerns about widespread uptake of these technologies. This was achieved with a minimal incremental cost but delivered important value. See CLNR Power Quality Assessment – Impacts of Low Carbon Technologies[22].

Planned learning outcome 3: to what extent is the network flexible and what is the cost of this flexibility?

123. The planned methodology was to trial the integration of EAVC, RTTR and EES with associated monitoring and control systems. We successfully delivered the GUS control system and then went a step further to **develop and evaluate alternative advanced control optimisation techniques.** We looked beyond the optimisation techniques deployed in the GUS in order to consider how more complex control scenarios could be managed using robust optimisation and cuckoo search techniques. Conventional techniques, as deployed in GUS, can sometimes underperform in cases of high network uncertainty due to the uncertainty in load and generation profiles and robust optimisation is an approach that can deal with these situations prudently. This has provided a better understanding of evolutionary pathways for control systems as LCT concentrations increase.

Planned learning outcome 4: what is the optimum solution to resolve network constraints driven by the transition to a low carbon economy?

124. The planned outcome was to develop optimum solutions to resolve network constraints under normal conditions. In addition to this, we **extended the modelling to consider fault conditions,** to examine the value of

the network solutions under n-1 & n-2 faulted conditions, and develop an understanding of 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 in the peer reviewed International Journal of Wind Energy[23]. 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. This subject was also covered in four papers to CIGRE[24 25] and to CIRED[26 27].

Project readiness and exceptional efforts to achieve timely delivery

125. We have described in A6 the external circumstances relating to the customer trials and network technology where we had to make additional effort to enable us to deliver the project outcomes. These all introduced delay to the project. Here we describe two other sources of delay and how we took exceptional effort to minimise the delay that these caused.

126. The GUS wide area control system was built to interface with the monitoring systems and EAVC, RTTR, EES and the DSR platform, using a range of communication protocols. Although this was completed successfully, it was highly complex and took 6 months longer than planned, thus eating into time that was scheduled for the network trials, with a knock on effect on the overall completion date of the project. We reduced the knock on impact of the delay in completing GUS on the network trials through a number of actions; the effective use of pre-trial simulation and emulation, and a phased commissioning of the control system and start of the trials.

127. The inverter unit of the largest EES unit failed causing damage to the power capacitor and secondary wiring on the inverter unit. Although there were no injuries and the battery cells themselves were undamaged, the unit was out of operation for five months while the failure was investigated, designs modified and applied, the repair made and the unit re-energised. We managed the impact of this on the network trials by rescheduling within the suite of planned trials to avoid this issue causing any delay to the overall completion of the trials.

128. We submitted a change request to Ofgem in relation to the material changes in external circumstances, proposing no change to the method or solution. The change that was requested and approved related to the delivery plan, specifically a 12-month extension to the project completion date and a restructuring of the project budget, although the overall project budget remained unchanged. Ofgem's Successful Delivery Reward decision letter confirms that we performed well in terms of timely delivery against the revised SDR criteria "We are satisfied that the evidence supplied demonstrates that NPg delivered its SDRCs to at least a satisfactory quality, in a timely and cost-effective way".

3.1.8 A8: Other Benefits

129. In this section we describe a wide range of initiatives in NPg that have built on CLNR learning and the benefits that they deliver – these benefits are additional to those set out in A1-A4. These initiatives encompass better asset specifications and replacement decisions, more automation on our network and in our processes, better management of voltage and better forecasting capability. They are delivering improvements which customers experience directly through improved reliability and availability and direct reductions in bills, as well as benefits which arise within the DNO and indirect customer benefits: savings in network capital investment, reduced cost of LV design activity through automation, reduced system losses, and better demand forecasting. We quantify, as far as possible, the benefits in terms of CO_2 emissions saving, capacity released, and financial savings.

130. We also describe how the 'customer-led' principle of CLNR and the better understanding of customers gained through CLNR has had, and is continuing to have, a lasting impact in several important ways: through third party use of customer data to facilitate the low carbon transition and by influencing industry thinking on fuel poverty.

Northern Powergrid initiatives derived from CLNR and which are delivering other benefits in BAU

131. **Reducing electrical losses by voltage reduction at primary substations:** In the course of CLNR, our work on additional voltage control and advanced automatic voltage control techniques led us to consider the benefits that voltage reduction at primary substations could bring: releasing capacity, reducing customers' energy consumption (and therefore CO_2 emissions and bills), reducing system losses and thereby CO_2 emissions. Based on the clear benefits we identified, we initiated an immediate roll out of a programme of voltage reduction. This started prior to the end of the CLNR project in 2012. Since that time the new target voltages have been codified in our revised voltage code of practice[28].

132. **Improved assessment of transformer losses:** We have used CLNR data on transformer loading, and in particular transformer half-hourly load profiles across an annual period, to create separate Loss Load Factors (LLF) for pole mounted and ground mounted transformers. This has led to an increased emphasis on losses for ground

mounted transformers which experience longer durations at high utilisation and loss levels, reflected in a revised standard on assessing losses[29] . This should improve our losses performance with minimal cost to the customer.

133. **Improved traditional asset reinforcement:** The servers used by CLNR to collect network monitoring data have since been redeployed for network monitoring in BAU coupled with CLNR specification monitoring devices. The greater intelligence we have on asset loading is enabling us to better target, and in some cases defer, traditional reinforcement, with an associated financial benefit. Information of load balance, voltage level and lower than expected level of loading have allowed us to take relatively inexpensive actions to address issues that would previously have led to replacement of assets with higher rated items. This is an ongoing programme.

134. **Improved demand forecasting**: With the CLNR learning about customer demand we have developed improved tools that will enable us to better forecast load and plan long-term investment. We are now starting to get results from this and we will be using these new forecasts for the first time this year for investment planning.

135. **Automatic power restoration**: In CLNR we deployed a state of the art wide area control scheme (GUS). We have built on the experience of area wide decision making and to date have installed automatic power restoration technology at 34 NPg substations serving more than 400,000 customers. This enables us to reconfigure the network more quickly when there is a fault and it has contributed to significant reliability and availability benefits.

NPg initiatives derived from CLNR delivering other benefits through further innovation

136. **AutoDesign**: Specified by NPg, this system will provide an automated design tool for LV connections in advance of the expected boom in EV charging applications. Here we set out the savings associated with automating the design process for LV connections. In NPg alone, the savings are expected to be in the region of £280k per annum with a net benefit of £1.4m NPV by 2030.

137. **Impact of LCTs on the design of the low voltage networks**: As domestic PV rises it can present challenges to the development, design and operation of LV networks due to the excess of local supply over demand affecting voltage and thermal limits and balance, and power quality issues. PV can also modify the voltage profile of feeders such that higher voltages occur at locations close to the PV installations and remote from the traditional maximum points at distribution substations. We are undertaking a project based on our CLNR learning to provide LV network designers with a simple and robust framework that enables them to apply the impact of domestic PV installations on their day-to-day network planning and design practices with certainty, consistency and grounded by demonstrable engineering analysis.

138. **Additional uses for EES**: CLNR learning was about using EES to provide local network support under normal conditions. We have built on this in project which deploy EES to non-intact networks where they can make a significant difference to people's lives when deployed in vulnerable locations or communities:

- **Microresilience project**: the goal of this is to create communities which have some capability to supply their own needs when systems above them fail with systems which kick in automatically. The trials are sited in three communities with critical infrastructure: a lighthouse, a lifeboat station, and a village with a high degree of wind power. This series of trials demonstrates how to use smart grid technology to improve service to range of customers and potentially save lives: at the lifeboat station, power outages often coincide with storms when there is the need to launch the lifeboat. In a power outage it can take 10-15 minutes to raise the shutters by hand, the battery will allow them to power shutters and a boat winch.
- **Silentnight project**: NPg presently deploys diesel generators on fault-repair activities for the direct benefit of the customers. However diesel generators are noisy, contribute to air pollution and greenhouse gases, and because they are sized to the peak load not the average load they supply generally fuel inefficient. The Silentnight project aims to investigate if using an EV equipped with a large battery instead, can efficiently cut running costs, noise and CO_2 emissions.

Quantification of benefits from initiatives derived from CLNR and being implemented by NPg

Northern Powergrid wide benefits from rollout of additional learning Carbon emission savings – million tonnes CO_2 cumulative					
	2016	2020	2030	2040	2050
Voltage reduction	0.005	0.264	1.296	1.706	1.901

Northern Powergrid wide benefits from rollout of additional learning Capacity released per year MW					
	2016	2020	2030	2040	2050
Voltage reduction	324	7,092	10,584	10,584	10,584

Northern Powergrid wide benefits from rollout of additional learning Cumulative financial benefits £million - NPV 2017/18 prices							
Initiative	**Nature of saving**	**Direct beneficiary**	**2016**	**2020**	**2030**	**2040**	**2050**
Voltage reduction	Reduced consumption behind the meter	Customers	2.4	124.3	691.7	1,101.9	1,392.6
Voltage reduction	Reduced system losses	Customers	0.0	1.7	9.6	15.3	19.3
Automated design	Automation	DNO	0.0	-0.8	1.4.	1.6	1.6
Total			**2.5**	**125.2**	**702.7**	**1,118.7**	**1,413.5**

139. It should be noted that the savings calculated for voltage reduction are based on present demand levels and are likely underestimated. Demand is expected to rise in future years due to the adoption of low or non-carbon transport and heat, which may lead to higher savings (assuming savings remain proportional). However supplying the higher loads may require voltages to be raised slightly in some places to ensure the far ends of networks remain within limits and some of the demand will be self-generated. These two factors mean that predicting the actual increased saving in future years is not simple and we have therefore used a flat load view.

140. Savings from voltage reduction once fully rolled out are in the region of £20 per customer per annum. The value of this were it to be applied to 30m customers on a GB-wide rollout might be in the region of £600m per annum or £10bn net present value; this is a similar scale to the benefits assumed for the DSO transition. Due to the peculiarities of different DNO networks, there will be greater or lesser benefits in some regions.

141. Automated design might be expected to offer similar benefits to all DNOs and the benefits might accrue in proportion to the number of connected customers. Based on the NPg 13% of GB customers, the NPV of £710k over 16 years would equate to £5.5m GB-wide.

Wider GB industry initiatives building on CLNR learning to deliver other benefits

142. **Transition to the role of Distribution System Operator:** CLNR was a project that explored different whole energy system solutions to introduce flexibility in to the electricity system. As such, it has generated much insight into the transition to DSO that is a key part of the Smart Systems and Flexibility plan. In particular:

- Procuring flexibility services – the commercial learning from CLNR included Element Energy reports that followed on from the trials and described the evolutionary pathway necessary to involve customers in flexibility provision. These were explored through the Smart Grids Forum commercial sub group and are now being used to inform both the BAU adoption of flexibility (through bilateral contracts) as well as the longer term direction to use aggregated domestic DSR when the smart meter infrastructure is in place.
- Customer-led markets and services – the trials on CLNR involved linking customer energy practices (social behaviours and technical electricity patterns) to flexibility solutions (customer or network). The insight gained is useful as we now consider the future market architectures in such projects as Ofgem's Future Supply Market Arrangements and NPg's Customer-Led Distribution System. Project partner British Gas is also trialling a local energy market in the Cornwall. This 'competition of ideas' is beneficial for customers by the experience gained by CLNR.
- Charging arrangements – Ofgem is engaged in a reform of charging to ensure fairness and efficiency in a changed landscape of distributed renewable generation and new local network loads such as EV charging. The Targeted Charging Review (TCR) is examining one aspect of the charging arrangements – how modelled residuals are apportioned between customers. In March 2018, Ofgem commissioned Frontier Economics to provide analytical input into the TCR, focusing on distributional impacts (identifying 'winners and losers') and wider system impacts (assessing market wide impacts on systems and consumer costs). To achieve this, the consultant is heavily reliant on CLNR data to derive profiles for different types of user, in particular domestic (including those with EV, PV and heat pumps) and SME, to assess the level and shape of consumption on a half hourly basis.
- Technology platform – the learning on wide area control that has informed the NPg smart grid enablers programme is highly relevant to the thinking required on how a future DSO may physically control DERs on a more complex, semi-autonomous, more active system.

143. **Understanding customers – third party use of customer data:** There has been substantial interest in the aggregate customer datasets: the profiling of domestic smart meter customers has been accessed over 1,000 times, enhanced profiling of EV users has been accessed approximately 400 times, smart meter ToU tariffs accessed 230 times, enhanced profiling of heat pumps accessed 140 times, and enhanced profiling of PV users

accessed 140 times. There has also been substantial interest in the It is clear that both the aggregated and disaggregated customer data published post-project (the latter described under criterion B). Both types of customer data has have been used by other parties to develop further insight into issues around customer behaviours, discussed here, and on EVs, PV, heat pumps and ToU tariffs discussed in C3. All this activity is helping to facilitate the low carbon transition and customer interests within that.

144. The environment think tank Sustainability First continues to use customer data from CLNR to influence Ofgem and Government. The report 'Engaged, or just good friends? An exploration of retail electricity and gas pricing and 'sticky customers' (April, 2017)[30], uses findings on customer flexibility to consider customer engagement through current markets structures and future consumption and fairer pricing in a smart electricity world.

145. Element Energy continues to use customer data on projects and consider it to still be relevant commercially:

'I would argue anyway it's still really early days in terms of people actively trying to use that data in a commercial business model, because most people don't have smart meters still, right.' (Respondent from Element Energy)

146. There is also an academic legacy from the customer data, which is being used to inform further work:

'It's still quite rich…I think it'll be used for a long time – decades probably' (Respondent at Newcastle University)

147. **Understanding customers – customer engagement:** Engaging domestic customers under CLNR was a new challenge for us as a DNO, and significant learning has subsequently been taken

and developed further from CLNR in this regard; for example SSE's 'SAVE' project and WPDs 'Carbon Tracing' project with the Carbon Trust.

148. PassivSystems undertook customer engagement as part of CLNR, and developed their skill set in this area accordingly. This has enabled them to win additional contracts by quoting CLNR findings. For example, in WPD's 'Freedom Project', the Energy Entrepreneurs Fund and a District Heating project funded by DECC.

'Out of all of the things that we did, probably the thing that people have seen most value in is actually that ability to go out and recruit the homes…the fact that they know about you because they know about your involvement in CLNR is definitely a help.' (Respondent from PassivSystems)

149. Activating Community Engagement (ACE) is a CLNR follow-on project by Newcastle University and NPg using gaming to engage with domestic customers and incentivise domestic demand-side response (DSR) instead of through financial incentives. In its second iteration, this is a game-based app 'The Gen Game' that incentivises household DSR through gamification.

150. **Understanding customers – Fuel poverty:** CLNR has influenced industry thinking on fuel poverty, as evidenced by the number of projects focused on fuel poverty that have drawn upon the learning offered in CLNR:

- European project 'Replicate' (Horizon 2020, £6m funding) includes partner Bristol City Council who are developing a live smart homes project and have drawn on the CLNR learning on TOU tariffs and smart appliances in the development of the project.
- National Energy Action's 'Health & Innovation Programme' (£26.2million funding from Ofgem) took forward lessons learned in CLNR on methods: *'It seems to me to have been absolutely informed by NEA's experience of CLNR.'(Respondent from NEA).*
- Pg's DS3 (Distributed Storage and Solar Study) or 'Energise Barnsley' project is a community project in partnership with Gen Community Ventures and Moixa that investigates whether domestic storage can reduce peak load on the system while also reducing bills. 40 EES units have been placed in social housing on an LV local network in Barnsley and the impact of PV/storage solutions is being monitored. This project is an alternative customer flexibility use case that has deployed the monitoring systems and methodologies developed successfully in CLNR and is in support of Barnsley Council's Anti-Poverty Action Plan 2015-2018.

3.2 Reward criterion B

3.2.1 B1: Details and significance of DNOs additional contribution

151. We have quantified over £5.75m of additional contributions across four areas of external funding and additional contributions by the project partners. These funds were used to ensure successful delivery of the project, either providing an alternative route to enable the project to proceed or providing additional value to the learning.

152. **£2.2m of DECC funding was secured and contracted to British Gas to subsidise heat pump installations.** This external funding was the prime determinant in the project achieving the 380 heat pump installations and trial participants in what we believe to have been the largest heat pump dataset ever recorded in the UK. Without

this funding we would not have been able to deliver the planned learning about heat pumps: their load characteristics, whether they can provide a level of DSR in conjunction with commercial propositions and smart technology, the socio-technical understanding of customers' experience of heat pumps that is needed for an effective rollout, and the heat pump functionality would have been missing from the NPADDS tool for designers. Neither would we have been able to include studies of heat pumps with thermal stores (see A7), nor deliver the additional heat pump related learning on the installation process, customers' attitudes, power quality and the implications for widespread take-up (see C2), or publish the disaggregated datasets from the heat pump customer trials (see A1) that have been downloaded by 38 different organisations for further research and analysis. Without CLNR learning on heat pumps, further facilitation of the decarbonisation of heat by third parties would also not have taken place (see A1).

153. **Durham University and Newcastle University obtained an additional £2.5m funding for smart grid laboratories to enhance modelling capability.** This is additional to the value in kind committed at bid stage. The £0.5m contribution from Durham University early in the project helped the university to establish upgraded modelling and simulation capability in the smart grid laboratory: a Real-Time Digital Simulator (RTDS) which was used in conjunction with a heat pump, PV emulator, wind turbine emulator, generator, load banks (reactive and resistive), EV charge post, energy storage, smart load, display screens and supporting communications and computing. This capability allowed us to model combinations and future scenarios and those which were unfeasible or not economically viable to pilot in the field and has been so important to delivering both the baseline and additional outputs from the project. Further, during the project, a £2m smart grid laboratory was provided at Newcastle University (following the transfer of the Principal Investigator and most of the academic engineering team). Funded 50/50 by the university and industry collaboration partner Siemens this facility boosted capability for simulation and emulation through control system links to observe, analyse and extrapolate the physical trials such that this aspect of the CLNR learning was enhanced. Additionally, it today provides a continuing legacy where CLNR models and control systems are retained in a facility with enduring funding from Newcastle University for open collaboration with industry and academic partners.

154. **Significant contributions in kind (totalling more than £1m) were made by the project partners by deploying scarce and valuable resources to overcome the challenges inherent in delivering a project as ambitious as CLNR.** This includes senior board level engagement, installation of smart meters for customer trials prospects, non-costed resource deployment including project management, technical design expertise, procurement, and operational engineering support including training 100 operational standby engineers. Included within this is NPg's funding of its active participation in ESOF and our contributions to its Good Practice Guide on Electrical Energy Storage (see A4). This project required huge organisational commitment from the partners (particularly from NPg and British Gas) which was delivered alongside normal service delivery. There is an unquantified cost to the companies that is the opportunity costs of deploying key resources on this project as opposed to other valuable organisational priorities.

155. After project closedown, NPg funded **data analysts and project management valued at ca. £50k to prepare and publish disaggregated customer datasets to make the CLNR data available** for other research and development activity by third parties and so enabling them to develop additional maximise the learning from CLNR.

3.2.2 B2: Issues that justified the additional contribution

156. The additional contributions were either made to deliver a successful outcome to the project when the original planned resources were insufficient or they were used to deliver an even better set of outcomes for the investment made by customers through the LCNF.

157. **£2.2m DECC funding for heat pumps:** At the time of submitting the CLNR bid in September 2010, the renewable heat incentive (RHI) was due to be introduced in spring 2011. In late October 2010 the government extended its own deadline meaning that the customer incentives were insufficient to expect 'able to buy' heat pump sales to provide sufficient trial participants. We sought alternative funding as the alternative would have been to descope heat pumps from the project.

158. **£2.5m funding for smart grid laboratories:** This was an opportunity to enhance the learning and add value to the outputs with no further funding required from customers. As a result, the modelling outputs were upgraded.

159. **£1m contribution in-kind of project resources from project partners:** We describe some of the specific external headwinds encountered on this project in section A6. But more generally, a project of such ground-breaking scale, scope and ambition understandably came across lots of issues that needed resolving by the partners in order to use the resources at their disposal to find solutions and achieve an exceptional outcome. This tended to require senior board and senior management action to ensure appropriate prioritisation to undertake tasks that were often firsts for the companies and the industry. This contribution was gladly made but should not go

unrecognised. Alternatives would have been to either de-scope elements of the project, cancel the project or seek additional funds from customers via the LCNF.

160. **The post-project preparation and publication of disaggregated datasets** was an opportunity to add more value by producing the data and making it available in a form that was readily usable and also could be tracked so that we could continue to collaborate and understand some of the impact. In order to support the widest possible onward sharing and to facilitate further reuse and to maximise the benefits of these outputs, we explored and provided access to the datasets under the Creative Commons Attribution-ShareAlike licence.

3.2.3 B3: Demonstrable benefits to customers

161. There have been clear outputs from the additional contributions that demonstrate the value to customers from the scope, quality or accessibility of the learning.

162. The learning on **heat pumps** would have been seriously curtailed without the additional funding. Instead, a substantial trial of 38 heat pumps was delivered; complete with the additional learning on storage, power quality and customer experience that is described in section A7.

163. **The smart grid laboratories** enabled greatly simulation and emulation work resulting in validated models as a key output from the project. They also provided an engaging space to explore CLNR with stakeholders that enhanced the quality of knowledge sharing. Today, the smart grid laboratory at Newcastle is a national asset that is continuing to be funded by the university as an open collaborative space for researchers and industry parties. The models created in it are being used by NPg to explore the value of local energy markets as part of the transition to DSO.

164. **£1m contribution in-kind of project resources from project partners** supported delivery of the project and meant that the project retained the value from integrated trials with the full range of LCTs and network technologies that we set out to test. Further, customers benefitted from not having to fund the totality of the costs associated with the project.

165. There was a clear appetite from third parties to use this **CLNR data for further research** – prior to its publication we were approached by 30 people asking us for the data. To date, over 300 people from over 100 organisations in 20 countries have downloaded the disaggregated datasets. These include international academic institutions in China, Germany, Greece, India, Iran, Jordan, Korea, Russia, Singapore, Spain, Switzerland, Taiwan, Turkey, the UK and USA; consultants in the UK, Netherlands and UAE; and established suppliers and new entrants, energy services companies, DNOs and technology companies in the UK, Canada, USA and India. The reach of CLNR is significant and moves beyond UK DNOs and the electricity sector, and further benefits will follow in future as this data is used by more people to address more research questions. By requiring third parties to register their details prior to downloading the data, we have been able to trace the significant interest in CLNR and how its impact continues to ripple out. We have now adopted the creation of a data legacy for third parties as our standard data access policy for all innovation projects – based on this tried and tested approach. Examples of some of the benefits that this is already delivering for customers are set out in section C3.

3.3 Reward criterion C

3.3.1 C1: Demonstrate where the project has delivered more learning than was expected

166. The interest shown in the CLNR outputs provides evidence that they are of value to customers. We explain here the additional learning that was delivered by following the method as set out at the bid stage and that was richer and/or deeper than the expectation. Further we identify 'tangential' learning that was less related to the methodology was generated on the project and was of benefit to our customers.

Additional learning through exceeding the methodology (as described in A7) and how it has been used

167. **Enhanced profiling of domestic smart meter customers**: Our "Insight Report: Enhanced Domestic Monitoring"[31] has been accessed 134 times and the data has been accessed over 190 times.

168. **Low carbon technology insight**: These four reports (para 119) form an important learning output and have been accessed in aggregate on almost 800 occasions, demonstrating that the output has been of value.

169. **Customer insight, social science behavioural learning: Academic lead for** social insight, Professor Harriet Bulkeley of Durham University, provided evidence to the Parliamentary Evidence Check[32], drawing on CLNR evidence to make an evidenced case of support for smart meters.[33] This is a good example of the importance of the social learning for informing policy.

170. Our report **SME Customers: Energy Practices and Flexibility** has been accessed on 36 occasions.

171. Our comprehensive learning on one of the biggest heat pumps trials conducted in GB is contained in four reports covering customer attitudes, the thermal store and power quality[13 21 23 25] and which have been viewed over 340 times

172. **Qualitative learning on I&C customer appetite for DSR** in our "Report on CLNR Industrial & Commercial Demand Side Response Trials" has been used by NPg to develop our strategy and plans for procuring DSR in BAU and the report has also been accessed 90 times.

173. Our set of five **socio-technical synthesis** reports (para 121) has provided a fuller understanding of the opportunities and limitations on customer flexibility. These have supported thinking on the wider institutional arrangements and business models required for successful deployment of LCTs and ToU tariffs, as well as the implications for network operation and design. These have been used by third parties, as evidenced by the more than 700 webpage views.

174. We **developed and evaluated alternative advanced control optimisation techniques,** providing a better understanding of evolutionary pathways for control systems as LCT concentrations increase. This could be of value when seeking to deploy control systems that require advanced techniques to optimise for higher LCT volumes.

175. We delivered additional learning in 5 papers on **the value of the network solutions under n-1 & n-2 faulted conditions and how these same technologies can also improve security of supply**. These have been used by third parties, as evidenced by the total of 49 times viewed in the project library.

Other additional tangential learning and how it has been used

176. **Investment planning (Transform):** The original GB-wide Cost-Benefit Analysis 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). It is now the standard tool used by GB DNOs to develop their long term investment plans in a consistent and comparable manner across GB.

177. We have demonstrated **modelling of smart grid solutions using wavelet and neural net** short term forecasting techniques. Specific outcomes of this modelling are: the ability to forecast the 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 and lowest nuisance factor; and how load forecasting allows not only the ability to use RTTR opportunistically but also the ability to forecast for how long it will deliver certain benefits so that network interventions can be planned and deployed much more efficiently. While we cannot at this stage demonstrate how this learning has been used, the demonstration of this modelling methodology will benefit future research in this field.

178. **Northern Powergrid as a local partner and collaborator:** our experiential learning over the course of the project has been significant and led to a greater appreciation of the benefits of working with other organisations and in raising the profile of the company locally as an innovator and collaborator. Relations established under CLNR with Newcastle University have been grown, with new projects being developed from CLNR such as ACE and further EV research with Nissan. We are also increasingly engaging with local organisations such as Newcastle City Council on sustainable solutions and the Science Central project. Developing partnerships under CLNR has led to involvement in other projects such as 'My Electric Avenue'. Our staff testify to this evolution:

'It's taught us to collaborate a lot better, it also taught us how to listen to our stakeholders and interact more'

'It gave us a vehicle…an agenda…for us to have a conversation externally'

'More people know who we are as a result of it'

'CLNR was a rich ground to develop skills, have those conversations and scope future work.'

'[We are involved in] more conversations around technical links, smart cities and things that are much more engineering…it allowed us to bring some cards to the table.'

'Because we have these types of conversations comes hard innovation outcomes'

179. **Cultural change in Northern Powergrid:** CLNR has brought a more flexible and open-minded approach to traditional operations and thinking: a willingness, awareness and confidence to look for alternative solutions. This continues to be balanced against an inherent cautiousness within the organisation which is typically risk-averse and focused on the need to maintain the grid and *'keep the lights on'*. CLNR has embedded a strong sense of trialling and analysing problems or alternative ways of working which has been grown within the organisation since the project end. CLNR has given us a significant step change in our ability to identify ways to do things

differently and to save money and this has led to an expansion in our innovation activity, both within formal innovation projects and within BAU.

3.3.2 C2: Additional learning as a result of exceptional effort of the DNO

180. CLNR was an ambitious project with significant scope, scale and ambition. Exceptional effort was applied to deliver the project and that same attitude carried through in the delivery of additional learning by taking advantage of opportunities to produce more outputs when that was possible at least cost.

Extra value from one of the most extensive trials of network and customer smart grid technology

181. The integrated £11m of network technology installed for the trials required significant effort to complete in the face of the external headwinds described in section A6 (storage vendor bankruptcy protection and supply chain difficulties). Not only was it completed, but extra value was also returned in the following areas:

- **Operational smart grid safety case study:** Achieving a safe technology roll-out and trials had always been a key part of the project scope in order that the risks of demonstrating this new active system on a real network with real customers were managed appropriately. However, in addition to conducting the trials, the operational safety aspects have proved to be useful outputs from the project in the form of 'how to' guides for DNOs; and the Health and Safety Executive has taken the opportunity to use CLNR to understand more about the training, risks and controls necessary for the management of active networks. These operational safety guidance documents have been used by NPg and are valuable for other DNOs considering the use of similar equipment. There are three documents relating to EES, OLTC and ANM interfaces.
- **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 the enhanced network monitoring Report[34] which recommended a cost-effective BAU 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. Since CLNR we have continued to use much of the equipment and methodology to monitor and learn from follow-on projects.
- **Extensive documentation of our experience with key network technologies:** these reports document the lessons learned about from the process of initial design, through commissioning, to operation and maintenance. These reports are intended for use by distribution network operators and other interested parties who are considering implementing the network technologies on a BAU basis or who are embarking on or undertaking similar projects. The lessons learned reports covered EES, RTTR EAVC and GUS.
- **Designing and running network trials:** we developed an approach to design and optimise 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 was developed as a mechanism to drive the trials towards gaining the maximum learning from the equipment and time available, thus ensuring that the trials delivered the best learning possible. This is 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. The outputs are Overview of Network Flexibility Trial Design for the CLNR Project35 and CLNR Learning Credits System36.

Extra value from the most comprehensive study of customer energy practices undertaken in GB

182. CLNR was one of the most comprehensive studies of customer energy practices ever undertaken in GB. Similar to the network deployment example, this took exceptional effort to complete so effectively but this did not stop the partners from seeking to deliver extra value at minimum cost.

- **Capturing our approach to successful customer interaction and engagement:** and these have been highly relevant to others seeking to understand the experience from CLNR (as described in A8). Our two principal reports on lessons learned from trial recruitment[37] and lessons learned from customer trial equipment installations[38] have received over 220 views.
- **Studying customers' usage of Economy 7 tariffs and hot water storage:** in 2012 we reported that our marketing activities had identified that electric hot water is not a suitable load for demand response since the majority of customers who heat their domestic hot water electrically typically do so overnight

and on an Economy 7/10 tariff. However, the learning from the marketing activity also indicated that there was very limited knowledge around electric hot water usage and customer behaviour in the UK and literature on the subject was theoretical. i.e. there was an opportunity for CLNR to fill a knowledge gap by including households with electric hot water heating and storage heating as distinct sub-groups within the trial of enhanced monitoring of domestic customers without LCTs. This provided an understanding of these customers' general loads and also how they respond to the existing E7/E10 tariff signals i.e. the extent to which people on these existing and long standing DSM tariffs 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.

- **EV uptake impact on networks:** a collaboration with the Switch-EV project enabled us to use additional data from thousands of charging events on a bigger dataset of a pre-existing Northeast project and combine it with the CLNR data. This allowed the analysis of data on journeys and recharging away from home. As a result, we produced a much more accurate view of where, when and how network challenges will emerge due to EV uptake. The key learning provided through exploiting this opportunity has challenged the assumption that if 40% of customers on a LV circuit have EV charging then the transformer would be overloaded. In fact, we can have higher penetration rates in urban areas on average (60%) and lower rates in rural areas (15%). 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 learning was reported in a conference paper (IEEE ISGT 2013 - Integrating smart meter and EV charging data to predict distribution network impacts[39]) and in a journal paper (Applied Energy - A probabilistic approach to combining smart meter and electric vehicle charging data to investigate distribution network impacts[40]). This learning was achieved with no additional cost to the project to obtain the data and only a minimal incremental cost for the additional data analysis.
- **EV power quality monitoring:** at the bid stage we planned to monitor just PV and heat pump clusters and not EV clusters because of the scarcity of EVs and also because they were less likely to be clustered. Our partnership with EA Technology and SSEPD on the My Electric Avenue (MEA) project provided the opportunity to add power quality monitoring on five feeders (4 residential; 1 at a work location) where there were clusters, each containing a minimum of 10 EVs each. This power quality monitoring was not part of the MEA 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 and is a good example of collaborating across projects. See Assessment of power quality impacts from disruptive technologies[41].

ACE49 research methodology 'rediscovered'

183. The electricity network planning standard ACE49 was last updated in the 1980s although its origin dates further back further. When designing the trials to gather data to update this national standard with new patterns of electricity use it was discovered that the methodology and knowledge required to calculate the assessments no longer existed in the industry. As such, we had to use exceptional effort to locate the industry knowledge and produce methodology reports in addition to doing the calculations to update the standards. Documentation of this 'rediscovered' academic research methodology is now available for subsequent updates.

3.3.3 C3: Exceptional capture and dissemination of learning in a way that maximises value for all customers

184. There were a number of company and industry firsts on CLNR. The range and scale of the knowledge capture, sharing and dialogue with interested parties was unparalleled.

Delivering learning in a way that is relevant and accessible to a range of stakeholders

185. The specification of the information required in the closedown report focussed on the information needs of DNOs. However, we recognised that there was and still is much very 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. Therefore, in addition to the closedown report, we delivered three additional key learning reports that summarised the learning in way that was relevant to our stakeholders and also acted as a bridge between the closedown report and the hundreds of detailed reports and datasets that we have published. The three reports are Developing the smarter grid: the role of domestic and SME customers[42], Developing the smarter grid: the role of industrial & commercial and distributed generation customers[43], and Optimal solutions for smarter distribution systems[44].

Project website and use of social media

186. We used CLNR social media channels (Twitter, LinkedIn and YouTube) to increase the reach of the project and drive more traffic to the website. In July 2014, we completed a major refresh and re-launch of the website to improve the visitor experience and to support the sharing of knowledge with our stakeholders. This included 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; and the website was made responsive across all platforms meaning it could be accessed from laptops, tablets and mobile phones.
187. The website content was written in such a way as to be search engine optimised. Links to the CLNR social media sites and content were displayed and users were given clear signposts of how to 'contact us' with any questions about the project. New pages were added which gave an overview of each of the CLNR trials, its purpose, its progress and links to relevant learning and videos. The usability of the project library was also significantly improved with the ability to search for material by keyword, and a summary synopsis page for each item in the library providing a concise synopsis of each item and providing information on related content.
188. At closedown we updated the website content to reflect the project's completion and added new pages to clearly signpost the project's findings and conclusions.

Data legacy

189. During the project we published datasets for network trials and aggregated customer datasets which are available via the project library. After the project we prepared disaggregated anonymised datasets from the customer trials and published these on a webpage page explaining the data available and how to access it. We made the data available under the creative commons 'share alike' licence to make it as widely available as possible, and without any limitation on how it could be used, provided that copyright was not infringed. We wrote to third parties to actively promote the new availability of this data which has since been downloaded by over 300 individuals from over 100 organisations in 20 countries.

Substantiated evidence of the impact of dissemination

190. The evidence that our dissemination was effective is demonstrated primarily through the many examples given below of how third parties are using CLNR learning to facilitate the low carbon transition and deliver further benefits.
191. We have identified CLNR data and information referenced by the following 16 organisations to progress understanding of ToU tariffs and pricing policy, EVs, heat pumps, DSR, flexibility, EES and PV. (Specific references available on request.)

    Aurora Energy Research, Brattle Group/Citizens Advice, Cambridge Economic Policy Associates, EA Technology, Element Energy, Eunomia, Frontier Economics, HubNet Supergen+ project, Newcastle University, Northumbrian Water, Oxford University, Passiv Systems, SSEN, Sustainability First, TNEI, WPD

192. As a result of our dissemination, CLNR has a wide and varied impact as demonstrated by the following testimonials.
193. *'I relied on the CLNR results for both and found the study to be highly useful. For the distribution tariff design work, we used the load profile data for customers who participated in the field trial to analyse the distributional bill impact of new tariff designs. For the TOU study, we benchmarked international price elasticity estimates against those in the CLNR trial for calibration purposes.*' (Respondent from The Brattle Group)
194. '*A lot of the car companies come to us and they're worried about whether or not the distribution infrastructure is going to be up to the task of accommodating all of these electric cars…and we reference three reports…CLNR, Low Carbon London and My Electric Avenue'* (respondent from Element Energy).
195. *'The experience within CLNR and other LCNF projects and afterwards in working with large customers to encourage flexibility, and to understand the drivers and constraints has been shared between the electricity network companies in forums such as the Energy Networks Association and will have contributed to the approach being adopted in Power Responsive. I would argue that it is this developing sharing of experience and understanding that is as important as the success of any particular demand side experiment'* (respondent from Sustainability First, ex-NPg employee)
196. Through the course of the project a range of channels and tactics were used to disseminate the learning. This included speaking at 59 industrial and academic conferences, taking part in 87 different stakeholder meetings, and external media coverage reaching over 11 million readers in regional, national and trade media.
197. Email was our primary tool for disseminating learning and engaging with our stakeholders and the list of opt-in subscribers had reached over 900 by the time of project closedown. Subscribers received priority updates on the release of any new project outputs and an e-news bulletin which kept them up to date with the latest project news.

198. We used our Twitter, LinkedIn and YouTube channels to significantly increase the visibility and reach of the project, giving our followers a medium to disseminate learning on our behalf. Our CLNR Twitter channel had 564 followers, our LinkedIn group consisted of 243 members and the 15 videos on our YouTube channel have been viewed over 14,000 times.

199. There have been over 4,900 visitors to the project website with over 28,200 unique page visits. The CLNR online project library[45] holds over 200 outputs and there have been over 10,000 views of the top ten items:

Most accessed materials in CLNR project library	Hits
After Diversity Maximum Demand Report	5,518
Project Closedown Report	1,253
Domestic Smart Meter Customers Profiling	1,022
Developing the smarter grid: optimal solutions for smarter network businesses	603
Developing the smarter grid: the role of domestic and small and medium enterprise customers	569
Review of the Distribution Network Planning & Design Standards for the Future Low Carbon Electricity System	517
Dataset (TC6): Enhanced Profiling of Domestic Customers with Electric Vehicles (EVs)	388
Developing the smarter grid: the role of domestic and small and medium enterprise customers	569
Developing the smarter grid: the role of industrial & commercial and distributed generation customers	267
Lessons Learned Report: Electrical Energy Storage	264
Insight Report: Domestic Baseline Profile	247

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