Low Carbon London
Project Closedown Report
V1.0

UK Power Networks
Delivering your electricity

Contents

Glossary of Terms

Abbreviation	Term
ANM	Active Network Management
CHP	Combined Heat and Power
CNO	Charging Network Operator
CP	Charge Post
CS	Carbon Sync
DG	Distributed Generation
DNO	Distribution Network Operator
DSO	Distribution System Operator
DSR	Demand Side Response
*d*ToU	Dynamic Time-of-Use
EIZ	Engineering Instrumentation Zone
EV	Electric Vehicle
FAQ	Frequently Asked Questions
GB	Great Britain
HP	Heat pump
HV	High Voltage
I&C	Industrial and Commercial
ICL	Imperial College London
IHD	In-home Display
kWh	Kilo-watt hour
LCL	Low Carbon London
LCNF	Low Carbon Network Fund
LCT	Low Carbon Technology / Technologies
LUL	London Underground Limited
LPN	London Power Network
LV	Low Voltage
MWh	Mega-watt hour
ODS	Operational Data Store
OLEV	Office for Low Emission Vehicles
PHEV	Plug-in Hybrid Electric Vehicle
PMS	Participant Management System
PV	Photo-Voltaic
RTU	Remote Terminal Unit
SDRC	Successful Delivery Reward Criterion / Criteria
SIM	Subscriber identification module
SMS	Short Message Service
ULEV	Ultra-Low Emission Vehicles

Foreword

The format of this report complies with the structure and content of closedown reports for Tier 2 Low Carbon Network Fund projects, as published by Ofgem on 29 October 2013.

All references to the Low Carbon London submission are made, unless otherwise explicitly stated, against the approved Low Carbon London amended submission, which formed part of the Ofgem-approved change request CR1, as set out in Ofgem's decision letter approving the change, dated 21 December 2012.

1. Project Background

"Low Carbon London – A Learning Journey" was an integrated, large-scale and complex project measuring and evaluating the impact of a variety of low carbon technologies (LCTs) on London's electricity distribution network through a series of trials. The project was established in January 2011 and completed in December 2014 with the findings, conclusions and recommendations contained in a portfolio of 27 final reports produced throughout 2014. The project also carried out a wide ranging learning dissemination programme to communicate these outputs to other Distribution Network Operators (DNOs), industry bodies and other interested parties through a series of roadshows and public events.

London has the highest concentrations of electricity demand and CO_2 emissions in Great Britain, and the most demanding carbon reduction targets (60% reduction on 1990 levels by 2025). Its central area electricity networks are already very highly utilised and its urban environment means that reinforcement costs to meet new demand are high. London also has the greatest scope for distributed generation, micro-generation, and electric vehicles. All these factors make London the ideal test-bed for a low carbon project.

The project was therefore closely aligned to London's objectives in becoming a leading Low Carbon Capital and promoting a low carbon economy. The Mayor of London's office has set stretching targets on the use of distributed generation to meet increased demand for energy (the London Spatial Development Strategy targets 25% of heat and power from local decentralised production by 2025), as well as a portfolio of other targets, for example, on the use of ultra-low emission vehicles, carbon reduction and air quality. London's decentralised energy strategy targets 25% of electricity and heat from local generation by 2025 to help reduce CO_2 emissions by 60% by 2025. The roadmap to achieve this indicated that by 2020 an estimated 68MW of photovoltaic generation will have been installed in London along with 6MW of micro-wind electricity generation, while 168MWth of heat demand would be supplied by ground or air sourced heat pumps.

The project was also keen to ensure the findings could be extrapolated to a national and international level so that the project's findings could be evaluated in terms of contributing to national objectives for greenhouse gas emissions. The Kyoto Protocol, in force since February 2005, committed the UK to achieving a 34% reduction by 2020 and an 80% reduction on greenhouse gas emissions by 2050, from 1990 levels. The UK's fourth Carbon Budget, published in June 2011, placed a further interim target of a 50% reduction by 2027. In addition, the EU Energy Efficiency Directive seeks to deliver 20% energy efficiency savings by 2020 (from a 2007 baseline).

The project brought together some of the best low carbon skills and capabilities available in forming the overall project team drawn from both UK Power Networks and project partners. The project partners ranged from key London government agencies such as Transport for London and the Office of the Mayor of London (which also incorporated the previous London Development Agency), alongside partners such as National Grid, electricity demand aggregators (EDF Energy, Flexitricity and EnerNOC), Smarter Grid Solutions, CGI, EDF Energy, Siemens, the Institute for Sustainability and the world-recognised Imperial College as the project's academic partner.

The diversity of skills and interests reflected the broad and complex scope underpinning the project's objectives, as well as representing the broad spectrum of stakeholders in the project's desire to take an end to end smart electricity supply chain perspective and in the development and delivery of a smart sustainable low carbon electricity network in London.

The multi-talented team gave the project access to an unprecedented range of skills and to a network containing many of the world's thought-leaders on addressing the challenges faced in ensuring the investment in the electricity distribution network continues in an informed, efficient and cost-effective manner as it supports the move to a low carbon economy.

The project gained approval from Ofgem on 17 December 2010, and formally commenced work on 4 January 2011 and completed work on 31 December 2014. The project applied and had approved a single change request in December 2012 with approved funding of £28.3m

2.Executive summary

Low Carbon London (LCL) is a game-changing initiative and has achieved a number of firsts during its ambitious and pioneering work. It has successfully investigated and tested a number of innovative approaches and technologies to developing and managing sustainable low carbon electricity distribution networks. It leaves a lasting legacy in the shape of a portfolio of detailed final reports and a library of data available for further research, including what is considered to be the largest contiguous smart meter dataset ever assembled in Great Britain.

The project successfully achieved a number of initiatives seen for the first time in Great Britain:

- Trialling a dynamic time of use tariff;
- Wind-twinning trials with both residential and I&C customers;
- Active smart management of EV charging to effect peak load shedding but with no perceptible degradation to the EV owner's charging experience;
- Successful implementation of project learning directly into UK Power Networks ED1 business plan with I&C DSR[1];
- Creation of what is considered to be the largest contiguous smart meter dataset ever assembled in GB – 16,300 consumers with a full year (2013) of half-hourly readings, coupled with detailed demographic profiling;
- Carrying out the largest household energy use and appliance survey for over 30 years; and
- Pioneering work on distribution system state estimation using the project's instrumentation and measurement framework.

All SDRC have been met on schedule, with 70 specific SDRC evidence items delivered by the project. The project has fulfilled and in many cases exceeded the aims and objectives originally set for it in 2010. Appendix Nine sets out the detail of how the project met its individual SDRC evidence objectives. The project direction and SDRCs were clustered into six themes that underpinned the original bid and shaped the subsequent structure and content of the project's work and analysis:

- Using smart meters and substation sensors to facilitate smart grids;
- Enabling and integrating Distributed Generation;
- Enabling the electrification of heat and transport;
- Residential and SME Demand Side Response;
- I&C Demand Side Management; and
- Wind twinning.

The project has met and overcome a number of challenges inherent in such an ambitious, complex and wide-ranging project, as well as getting approval from Ofgem in December 2012 to a change request to mitigate three specific material changes in circumstances outside of the project's control. These related to:

a) a fresh focus on three Engineering Instrumentation Zones (EIZs) geographic areas in London with a diverse mix of Low Carbon technologies (LCTs) and intense instrumentation and away from the recently (May 2012) obsolete ten Low Carbon Zones (LCZs);
b) the unavailability of heat pumps in London, in part probably due to delays in the launch of the Renewable Heat Incentive (RHI) scheme; and
c) a new approach to acquiring a carbon impact reporting tool due to changes in ownership of the software company originally identified.

[1] DSR refers to Demand Side Response and the abbreviation is used through the report; the original bid referred to Demand Side Management (DSM) which is now less commonly used to describe the same concept.

Business case revised based on project findings

The project has met its core within-project business case objective of providing £1.5m of deferred network reinforcement through the in-project deployment of I&C DSR against Ebury Bridge substation, and has had a significant beneficial impact on UK Power Networks' capital investment plan for RIIO-ED1.

When the project was designed in 2015, UK Power Networks projected at the time that the GB faced an estimated cost of £52bn on the distribution networks between 2010 and 2050 to support the electrification of transport alone. The project also estimated that as carbon emissions were increasingly measured and penalised financially, that the GB generation sector faced substantial costs unless demand could be made flexible, new peaks in demand avoided, and peaking plant could be retired.

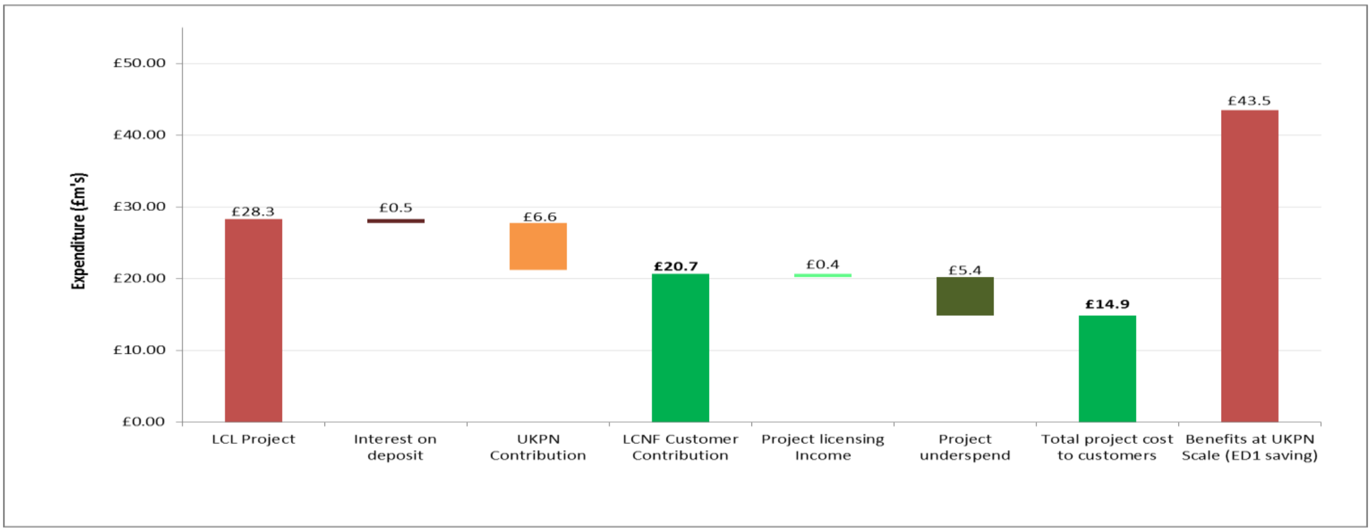
The results of the project, particularly in the area of Electric Vehicle charging, have demonstrated that the cost of the transition to Low Carbon Technologies should be much less than first estimated. Our new calculations based on the Low Carbon London results estimate that the GB would face a smaller "transition" cost of £6.4bn were electric vehicles to be supported by continuing to build out "conventional" distribution networks. Similarly, the carbon intensity of the grid (including peaking plant) is already forecast to be less in future decades than was thought in 2010. The project has nevertheless shown the additional savings and benefits that can be achieved by avoiding even these lower costs by introducing customer flexibility and operating networks more flexibly with tools such as Demand Side Response.

As it closes, the project estimates that the GB will gain in the order of £9.5bn of gross benefits, of which £1.0-2.0bn might be expected to accrue to DNOs from their making use of flexible demand and the remaining £7.5 - £8.5bn might accrue to the electricity system more broadly as a result of avoided carbon emissions and carbon penalties. The estimated cost of accessing these benefits has reduced from £3.5bn to £2.3bn. The table below summarises the review and outturn business case based on the project's findings and highlights the component variances. Further details can be found in section eight and appendix 10.

Benefit of "smart"	Original bid	Revised
Direct benefits	£1.5bn	£1.5m (corrected figure - error in original bid)
DNO benefits (residential dToU & commercial DSR)	£0.22bn	£0.12bn
DNO benefits (EV & HP flexibility)	£10.4bn	£0.9-1.9bn
DNO benefits (other)	£1.7bn	-
System carbon benefits	£28.9bn	£8.6bn
Gross benefit	***£42.7bn***	***£9.6 – 10.6bn***
Costs	(£3.6bn)	(£2.3bn)
Net benefit	**£39.1bn**	**£7.3-8.3bn**

Project learning directly informing £43.5m in UK Power Networks ED1 savings - pays for itself within ED1

Learning directly derived from the project's Industrial and Commercial (I&C) demand side response trials has enabled UK Power Networks to commit to a total network investment savings of £12m within the London Power Network (LPN) and £43.5m across all of the DNO area by deferring or avoiding network reinforcement through the application of DSR. The final outturn cost of LCL to the customer is £14.9m; taking into account the ED1 DSR savings based on the project's learnings of £43.5m means that the project pays for itself over 2½ times within the ED1 period. The graph below illustrates the project costs, money returned and benefits generated by LCL.



DNO roadshows

LCL took its findings out to visit DNOs in their own backyard with a series of well-received roadshows, to disseminate the learning and engage locally in detailed discussions and challenge on how the project's outcomes could be replicated in other DNOs.

Trial numbers

The project's trials can in part be articulated in the following numbers:

- A smart meter trial involving over 5,500 residential/SME Londoners;
- A dynamic time of use tariff trial involving 1,100 residential/SME participants across London;
- EV trials with 72 residential EVs, 54 commercial EVs, 1,408 public charge posts, 30 EVs with driving pattern loggers, 10 EVs on a time of use tariff trial and 62 public charge posts involved in the smart peak load shedding trial;
- Heat pump trials with 18 heat pumps, all fitted with power quality analysers for detailed monitoring;
- A total of 185 demand response events were called across residential/SME and I&C customers;
- DSR trials with I&C customers that at peak had over 18MW under contract and provided over 300MWh of support to LPN;
- 708 households took part in a pre-dToU trial survey and 408 took part in a post-trial survey; and
- 79% of dToU trial participants said they did not find the tariff complex whilst 71% said it gave them a greater sense of control.

Key project trial highlights and findings

The project's main findings can be summarised as:

- Voluntary contractual reductions in demand by large customers (Demand Side Response) shifted enough electricity to serve 18,000 homes at peak;
- A survey of appliances in 2,830 homes across London collected the most accurate data on electricity consumption since the 1980s to guide investment in electricity networks;
- From data collected within the home appliance survey, it is estimated that there could be a 10TWh pa saving in electricity consumption by 2020 by consumers switching to more efficient appliances;
- Mass charging of electric vehicles will have a substantial impact on electricity networks at 0.3kW per household, but LCL's trials showed this was more manageable than previously thought;
- Wind-twinning tariffs could work in cities. Customers can be incentivised by time-of-use tariffs to 'do their washing on windy days', using more electricity when wind power is plentiful (domestic Demand Side Response);
- A system called Active Network Management could allow up to a third more distributed energy plants to export 'green' power to urban networks;
- Carbon emissions from today's electricity system are around 450g/kWh and the Government is seeking ways in which to reduce this by between 100-200g/kWh by 2030. If only one of the initiatives demonstrated in Low Carbon London was fully adopted across the country, an additional contribution of 5g/kWh towards this reduction would be achieved, with the potential for far more;
- Smart grids save customers money by making better use of network capacity; and

- Millions invested digging up roads to lay cables and strengthen substations can be deferred.

LCL's findings in London are replicable for any major city in the UK, or around the world.

Green cost-cutting using 'smart grids'

LCL has tested intelligent electricity systems – so called 'smart grids' - that can monitor, control and balance significant extra pressures on distribution networks from increased use of low carbon technologies without human intervention. This avoids expensively over-engineering our electricity networks, which everyone pays for in their electricity bills.

Low Carbon London demonstrated new organisational relationships required to deliver smart grids and these can be achieved within the existing industry structure. UK Power Networks implemented commercial relationships with four energy aggregators and established bilateral arrangements with 37 demand response sites. The project enabled control room integration with two demand response sites. It successfully achieved system integration with a Charging Network Operator (CNO) in order to call off demand response from electric vehicle charge posts.

First LCNF project to attract external revenues

The project has actively promoted the intrinsic value in the project's work and this is underlined by the use being made of the Active Network Management System and Operational Data Store (ODS) by another collaborative project involving UK Power Networks and Shell UK, resulting in licence fee revenues of £420,000 being paid by Shell and returned, in full, to network customers. The project has also released its EV data for further research by Centre for Transport Studies at Imperial College.

If it can work in London then it will work elsewhere

Due to the multi-faceted nature of the network, London has proved to be the ideal test bed for such a project. The city and Greater London area has the highest concentrations of electricity demand and CO_2 emissions in Great Britain, and the most demanding carbon reduction targets (60% reduction on 1990 levels by 2025). However, the trials and associated findings are designed in such a way as to be relevant and applicable to other urban networks across Great Britain, as well as being relevant to all major urban centres globally.

Successful active network management of distributed generation

The project has successfully demonstrated the ability to directly control and manage distributed generation on the electricity distribution network, driven by automated assessment of the status of the distribution network. Systems were tested which have potential to increase by a third the amount of green, locally-produced electricity being connected to the London network. These systems dynamically calculate spare network capacity and can adjust the amount of electricity exported to the network by local generators to prevent the network from being overloaded.

Improved network visibility

The project has clearly identified that the efficient planning and operation of smart electricity distribution grids requires improved network visibility. The project concluded that this improved vision is not just limited to enhanced instrumentation and telemetry of supply, but also implies a significantly enriched understanding of the drivers of energy consumption of electricity customers and the factors influencing the ability to exploit flexibility in electricity demand through that increased understanding of how and why electricity is consumed and how the I&C sector can participate in DSR and on-site generation or co-generation.

LCL installed monitoring equipment in three unique areas of London to enable technical visibility of the electricity network, from grid supply points to the last point on the Low Voltage (LV) networks. This has enabled a significantly better understanding of the Low Voltage areas of our network, specifically in terms of voltage. Low Carbon London has provided significant new data on voltage levels which is fundamental for understanding a future with many low carbon technologies connected to the network. This analysis has also informed DNO network planners for the smart meter rollout and provided insight to the expected number of voltage alerts that Distribution Network Operators will have to manage once it has full visibility of residential customers. These 'Engineering Instrumentation Zones' (EIZs) have also helped understanding of approaches to monitor the network efficiently, by determining where the best place is to locate monitoring using techniques such as distribution system state estimation (DSSE) – another example of pioneering work carried out within LCL.

Planning load forecasts and Transform Model

LCL has validated the DNOs load forecasting methodology, which is aligned to the Transform Model and has replaced the final few assumptions in the methodology with real, measured values and these are being discussed with the Transform Model team.

The purpose of load forecasts is to anticipate large-scale trends and to prioritise regions of high growth on the network. Their resolution is typically of the level of the 5,500 primary substations across the GB, each serving typically 10-11,000 customers. Since 2011, DNOs have developed sophisticated tools to support their load forecasting processes, which include to a greater extent than previously a bottom-up assessment of new demand drivers such as electric vehicles (EVs), heat pumps (HPs), and the growth in small-scale embedded generation (SSEG), communally known as Low Carbon Technologies (LCTs), and domestic consumer load.

Whilst the tools are designed to ingest the latest and most current data on the housing stock, and residential background demand, these factors will only change over the longer term. The main drivers for change over the next period, which must be monitored annually, are likely to come from any adjustments in the forecast uptake of LCTs. LCL has further strengthened this bottom-up approach by replacing assumed charging profiles of EVs with measured profiles from a daily average of 44 vehicles and showing good stability out to 95% percentile/2 sigma, and update current heat pump assumptions with measured profiles from the trials.

The revised forecasts closely align with the outcomes of the original assumptions, and re-validate that the vast majority of the forecast impact from LCTs is on the secondary distribution network. Specifically, from the load forecast an estimated 4,600 secondary substations will require reinforcement due to LCT uptake; this means that 25% of the stock in London will require reinforcement for this reason alone in the LPN licence area by 2050. It is recommended that these new profiles are adopted by the other DNOs and brought under change control of the GB Transform model.

Smart meter data privacy in rural networks

The benefits from aggregating smart meter data could be restricted in certain rural networks. Complying with data privacy obligations could limit the benefits of smart meter data in locations with low customer numbers. UK Power Networks estimates that over 10% of the substations within London have fewer than 10 customers. In the South East region which has a significantly higher proportion of rural substations, approximately 30% of the substations, including pole-mounted transformers, have less than 10 customers. This indicates that the minimum number of customers over which smart meter data is aggregated should be carefully considered, especially for rural networks, in order to draw on the benefits of the data. It is therefore important that the minimum level be defined such that networks with a low volume of consumers by substation can adequately be monitored, or their data can be accessed.

Heat pump uptake

DNOs should maintain a close eye on heat pump uptake, particularly in clusters. Visibility will allow adequate consideration on the maximum demand (MD) contribution and associated risks of clusters to a network. In the case of networks with heat pumps, the MD could be adversely affected by 'extreme cold' weather conditions. The LCL trials showed that for an average temperature of -4°C and a penetration level of 20% of household owning heat pumps, the peak daily load increases by 72% above baseline. There is therefore a risk during periods of extended cold spells where heat pumps present no diversity, which DNOs must consider in their planning assumptions.

DSR and network planning

LCL has identified the value of DSR to operational and planning functions of the business. LCL has contributed significantly to the understanding and application of DSR enough to be rolled out as part of UK Power Networks' RIIO-ED1 strategy. This includes developing tools and approaches to assist the appraisal, procurement and contractual agreements to implement DSR. Implementing DSR will be beneficial in managing planned and unplanned faults as well as enabling the deferral of network reinforcement investments.

Values for contribution or 'F-factors' which can be used in the existing network planning processes laid out in Energy Networks Association documents ETR130 and P2/6 have been derived for different types of demand response sites. For example, a diesel generator's contribution can vary from 70% to 81%, depending if it's a single site versus a portfolio of up to ten sites. These values have also been calculated for CHPs (69%-80%) and 'turn down' sites (54%-64%) respectively. It is recommended that DNOs adopt the values derived in LCL when assessing the contribution of DSR to security of supply.

Future Distribution System Operator

In future DNOs are likely to play a far more active role in managing load and generation on the network than is currently the case today and the LCL project has demonstrated new organisational relationships within the current industry structure. Specifically, LCL has demonstrated commercial relationships with four energy aggregators and bilateral arrangements with 37 demand response sites; control room integration with two demand response sites; system integration with a Charging Network Operator (CNO) in order to call off demand response from electric vehicle charge posts; and a shared or multi-purpose Time-of-Use tariff with one of the major energy suppliers (EDF Energy).

The project has also clearly demonstrated areas in which closer inter-working will be required in future, either within the same or any modified industry structure. Over the next decade, DNOs will be procuring DSR as a new entrant alongside the largest single procurer today, the Great Britain System Operator (GBSO), National Grid. By the mid-2020s, modelling carried out within LCL suggests that energy suppliers will be an equally significant player as the GBSO is today, as they seek to balance a much larger proportion of renewable generation within the generation fleet.

Finally, the project has demonstrated that under all future uptake scenarios, there is potential for DNOs and smart grids to contribute a 5g/kWh reduction in Great Britain's carbon intensity, if the appropriate business cases can be made to support the roll-out of controlled EV charging, time-of-use tariffs and controllable electric heating in the home.

The project also explores approaches that are alternate to the current planning practices. These topics are explored in detail and include:

- Option Value of DSR and Min/Max regret investment;
- New approaches for considering reliability of DSR;
- Implementation aspects of relying on commercial arrangements, such as controlling pay-back or the resumption of energy use after DSR events, and methods of measuring baselines amongst industrial and commercial customers whose energy usage varies considerable from one to another; and
- Virtual power plants

LCL's 27 final reports

The LCL project has produced 27 final reports in addition to this closedown report. They are listed in section 13 of the main body of this report. These reports describe in detail the project's trials, analysis, findings, conclusions and recommendations and the reader is recommended to refer to those reports for further information on topics covered in this closedown report.

3. Details of the work carried out

The project was contracted to introduce, test and prove three fundamental methods and elements of operating and managing electricity distribution networks:

- New commercial arrangements to maximise network utilisation/improve load factor;
- New system design and planning practices that leverage the benefits of active network management and customer participation; and
- New operational practices such as active management of demand, generation and network configuration to optimise network power flows and minimise constraints.

In conventional circumstances, network utilisation and load factor is determined by the need to meet peak demand, even if this peak demand is relatively short-lived, and assumes that existing customers cannot shift their load. The project's methodology explored the ability to shift load. Separately the project measured the impacts and the opportunities offered by LCTs connected to the distribution network, through a series of experiments and trials.

The Low Carbon London bid submission included an ancillary document that described in greater detail use-cases that the project would consider. This described a series of envisaged experiments built around use cases that were expansions of each of the three methods being investigated. Each use case experiment articulated a series of potential learning points that could emerge as learning outcomes from the trials. These learning points were described in a manner that sought to ensure that learning could be captured and obtained from all trial outcomes – both successful and unsuccessful outcomes, hence the label of Low Carbon London as a "Learning Journey".

Table 1 below sets out the structure of the trials, and which also set the structure of the success criteria for the project's final outputs. The project used the term "wind twinning" to describe the active participation of customers, whether residential or industrial and commercial (I&C), in shaping their electricity demand to meet the availability of wind generation across Great Britain. Each of these is specified in more detail on page 17 onwards.

Project trials and outputs	
Using smart meters and substation sensors to facilitate smart grids	Trials to deliver SDRCs
Enabling and integrating Distributed Generation	
Enabling the electrification of heat and transport	
Residential and SME Demand side response*	
I&C Demand side response*	
Wind twinning	
New network design and operational practices	Trial outputs aligned to project methods
New network planning and operational tools	
* These two trials also underpinned the "new commercial arrangements" method	

Table 1 - project structure and drivers

Each trial identified challenges and opportunities associated with the particular topic of the SDRC theme (e.g. using smart meters and substation sensors to facilitate smart grids; wind twinning; and electrification of heat and transport) and then articulated a set of envisaged experiments that aimed to deliver the potential learning points identified. Figure 1 below sets out the relationship between the trials and project outputs.

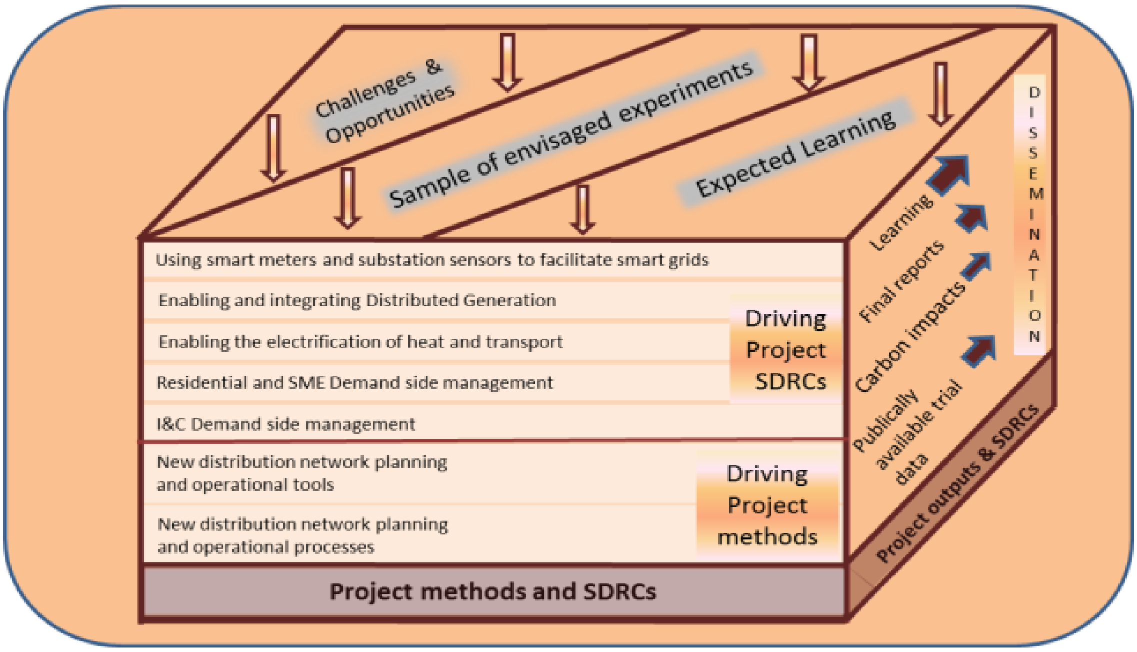


Figure 1 - project structure

As the project prepared to disseminate its findings, it was felt useful to organise the findings according to four themes: Distributed Generation and Demand Side Response, Electrification of Heat and Transport, Network Planning and Operation, and Future Distribution System Operator (DSO). Each of these themes now contains the commercial arrangements (e.g. the requirements agreed in contract with I&C Demand Side Management participants), operational practices (e.g. requesting the response by telephone or by an Active Network Management (ANM) ICT platform), and planning practices (e.g. the rated contribution to network capacity of a Demand Side Management site) associated with that theme. Appendix 14 formalises this, and was driven with the readership in mind.

3.1 Project Structure and Organisation

Each trial was constructed and co-ordinated within a project workstream, with the overall architecture and design developed, changed and maintained through an explicit project design authority office and associated processes. The workstreams were established around following themes:

a) **Smart meter deployment;** (Covering the pilot roll-out of 500 smart meters and the subsequent roll-out of 5,000 more to EDF Energy residential and SME customers);
b) **Electrification of heat and transport;** (This included monitoring and assessing heat pumps as well as private and commercial electric vehicle charging regimes, examining the response of private electric vehicle owners to time-of-use tariffs and integrating on-street charge posts into a DSR scheme.);
c) Demand side response and distributed generation; (This encompassed the design of contractual terms with both I&C and residential participants and recruitment of participants; as well as engagement with the full range of customers with DG, e.g. from PV through to large-scale CHP, turbine and standby diesel resource);
d) **Instrumentation and tools;** (This theme included the establishment and instrumentation of the EIZs, emerging data and IT considerations in addition to the traditional impacts on the network through refreshed and improved load profiles. The theme also encompassed innovative new and developing aspects through DSSE and the use of smart meter data and the use of DSR for outage management and network maintenance); and
e) **Learning dissemination and communications;** (This included internal and external learning dissemination and events, visualisation approaches, monitoring workstream learning logs, project newsletter, stakeholder management, website content and access and social media).

From its inception, the project was centrally and actively led, managed and organised by UK Power Networks, with a full-time UK Power Networks senior manager in the full-time role of Programme Director, with the project's partners actively involved throughout the project. The project adopted the UK Power Networks internal project management methodology which is based on the PRINCE2 (Projects in a Controlled Environment) methodology.

This was selected not just because it was the internally available methodology but because it offered a level of explicit control through the formal project methodology artefacts PRINCE2 requires (in particular the Project Initiation Document, Product Descriptions and Product Flow Diagrams). This was felt to be particularly valuable in a project with a broad and ambitious scope and being delivered through a project team consistently of UK Power Networks and 11 external partners, geographically located across many parts Great Britain.

The breakdown of a complex project such as LCL into a number of separate but interdependent stages lent itself well to the multiple trials and subsequent analysis and reports obligations the project had committed to. The methodology was supplemented by a comprehensive solution design authority and architecture framework and a project-wide change management process.

Project solution architecture – design, development and control

It was always recognised that the initial design submitted and approved within the bid in 2010 required significant further work and development to produce a cogent and integrated detailed design that could be translated into a series of physical trials and experiments. The project recognised this from the start and established the project Solution Design Authority office to provide an over-arching framework and process to enable further solution development to occur in a managed and integrated fashion. The project leveraged one of the partner's recognised capabilities in this area and co-opted a Chief Solution Architect from Siemens to establish the SDA office and accompanying processes during the first year of the project.

This enabled each workstream to work independently whilst ensuring that the project's overall objectives and goals were met in an efficient manner and leveraged cross-workstream dependencies and learning. The wide breadth and complexity of the project scope required this approach to be adopted and implemented from the start of the project. It also enabled some unique hybrid trials to be devised during the project that integrated different trial components. Two examples of this were a) the ANM-enabled DSR trials and b) the ANM-Carbon Sync EV charging trials – both these trials combined two or more aspects of the project's trials to demonstrate the ability to synthesise different LCTs to develop new offerings and approaches to exploit more efficient use of the distribution network.

In addition, from the outset of the project there was a keen awareness of the need to assess the requirements of the evolving role needed to effectively and efficiently manage the electricity distribution network in an increasingly complex and multi-agent context and what this may imply for any Distribution System Operator (DSO) role; i.e. the project sought to assess its findings in both a current (tactical) and a future (strategic) context. This evolving role is likely to imply an increased level of both distribution network management intervention actions in response to events on the increasingly complex low carbon electricity network as well as proactive behaviours and actions to address issues in advance of them becoming real problems.

Multi-agency partnership-based project team

The project brought together some of the best low carbon skills and capabilities available in forming the overall project team drawn from both UK Power Networks and project partners. The diversity of skills and interests reflected the broad and complex scope underpinning the project's objectives.

The partners ranged from key London government agencies such as Transport for London and the Office of the Mayor of London (which also incorporated the previous London Development Agency), alongside partners such as National Grid, electricity demand aggregators (EDF Energy, Flexitricity and EnerNOC), Smarter Grid Solutions, CGI, EDF Energy, Siemens, the Institute for Sustainability and the world-recognised Imperial College as the project's academic partner.

The multi-talented team gave the project access to an unprecedented range of skills and to a network containing many of the world's thought-leaders on addressing the challenges faced in ensuring the investment in the electricity distribution network continues in an informed, efficient and cost-effective manner as it supports the move to a low carbon economy.

Project organisation and reporting

The project established a comprehensive and robust governance framework from the start of the project. Led by the DNO, the project set out to ensure that both the DNO and project partners had good oversight and control of the project. The project organisation flexed and evolved to meet the changing needs throughout its life-cycle whilst maintaining its core shape and a firm oversight framework.

The project ran with weekly team meetings involving all active project team members. This was augmented by a bi-weekly solution design process to address solution development and technical queries. A monthly programme steering group meeting was held involving senior representatives from the DNO and frequently from project partner organisations. Executive oversight was provided by a quarterly meeting chaired by the CEO of UK Power Networks and attended by senior executives from project partner organisations. A comprehensive reporting mechanism accompanied this meeting cycle. Figure 2 below sets out the core project control and reporting structure that was in place for the duration of the project.

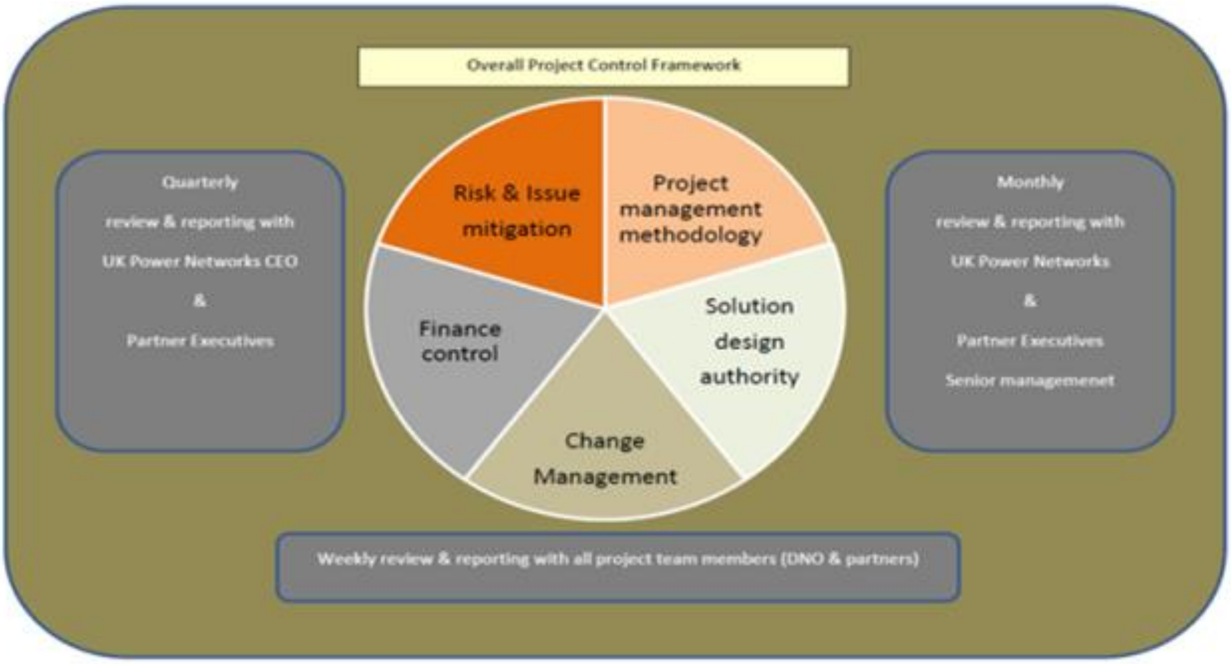


Figure 2 - Project controls

Frequent reporting to Ofgem

As part of the change request approval in December 2012, a monthly report back to Ofgem was put in place from 1 January 2013 with Ofgem, specifically focusing on the project's trial developments and progress towards SDRC themes, some of which had also featured in the change request. This regime continued until Q2 2014 when it was discontinued as the project concluded its trials.

Timescales

The project ran from January 2011 until December 2014. As part of the approved change request detailed below, the original project completion date was extended by six months to accommodate the changes. The summary timeline for the project is set out in Appendix 2.

Project IT Infrastructure

The project established a comprehensive IT infrastructure to underpin the project's trials. The core of the IT architecture was built around two databases, the Operational Data Store (ODS) which held transactional and network configuration data for the project's various trials and the Participant Management System (PMS), which held details of trial participants recruited directly by the project onto trials (e.g. EVs and DSR), but importantly, no data was held on any EDF Energy customers who participated in the smart meter and dToU trials.

The core architecture was then expanded with a series of secure data and file transfer interfaces from the variety of data points sources used in the trials. The physical infrastructure was operated and controlled under UK Power Networks production IT processes and controls, enabling a highly secure, audited security access framework to be in place across the whole IT system. A secure file interface with Imperial College was established to enable the project's academic partner to undertake their detailed analysis of trial data; access to this interface was similarly controlled and managed as part of UK Power Networks production IT security controls. Appendix Three sets out the final IT architecture.

Project design

As mentioned above, the project set about designing the detailed content of the trials proposed in the bid to demonstrate the impact of LCTs on the electricity distribution network, focusing on the three methods that underpinned the project's objectives, SDRC themes, benefits case and envisaged learning. Extensive detailed design work was undertaken throughout 2011 and 2012 to expound a comprehensive set of trials and associated measurement instrumentation needed to generate the required empirical data to be subsequently analysed and fulfil the project's aims and objectives.

Pilot 500 smart meters and unavailability of a SMETS-complaint smart meter

An early trial activity was to design and execute the roll-out of the first 500 smart meters to EDF Energy residential and SME customers. This exercise was itself held back several months whilst the position around the availability of a SMETS-complaint smart meter was established. The delays in the availability of a SMETS-compliant smart meter meant that the project had to adopt a non-SMETS meter and make additional measurement provision to address gaps in trial data able to be captured. The astuteness of the decision not to wait further was borne out by subsequent additional delays of over 18 months in the eventual SMETS-meter availability, which was outside of the project's viable timescales. The pilot exercise to recruit 500 customers and install smart meters in their homes was carried out successfully and generated valuable learning that was applied to the subsequent main recruitment and deployment of over a further 5,033 smart meters. The pilot exercise also established that the smart meter reading data collection infrastructure and onward transmission to the project's Operational Data Store (ODS) was working well. A provision has been agreed with EDF Energy to cover their costs in replacing these meters with SMETS-compliant meters.

Geographic locations – Engineering Instrumentation Zones

The project originally focused exclusively upon 10 specific geographic areas within London, which comprised the Mayor's Low Carbon Zones (LCZs), which was an initiative centred on areas of social re-generation and refurbishment. We had expected these areas to generate opportunities in terms of being able to measure household demand pre- and post- heating and energy efficiency measures, and to generate clusters of micro-generation and possible EV and heat pumps. In practice, their focus was primarily on local energy efficiency, with loft and door insulation campaigns predominating and the LCZs closed down in early 2012. However, as part of the December 2012 approved change request, the project defined three geographic areas (all previously designated as LCZs), Brixton, Merton and Queens Park, as locations of intense low carbon activities, instrumentation and measurement. Where appropriate, trial recruitment was also expanded to Greater London to allow for more balanced demographic participant pools and greater ease of trial findings extrapolation and replication elsewhere.

The project also changed approach to measuring the baseline within the EIZs and measuring individual LCTs more widely across LPN, given the limitations of current LCT uptake. As such, the EIZs were established as areas of intense instrumentation. The LPN 11kV feeders in the EIZs (three in all), were instrumented to understand active and reactive power flow per feeder as well as enabling Imperial College to test and verify their new distribution systems state estimation (DSSE) application. See Figures 3 and 4 below.

Key:
1 = Queens Park (urban residential, radial network)

2 = Brixton (urban commercial, radial network)

3 = Merton (suburban residential, radial network)

Figure 3 - EIZ locations in London

As part of the EIZ instrumentation framework over 100 measurement devices were installed at the end points of the LV circuits from the associated distribution substations, which also had monitoring instruments installed on all outgoing ways. This comprehensive and integrated measurement framework enabled detailed analysis to be undertaken on of the impacts of LCTs on the EIZ distribution network from 11kV down to end points on LV circuits.

Figure 4 - EIZ instrumentation

3.2 Project trials

3.2.1 Using smart meters and substation sensors to facilitate smart grids

Through these trials, the project sought to determine how smart meter and substation sensor data could be used to better understand the way in which customers contribute to network load and how the data that will be available from smart meters as part of the national roll-out will be useful to a DNO when planning and operating electricity distribution networks.

The project deployed 5,533 smart meters into the homes and premises of EDF Energy residential and SME customers. These were installed in two phases; a pilot exercise deploying 500 smart meters into EDF Energy participants' homes and the main deployment that was shaped by valuable learning gained during the pilot exercise (for example, the use of roaming SIM cards in the main roll-out, to overcome poor mobile phone reception issues). Associated demographic profiles for all trial participants were obtained from CACI based on their Acorn consumer classification system. This enabled the overall demographic mix of the smart meter and dToU trial pools to be careful managed to enable straightforward extrapolation and replication to other scenarios.

During the trials half-hourly meter reading data for the full 2013 calendar year was successfully collected for the meter population. Towards the end of the project, smart meter consumption and Acorn demographic data was obtained for the same time period for an additional 10,800 British Gas customers. This resulted in a combined contiguous dataset for the full 2013 calendar year of half-hourly consumption data for 16,300 smart meters. This is probably the largest ever GB dataset of energy consumption and demographics ever gathered and represents a potential valuable resource for future research. An important feature of this full dataset was the demographic profiling that was obtained for all 16,333 households; this enabled subsequent valuable analysis and insight on energy consumption and demographics beyond those based on traditional primarily on property and premise categories. The EIZ instrumentation framework comprised over 100 measurement devices installed at the end points of the LV circuits, together with sensors deployed on EIZs substations and feeders. This comprehensive and integrated measurement framework enabled detailed analysis to be undertaken on of the impacts of LCTs on the EIZ distribution network from 11kV down to end points on LV circuits.

Home energy use survey

As part of this trial an extensive home energy and appliance ownership survey was undertaken, involving 2,830 homes across London. This represents one of the most comprehensive surveys in Great Britain of appliance ownership ever conducted and has provided useful input and insight to a number of the analyses undertaken within the project.

3.2.2 Enabling and integrating Distributed Generation

Decarbonisation of London is expected to lead to a significant increase in levels of installed distributed generation (DG). The project's trials aimed to investigate if ANM could utilise the expected increase in DG could contribute to network security and, in reverse, identify any obstacles to DG joining the urban network. The ANM trials monitored, managed and controlled distributed energy resources (DER), consisting of distributed generation (DG) and load on the LPN electricity network, providing increased visibility and control capabilities. The strategy for the ANM trial was to use this technology to monitor and control distributed energy resources (DER), including distributed generation (DG) and controllable load.

This would provide learning on their behaviour and how exerting control over them at critical times could increase the DNO's capacity to utilise existing assets more fully, deferring network reinforcement. The project structured the DG trials around three themes:

a) Monitoring DG installations with ANM technology - this improved network visibility of DG would provide valuable learning on the behaviour of installed DG;
b) Enabling ANM technology to directly control DG to provide DSR services - how exerting control over DG at critical times could increase the DNO's capacity to utilise existing assets more fully, deferring network reinforcement; and
c) Utilising ANM technology to indirectly enable automated control of DG, in conjunction with demand aggregators, to provide automated DSR services.

Monitoring DG

The LCL team was successful in finding 15 participants for the DG monitoring trials; however, to increase the sample size, two generators participating in the monitoring trials were located in UK Power Networks' EPN/SPN distribution areas. 13 sites were CHP installations and two photovoltaic (PV) sites. Monitoring of DG was accomplished by locating ANM hardware and software at the site of the DG, directly interfacing with measurement devices or the DG control system. This provided learning on the infrastructure that would be required to exert direct control and its performance during the trial period.

Enabling ANM technology to directly control DG to provide DSR services

This trial comprised two separate participants, Islington Borough Council's Bunhill Energy Centre and Transport for London's (TfL) Greenwich Power. Bunhill Energy Centre is a CHP installation installed as part of a district heating scheme that will deliver energy to over 700 residential properties and two leisure centres. Greenwich Power is TfL standby power supply, comprising eight Rolls Royce Avon gas turbine engines which were installed between 1967 and 1972, which can be fuelled by natural gas and are also capable of running on fuel oil which is stored as an emergency reserve at the site.

Four substations were monitored by the ANM system: Lithos Road, Bankside C, Wimbledon 132 kV Section 3&4 and City Road B. Maximum power flow limits through the substations and/or individual transformers were enforced using the ANM system. A threshold configured in ANM sets the limit at which DSR events are triggered. When overloads were detected, ANM sent a dispatch signal either directly to the corresponding generators or indirectly via the demand aggregator requesting to decrease the consumption or increase the power export of the corresponding DSR portfolio to remove the overload.

Recruitment of these two sites was a prolonged and complex process, carried out over 30 months of the project, requiring detailed contractual negotiations for both the physical installation works and the commercial DSR arrangements in place during the trials; the trials were finally able to be conducted in the final months of the project and as a consequence the results do not appear in the trial-centric final reports published in September 2014.

By this point in the project the use of standby generation as part of DSR had been robustly demonstrated, the profiles of typical CHP plants had been measured during normal operation and the profile of both CHP and standby generators during demand-side events had been measured. Similarly, the ANM technology had been demonstrated by several DNOs including UK Power Networks with renewable generators. As such, what remained was a technical demonstration that the same automated control philosophy could be achieved with organisations for which, in contrast to renewable generators, generation is not the day-to-day activity but instead one aspect of facilities management and operations management. The trial comprised two separate components:

a) 1-week trial from 29 September - 3 October 2014, using the Bunhill Energy Centre (BEC) CHP DG installation, with DSR events triggered by the total power flow through City Road B primary substation (CITB); and
b) 2-week trial from 20- 31 October 2014, using the Greenwich Power Station (GPS), with DSR events triggered by the total power flow through Wimbledon 132kV Section 3&4 substation (WIMB).

Appendix 5 illustrates the architecture used at Bunhill Energy Centre. It shows the central ANM controller (CAC) communicating with the following external systems:

a) Remote terminal unit (RTU) at City Road B primary substation (CITB);
b) UK Power Networks pre-production SCADA, via the RTU;
c) LCL Operational Data Store (ODS); and
d) Building Management System (BMS), via sgs connect.

Network measurements were provided by the RTU, sent to the central ANM controller, as well as providing the link between UK Power Networks pre-production SCADA and ANM. (The pre-production SCADA system is a SCADA test environment used to ensure stability to the operational production SCADA system). The direct link between the CAC and the BMS enabled the BMS to control the CHP unit via the ANM infrastructure. The BMS communicated the availability of the CHP to the CAC considering the spare thermal storage available within the district heating system connected to the CHP.

Appendix 6 illustrates the architecture established for the trial with Greenwich Power Station, detailing the CAC communicating with the following external systems:

a) Remote terminal unit (RTU) at Wimbledon 132kV Section 3&4 substation (WIMB);
b) UK Power Networks pre-production SCADA, via the RTU;
c) LCL Operational Data Store (ODS);
d) Gas turbines (GT) at Greenwich Power Station (GPS), via sgs connect;
e) ANM Human Machine Interface (HMI), via sgs connect; and
f) TfL's Control Room at Palestra, via sgs connect.

The RTU provided network measurements to the central ANM controller, as well as providing the link between UK Power Networks pre-production SCADA and ANM. A total of eight events were carried out, five with Bunhill Energy Centre and three with Greenwich power.

Enabling DG to participate in DSR services

As noted above, the project has concluded that there were significant overlaps between ANM and DSR. The trials utilising ANM enabled DG through demand aggregators to provide DSR services split into two trial timeframes, a summer trial in 2013 and a winter trial in spanning 2013-2014. All DG sites providing indirect DSR services in each trial were recruited via demand aggregators the project was working with, namely Flexitricity and Kiwi Power. The sites consisted of both DG and controllable load, i.e. load that could be shed or turned down. Appendix 7 sets out the architecture used in this trial and Table 2 below sets out the summer and winter trials. A total of 84 indirect DSR events were triggered by ANM. In summary, an improved overall compliance is seen in summer than winter and from generation than load

	Summer trial		Winter trial	
	Generation-led DSR	Demand-led DSR	Generation-led DSR	Demand-led DSR
Number of events	4	28	27	25
Number of events with ≥90% compliance	3	16	5	4
Number of events with ≥90% compliance (%)	75.0%	57.1%	18.5%	16.0%

	Summer trial		Winter trial	
	Generation-led DSR	Demand-led DSR	Generation-led DSR	Demand-led DSR
Number of events with ≥95% compliance	3	13	5	2
Number of events with ≥95% compliance (%)	75.0%	46.4%	18.5%	8.0%
Number of events with 100% compliance	2	12	3	1
Number of events with 100% compliance (%)	50.0%	42.9%	11.1%	4.0%
Totals (for 100% compliance)	43.8%		7.7%	
	21.4%			

Table 2 - DG in DSR services

3.2.3 Electrification of heat and transport

The project undertook a series of trials based around charging electric vehicles and the use of heat pumps. These trials sought to investigate if growth in these LCTs on the distribution network could be managed just through traditional methods and planning assumptions by measuring and analysing their impact on the electricity distribution network, either directly by investigating voltage and power quality characteristics or indirectly, e.g. investigating the usage behaviours determining the demand through these LCTs.

EV charging monitoring trials

The bulk of these trials were designed to fulfil our requirement to provide evidence of real changes in load patterns due to heat pumps and electric vehicles, as set out in the SDRCs in Appendix 9. UK Power Networks monitored EV charging impacts on the distribution network through data captured with EDMI smart meters. These trials involved 72 residential and 54 commercial EV charging posts located across London, collecting a range of voltage and power network impacts. Charging event data was also collected throughout the project from a further 491 public charging posts in London. EV charging data was also obtained for analysis that had been collected during the London Olympic Games from EVs used as official event transport across six different Olympic locations, using power quality meters to collect a range of charging and network impact data.

EV charging intervention trials

Two further trials sought to take a more active intervention-based role in order to fulfil our requirements to provide guidance on successful approaches to, and the value of, smart optimisation of EV charging as set out in the SDRCs in Appendix 9:

a) time of use EV charging, with 10 residential EV's being monitored with the residents being on EDF Energy's "Eco 20:20" tariff, that promoted off-peak usage; and
b) Public EV charging peak load-shedding, involving 62 public charge posts located in three areas of London – this trial brought together the project's ANM capabilities in conjunction with charge posts management software developed by the public charge post operator Pod Point. Table 3 below summarises the trials investigating network impacts from EVs.

Trial description	Participants & data collected
EV Charging	72 residential EVs – metered data 54 commercial EVs – metered data 491 public EV charge posts – charging event data 30 EVs – logger data capturing driving patterns/charging behaviours
2012 Olympic Games EV charging data	Power quality meter data collected from six EV charging locations
EV time of Use charging	10 residential EVs
Smart ANM-enabled EV charging "Carbon Sync"	62 public charge posts across 3 locations

Table 3 EV trials

Heat Pumps

The project submitted an amended approach to the inclusion of heat pumps within the project's trials as part of the change request approved by Ofgem in December 2012. The amended approach was driven by changes in material circumstances outside of the project's control regarding the very low demand for heat pumps in LPN area, which may have been in part due to delays at the time in the availability of the Renewable Heat Incentive scheme. The approved revised approach was to obtain suitable heat pump data from external sources; this came from two sources, the Energy Savings Trust, who sourced data from 10 heat pumps, and Passiv Systems who sourced data from eight heat pumps. Both sets of data were provided by the use of power quality analysers, which enabled a rich spectrum of network impacts to be captured. In addition, a range of non-electrical characteristics (e.g. inlet and outlet water temperatures, internal and external ambient temperatures) were also captured to assist in the analysis. Table 4 below details the data points captured.

Trial description	Participants and data collected	
Heat pump monitoring	Data for 18 heat pumps provided by Energy Savings Trust and Passiv Systems	
	Power quality analysers used to collect data from all 18 heat pumps.	
	Voltage (RMS)	THD of voltage
	Current (RMS)	THD of current
	Power factor	RMS of the odd voltage and current harmonics from 1st to 49th
	Apparent power (VA)	Phase of the harmonics measured
	Reactive power (VAr)	Frequency (Hz)

Table 4 Heat pumps data points

3.2.4 Residential and SME demand side response

The philosophy behind the Dynamic Time-of-Use (dToU) trial was based on three aspects:

a) Time of day – Prices can vary by time of day so that, for example, the customer is subject to a higher price during peak periods. This is already possible, and already happening, today, but the potential uptake of such tariffs will be larger as a result of smart metering. Smart meters also remove the need for time of day price patterns to be static i.e. to repeat according to a pre-agreed timetable;

b) Day of the year – Prices can also vary by day. This again can already happen, but similarly smart meters widen the audience and allow for the price changes to be more dynamic; and

c) The client for the services – The setting up of a willing community of customers, but then calling them on individual occasions, allows various different clients to be the trigger and eventual beneficiary of the services. Today's event may be designed and agreed with the DNO to serve the DNO's purposes, whereas tomorrow's event could be designed to serve the supplier's purposes in balancing their wholesale market position. The domestic customer is not impacted by this distinction, but it allows various parts of the energy chain to benefit from the service.

The residential dToU tariff trial served to meet further trial objectives for residential demand, to investigate the potential use in both deferring network reinforcement and that of constraint and outage management. Table 5 below summarises the potential value of dToU tariffs to a DNO.

	Deferred reinforcement	**Mitigation of capacity shortfalls ahead of reinforcement**	**Planned outages**
Rationale	A reinforcement investment requirement can be deferred by reducing net load beneath the affected substations at peak load times	A reinforcement that is planned or underway will not be complete in time to avoid peak substation load from exceeding capacity. A domestic DSR is used to maintain P2/6 compliance ahead of reinforcement completing	Capacity is unavailable during a planned outage period. A domestic DSR is used to reduce net load during high demand periods. When either a more expensive scheme or a derogation from P2/6 compliance would have otherwise been required
Application	A high price signal could be applied pre-fault through the dToU tariff, i.e. during any relevant high load periods		
Voltage level of application	LV customers feeding into an affected primary substation		
Benefits	Deferred reinforcement	Savings compared to a more expensive conventional outage management scheme and/or reduced risk of use for customers	
Voltage level of benefits	The targeted EHV or HV substation		
Site selection	Identification of substations where load is expected to	Identification of substations where load is expected to exceed firm	Identification of planned outage management schemes where the

	exceed firm capacity and with significant domestic load but for which reinforcement spend has not yet been committed	capacity in spite of committed reinforcement spend and with significant domestic load	conventional management solution is expensive or where a P2/6 derogation is required and with significant domestic load

Table 5 - potential value of dToU to the DNO

Residential dynamic time of use tariff trial

The trial participant pool consisted of 5,533 EDF Energy customers who had agreed to have a L&G 5236 smart meter installed in 2012. Of those, 1,119 were recruited to participate in the dToU trial; the remainder acted as the control group. The demographic profile of both pools had been carefully managed during the recruitment phase to enable ease of data extrapolation and replication elsewhere. The dToU tariff was marketed by EDF Energy as their "Economy Alert" tariff, the name highlighting the notification process advising participants of future tariff changes.

Figure 5 below summarises the recruitment for the smart meter and dToU trials (see also LCL ICL report A2). The recruitment process filtered out potential recruits who had any of the following characteristics:
• Customers on Economy 7 tariffs were excluded from the trial as these customers would already be used to adapting their behaviour for ToU tariffs;
• Dual fuel customers were excluded to avoid confusing the customer experience; and
• Customers with a prepayment meter were also excluded, since smart meters with pre-payment functionality were not available at the time of the trial.

Figure 5 Smart meter and dTou recruitment (see also Imperial College report A2)

The tariff structure was a three-tier framework. The price differentials used in the tariff are much greater than the price differentials seen in previous GB ToU trials, although they are towards the lower end of the differentials noted for previous dToU tariff trials conducted in other parts of the world. The prices reflect the variation in wholesale prices that might be expected in future with high levels of intermittency.

The three price bands set for the trial were:
- High price: 67.20 p/kWh;
- Default price: 11.76 p/kWh; and
- Low price: 3.99 p/kWh.

These prices were set such that the impact on the bill of a customer following a typical residential demand profile would be neutral. They compare against a fixed rate of 14.23p/kWh, which was charged to non-ToU EDF Energy customers in the control group for the trial. In addition, a customer bill "safety net" operated throughout the trial, with a reconciliation process at the end of the trial to ensure that no participant paid more for their electricity by participating in the trial than they would have done if they had been on their previous tariff. The trial ran from January 2013 until 31 December 2013. The dToU trial participants were notified of impending tariff changes at 0800 the day before the change was to take place. They were notified by using the messaging facility on the L&G 5236 smart meter in-home display and by text message if they had opted to receive that service. Appendix 8 shows a typical message sent to participants at 0800 the day before the tariff change.

The constraint management (CM) events were set up with a Low-High-Low (LHL) price pattern, meaning that customers would see low rate periods into which they could shift their demand either side of a high rate period. Placing the high price period between two low price periods differentiated the CM events relevant to DNOs, from the supply following (SF) or wind twinning events relevant to suppliers, or the system operator, and maximised the price differential for customers during the CM event. During the trial, CM events triggered on behalf of the DNO lasted between 3 and 6 hours, which reflect the fact that a customer response requirement would most likely be focused on a few hours around a network peak. Most of the events were therefore focused around the evening peak (e.g.1700-2300h), although a small number of events was targeted during the morning or during the day.

Some events were also repeated for up to 3 days, to reflect that CM events might be required following a fault. The tariff design allowed for up to 3 events per week, which was agreed with EDF Energy in order to limit inconvenience to customers. In practice the duration of faults can be much longer than 3 days. The commercial terms of any tariff used to target constraint events would clearly need to take into account how the tariff is expected to be implemented. SF/wind twinning events included a period of high or low prices. SF/wind twinning events were 3, 6, or 12 hours in length. These durations were set based on analysis of system-wide wind generation data, showing that 70% of high wind output events are less than 3 hours in duration, and that the next 20% of cases are between 3 and 20 hours. A total of 185 demand response events were called during the year-long trial.

Smart meter reading data was collected via the head-end system operated by CGI. Data was stored on the project's secure Operational Data Store (ODS) for analysis at the end of the trial. The trial findings are discussed in the section below.

3.2.5 I&C Demand side response

This trial set out to investigate how DNOs can utilise Demand Side Response (DSR) services in order to defer capital expenditure or to manage network constraints during construction and maintenance outages. It also set out to assess the risk weighted contribution of DSR to network security, the compliance with the philosophy of the current network security standards (ER P2/6 and ETR130) and the DSR capabilities available from the Industrial & Commercial (I&C) customer market.

The trials included both generation-led and demand-led DSR services to the DNO and were designed to relieve network constraints when network load was at its peak. The DSR trials were completed over a 3 month time period within each season: summer 2013 (June to August) and winter 2013/2014 (December to February). In addition, small scale testing of commercial and technical systems was completed in winter 2012/2013. The trials set out with the following objectives:

- To assess the effectiveness and reliability of DSR across a range of load reduction and generation-led providers;
- To make a qualitative analysis of the barriers to participation in DSR programmes;
- To develop DSR service contracts fit for the purpose of distribution network management, including incentive and penalty mechanisms and base lining methodologies;
- To develop DSR operational procedures and monitoring and dispatch systems fit for the purpose of distribution network management; and
- To gain real-world experience of procuring, operating and managing DSR portfolios through full-scale case studies on constrained sites in the LPN.

The DSR customers who took part in the trials were almost exclusively contracted via third party demand aggregators, although examples of directly contracted DSR providers were also tested as part of the Enabling and Integrating DG trials (with Bunhill Energy Centre and Greenwich Power). The key elements of the contracted demand response were as follows:

- Contracts were signed with a total of 37 DSR facilities;
- A total of 21 (57%) of the facilities were demand-led (water pumping stations and HVAC) providing a total of 4.2 MW of DSR capability (23%);
- A total of 16 (43%) of the facilities were generation led (CHP and diesel) providing a total of 14MW of DSR capability (77%);
- A total of 26 and 19 facilities took part in the summer and winter trials respectively;
- A limit was applied on the number of times DSR could be called which was as follows: once per day, three times per week and ten times per trial period;

- The maximum DSR response time was typically 30 minutes from receipt of a dispatch request with the exception of 2 facilities where a response time of less than 3 minutes was tested;
- The demand window for all facilities included weekdays only, excluding weekends and bank holidays;
- The DSR event duration was fixed at 1 hour for 19 facilities and allowed for 1-3 hours for 18 facilities;
- The demand windows for DSR facilities were primarily set by the time of the associated network substation peak, with a few exceptions motivated by provider capabilities - the following demand windows were used: 1000-1600, 1200-1800, 0900-2100, 0700-1900, 0800-2000 and 1400-2000;
- The availability windows were either 6 or 12 hours for the summer trial (14 and 12 facilities respectively for the summer trials and 6 hours for all of the facilities for the winter trials; and
- The utilisation payment was £200/MWh. The availability payment was either: £50, £70 or £100/MWh which was dependent upon the DSR mechanism used and whether or not the provider served an existing network constraint. For a number of diesel generation DSR facilities the availability payment was reduced over time.

The DSR trials resulted in 185 separate DSR events being called, where the minimum DSR event duration was 30 minutes providing a DSR response of 0.02 MWh. The maximum DSR event duration was 4 hours providing a DSR response of 9 MWh. The average DSR event time was 1.26 hours providing an average DSR response of 1.4 MWh and the total DSR response provided by the trials was 254 MWh. (In addition and as described above, the DG trial carried out two DSR-based trials with Bunhill Energy Centre and Greenwich Power respectively, which due to delays in the contractual negotiations for the physical and commercial arrangements necessary for the trials, occurred after the above statistical analysis had been undertaken).

3.2.6 Wind Twinning (or supply following) Tariff trial

The objective of this trial was to investigate the ability for energy demand within the distribution network to follow local and national wind energy production. This is crucial for the low carbon mitigation of the intermittency of wind generation and to minimise the reliance on either additional thermal peaking plant operating in spinning reserve mode or OCGT generation on cold standby to provide the necessary capacity reserve and balancing should renewable generation output deviate significantly from short-term forecast demand. The corresponding impacts on distribution networks were also identified and explored.

I&C wind twinning

The I&C wind twinning trial was designed around invoking a fully-automated DSR process driven by alerts from Elexon's Balancing Mechanism Reporting System (BMRS), triggered by significant drops (30MW per minute or greater) in available wind generation in the grid mix.

Residential wind twinning

The residential trial was designed around the specific sequence, duration and timing of variations in dToU tariffs as described above to reflect real-world intermittency of wind generation.

4. The outcomes of the project

Low Carbon London set out as an integrated, large-scale and complex project measuring and evaluating the impact of a variety of low carbon technologies (LCTs) on London's electricity distribution network. The outcomes were clustered into six SDRC themes, which shaped not only the project's SDRCs but directed its trial, analysis, reports and outcomes. The SDRCs and outcomes are structured into the clusters outlined below and the following section discusses the project's outcomes within these groupings, declaring the base hypothesis defined to underpin the SDRCs and trial outcomes:

a) Using smart meters and substation sensors to facilitate smart grids;
b) Enabling and integrating Distributed Generation;
c) Enabling the electrification of heat and transport;
d) Residential and SME Demand Side Response;
e) I&C Demand side management; and
f) Wind twinning.

4.1 Using Smart Meters and Substation Sensors to Facilitate Smart Grids

Aims and objectives:

The central hypothesis was that Smart Meters could support a wide range of smart grid functionalities, with implications for network planning (in other words, planning for new connections and load growth), operations (in other words, the settings by which the network runs on a day-to-day basis) and real-time or near- real-time operations (in other words, responding to or anticipating faults). There was an assumption that different customers used electricity differently, that this could be linked to their membership of a particular demographic group, and that their usage may differ from the After Diversity Maximum Demand (ADMD) assumptions currently in use by the DNOs. Finally, there was an assumption that existing processes would be improved and give improved outcomes for customers by using data from Smart Meters or substation sensors

Outcomes

The outcomes of the work are summarised in reports C1, C2, C3 and C4 and report D1. Report C1 examines both voltage measurements and load profiles measured from Smart Meters or equivalent devices. Imperial College set out the method by which the underlying load curves are assimilated from the Smart Meter data in report A3, and assurance on the data quality of the underlying Smart Meter data is provided in an additional report C5. Reports C2 and C3 take complementary approaches to studying the impact of energy efficiency at both a licence-area and substation-level.

As expected, the project identified different consumption patterns across seasons, during on-peak and off-peak hours, and between weekends and weekdays. Based on the actual energy consumption measurements and the extensive survey conducted, the LCL project has enabled pioneering analysis to correlate consumption patterns with household's income levels and occupancy class.

The project has proposed a practical categorisation of customers which captures the most significant variances but can be generated from publically available (or purchasable) datasets. Table 6 below (see also LCL ICL final report A3) shows the maximum diversified peak demand per household across three different LCL Acorn income classes and three different occupancy levels. This demonstrates significant variability of diversified peak demands (from 0.54 kW to 1.78 kW) associated with different demographics. This analysis highlights the benefit of knowing an area's demographic and consumers' behaviour, alongside the likelihood of take-up of new loads such as EVs, HPs and solar PV.

	1 person	2 people	3+ people
Adversity	0.54 kW	0.89 kW	1.12 kW
Comfortable	0.64 kW	0.98 kW	1.34 kW
Affluent	0.79 kW	1.16 kW	1.78 kW

Table 6 - peak demand analysis

Demand diversity was found to be consistent among customers, so that a single diversity curve can be used to assess demand at different points on the network. A single view of diversity has been produced based on the 2,541 smart meters consumption datasets for which survey results were available. This analysis of demand diversity allows robust, data driven diversity factors to be identified for any customer population and asset size. While the results in this report are based on the balanced sample of London Power Networks (LPN) customer data obtained on LCL, the methodology will be able to be applied to all network areas once smart metering data is more widely available, following the national rollout. Figure 6 below illustrates the single diversity curve derived from the trial data.

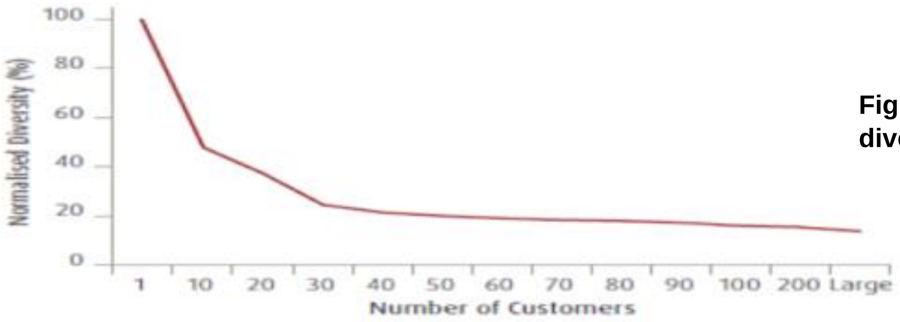


Figure 6 - single diversity curve

In addition to the smart meter trials, LCL has studied and reports on the effect which energy efficiency may have on the network in the future. The findings from LCL show significant potential for Great Britain, based on three case studies: reference, which considers only currently implemented policies; future energy efficiency policies, and implementing the best technology available; and is illustrated below in Figure 7 for both 2020 and 2030 scenarios.

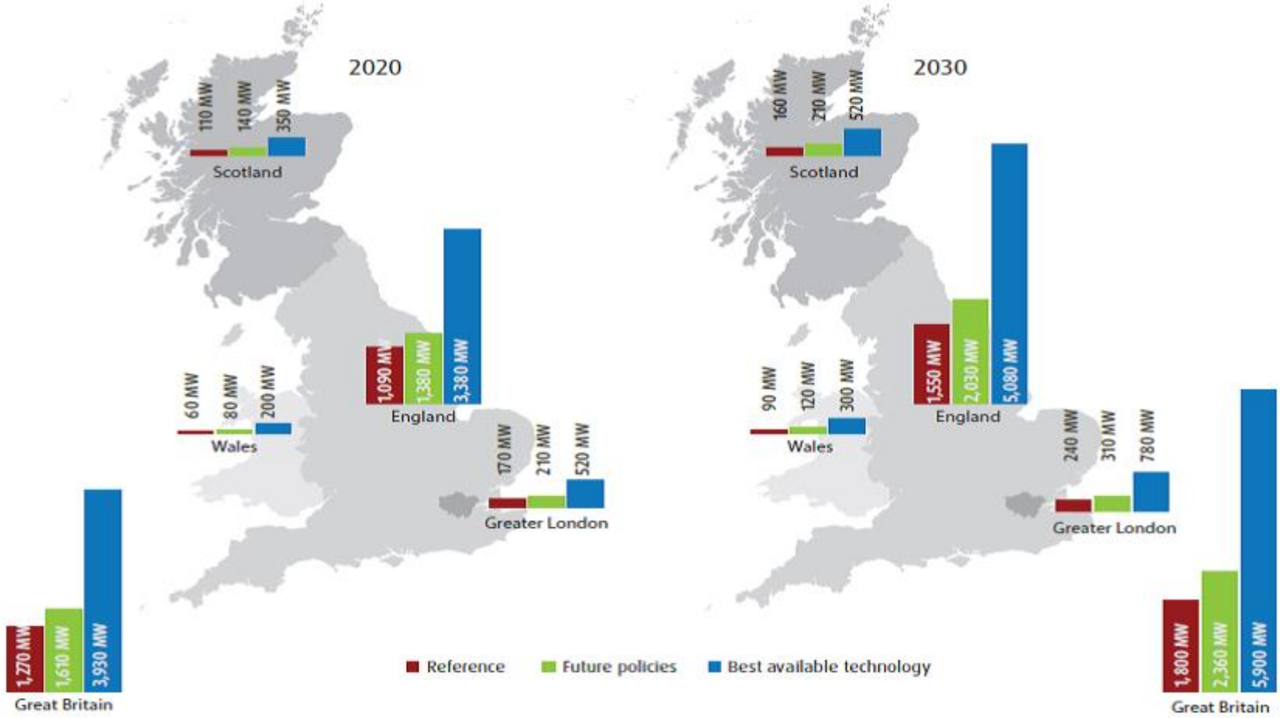


Figure 7 - 2020 and 2030 scenarios

The voltage settings at primary substations and position of open points on the 11kV and LV network determine the day-to-day voltage variations on the network as the customers consume from and increasingly frequently also generate onto the network. Whilst Smart Meters capable of voltage measurements were not available on the project's timescales, devices with equivalent functionality demonstrated that future Smart Meters will be a reliable source of voltage information at network extremities. The voltage level on selected areas of the London Low Voltage (LV) network was analysed and shown to generally be compliant with statutory voltage limits. 78% of the phases measured at the end of feeders had no readings at all outside of statutory limits. Only 0.35% of all the phases measured showed more than 1% of readings outside of statutory limits using 10 minute data resolution. (All voltage compliance issues discovered are being investigated). In general, voltage on the London network is towards the higher end of the allowable limits.

This means there is less headroom (margin compared to the upper limit) than legroom (margin compared to the lower limit) suggesting that the London network is more sensitive to an increase in embedded generation than increased demand from other technologies such as Electric Vehicles (EVs) and Heat Pumps (HPs). However, the lower voltage limit is responsible for more voltage excursions currently. The project has shown that, based on the smart meter data which will be available from the mandated roll-out of smart meters, clear examples of current processes can be improved, and will benefit from with the inclusion of such data. These include the connection of new load, the planning of reinforcement of existing network, voltage issue investigations and supply interruption management. Not all of these processes will require real-time data, and indeed not all will need localised data. For example, a periodic update to the industry-standard residential load profiles may not need to happen for a further 5-10 years, and only needs to take place once nation-wide. Reinforcement issues may need to be screened annually and per licence area in response to accelerated load growth associated with Low Carbon Technologies (LCTs).

The LCL Smart Meter trial has provided evidence on how customers can be categorised based on occupancy data. This can provide benefit when assessing the connection of new customers for which no data will be available. Although there are concerns that having limited visibility of voltage may be an existing problem which could be unmasked once the smart meter roll-out takes place, the analysis of the LCL Smart Meter trial data demonstrates that voltage is not currently a significant issue in the LPN network. However, with the onset of LCTs, this may become more challenging in the future. The analysis also reveals that the network is currently more sensitive to high voltage than low voltage but simple solutions such as off-load tap changes can be used to address this problem in some cases. Finally, there is potential benefit for DNOs from the use of smart meter data in a case specific way. This could involve future network load/voltage studies, analysis of voltage alerts, verifying load growth and using the smart meter data for outage management.

A state estimation algorithm was also tested using substation sensors, in order to estimate load flows and voltages. Results on simple radial feeders demonstrated that measurements of power flow even into neighbouring substations at which no monitoring was present and no analogues available were accurate to within +/-20% on 90% of occasions. This could be of assistance to control engineers in understanding what load they might be about to pick up when sectionalising the network following a fault, and deciding on how to sectionalise the network. Additional monitoring may be required at teed-off circuits, which tend to increase uncertainty in the results.

4.2 Enabling and integrating Distributed Generation

Aims and objectives
Many of the primary and secondary substations in the LCL trial areas either require reinforcement or are anticipated to require reinforcement prior to 2020. These reinforcements are necessary to ensure compliance with P2/6 planning criteria. P2/6 does not account for the contribution of the full range of low carbon technologies anticipated to form part of the LCL trial and the contribution that can be made by low carbon DG units controlled by ANM to providing security of supply. In this trial, DG units will be subject to control by an ANM scheme to ensure pre-fault and post-fault loading of primary and secondary substations is within limits according to Engineering Recommendation P2/6 and ETR 130. Demonstrating the capability of ANM and deployed DG units to deliver this, while also ensuring demand can be met, will provide useful learning regarding the reform of existing planning standards for security of supply to ensure they are fit for purpose for low carbon networks.

Outcomes
The outcomes of the work are summarised in reports B3, B4, A7, A8 and A9. Report B3 investigates the impact on power quality of LV-network connected LCTs. Report B4 examines the impact on network utilisation of the same LV-connected LCTs. Report A7, from Imperial College, sets out to understand and characterise the performance of DSR services within the distribution network, in order to inform future smart distribution network operation and planning. Report A8 presents new thinking on how Distributed Generation (DG) and Active Network Management (ANM) could enhance security of supply on the distribution network, as required by Engineering Recommendation P2/6. The Low Carbon London (LCL) project has provided new sources of data to support analysis of case studies in a dense urban network, whilst report A9 focuses on facilitating the connection of Distributed Generation (DG) to dense urban networks, such as those in London, which face particular challenges in terms of the types of DG seeking connection and the network constraints that make connection difficult and expensive. Urban networks typically host CHP, diesel and small-scale PV, making the DG mix very different from rural areas, where wind and large scale PV predominate. The barriers to connection are most often associated with fault levels rather than thermal or voltage constraints.

Distributed Generation

LCL has considered the rapid growth in DG and the expectation is that this will continue. The project has also measured how the diversity of DG has changed. In recent years, there has been a steep increase in the number and capacity of DG connected to distribution networks in Great Britain, including in the LPN licence area.

Facilitating DG

The focus in these trials was on facilitating the connection of Distributed Generation (DG) to dense urban networks, such as those in London, which face particular challenges in terms of the types of DG seeking connection and the network constraints that make connection difficult and expensive. Urban networks typically host CHP, diesel and small-scale PV, making the DG mix very different from rural areas, where wind and large scale PV predominate. The barriers to connection are most often associated with fault levels rather than thermal or voltage constraints. The Low Carbon London (LCL) project has explored these issues. As shown in Figure 8 below, the capacity now installed in LPN is around 1,250 MW, with a large proportion being diesel and Combined Heat and Power (CHP) plants. This represents slightly more than one fifth of the maximum demand. A combination of factors, including targets for 25% of energy in London to come from decentralised sources by 2025, means further growth in DG is expected.

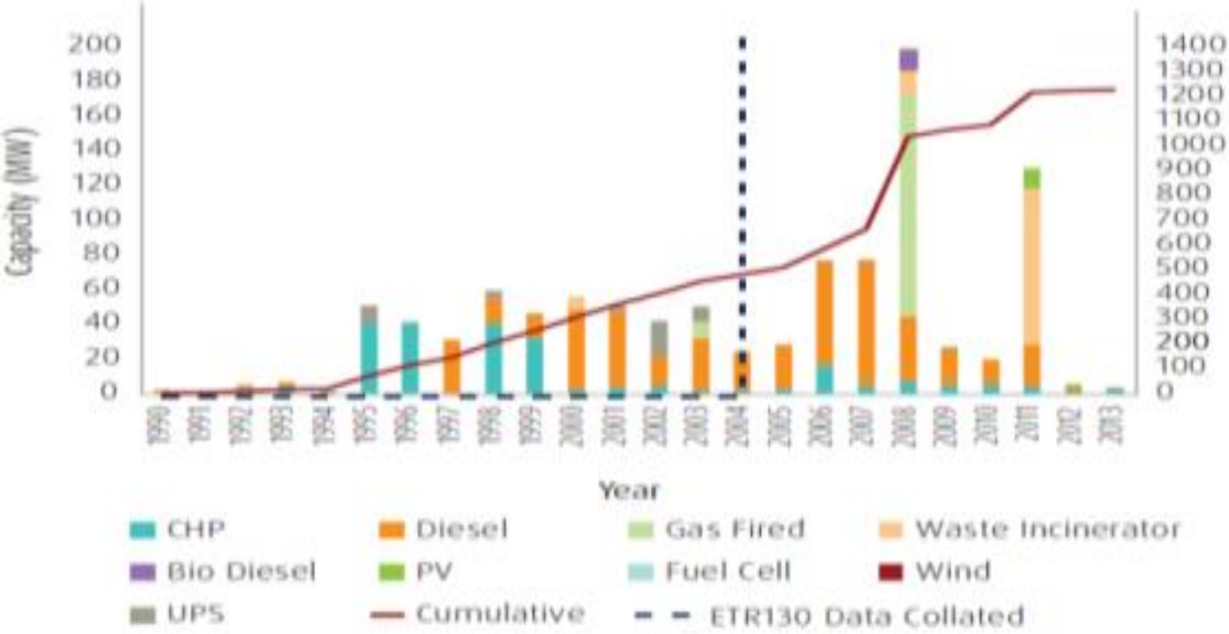


Figure 8 installed DG in London

The project looked in detail at how DNOs may consider the use of active and passive management of DG in the climate of significantly increased volumes making application for connection at both LV and HV network levels. Through significant levels of monitoring of DG plant connected to the network, LCL has contributed a significantly better understanding of the generation profiles in urban networks and their operating annual cycles. As discovered through the trials, having enhanced visibility could, potentially provide support to the network, and having control of the generation sites could potentially increase the security of supply.

Fault levels are a barrier to DG growth in urban networks rather than thermal or voltage constraints as found in more rural areas. The total installed DG capacity in the London Power Network (LPN) licence area is approximately 1,250 MW. A screening analysis of fault level constraints indicates that, based on the conventional approach, 58 out of 114 primary substations have no spare capacity and, where there is some headroom, the average acceptable new DG capacity is around 6.6 MW. This review confirms the experience of network planners at UK Power Networks, which is that fault level constraints in urban networks are the primary barrier to the connection of DG, and therefore a barrier to the achievement of goals in renewables and decentralised energy.

Active Network Management (ANM) can be used to facilitate DG connections in rural areas with thermal and voltage constraints, as other projects have demonstrated (such as Flexible Plug and Play (FPP), run by UK Power Networks). The screening analysis performed in these trials indicates that up to an additional 619 MW of DG could be connected across 88 primary substations, representing a significant increase in the total potential DG capacity in London. In the majority of cases, the role of ANM is to detect when the network is in an abnormal arrangement or temporary generation is connected, which means the new DG must be disconnected. This report describes how ANM can also be used in urban areas with fault level constraints to make available additional capacity for new DG based on recognising the additional fault level headroom created:

- By the difference between fault level headroom in intact and outage conditions; and
- When Short-Term Parallel (STP) is not connected – this is the case for the vast majority of the time.

ANM can help improve network visibility and controllability in general, which means network operators have more data and more options for improving network performance. ANM means DNOs have a greater level of flexibility in network development, making it easier to implement incremental changes such as the connection of a new generator. Of special relevance in areas of high demand growth such as London, ANM not only allows more DG to connect but can also enhance the contribution to security of supply made by new or existing DG. ANM can thereby help to reduce the overall costs of maintaining a secure network.

The LCL project sought to connect existing DG to ANM on the basis that it would have little impact on their operation but would release capacity for others. In practice, this was a difficult proposition that highlighted the need to engage with customers and other stakeholders early in the connections request process. There are a number of specific areas where early collaboration between DNOs and customer representatives will be beneficial, for example, clarity on technical requirements for ANM control from both a network and a customer perspective, to address fault constraints. Eventually, this will lead to the content and wording of connection offers, where DG customers who operate across multiple DNO areas would benefit from consistency of approach. Analysis tools and methods are already shared across DNOs and the new approaches developed to assess and quantify the benefits of ANM should be discussed and developed in collaboration with software providers and a community of users.

A Cost-Benefit Analysis (CBA) was performed to estimate the value of deferral of network reinforcement made possible by the connection of more DG. This exploits the potential of ANM to facilitate more DG connections and to provide a degree of control over DG that enhances its contribution to security of supply. The CBA was based on a subset of substations, identified through a review of existing plans for reinforcement and forecast demand growth in the London Network. By recognising that reinforcement could be deferred in 10 LPN substations out of the 88 with potential additional capacity under ANM, the CBA concludes that the NPV of gross network benefits could be £2.6m for a passive approach that connects more DG and uses more monitoring, or £8.7m for an active approach that uses ANM.

4.3 Electrification of heat and transport

Aims and objectives:
The central hypothesis was that the introduction of EV charging to existing distribution networks had the potential to add significant loading to the network, resulting in direct impacts on load flows and voltage profiles (the latter possibly breaching statutory limits). In addition, EV charging could coincide with existing peak network demand, providing a significant additional burden to the distribution network, and indeed the entire electricity supply chain. A further assumption was that some form of EV charging management would provide significant economic and carbon benefits. Similarly, the project proposed that the introduction of heat pumps in volume to properties connected to the electricity distribution network in London would be likely to add significant loading to the network, resulting in direct impacts on power flow magnitude and voltage profiles.

Outcomes:
The outcomes of the work are summarised in reports B1, B2, B3, B4 and B5, and reports D3 and D6. Imperial College set out the method by which the underlying load curves of EVs and public charge posts are calculated in report B1, whilst report B4 models heat pump load curves and their impact on substation load profiles. Report B2 then uses these to estimate implications for network investment. Report B5 carries out a market analysis of the most suitable methods for controlling EV charging for different market sectors and reports the results of direct control of charge posts, and of time-of-use tariffs. Report B3 examines both EVs and heat pumps from a power quality perspective. Finally, reports D3 and D6 put into context the potential financial benefits and carbon benefits over the coming decades of controlled EV charging and controlled electric heating, by examining the benefits relative to other “smart” techniques.

Previous studies into the impact of the electrification of heat and transport have modelled networks which were reasonable representations of the networks in GB and have used estimated profiles of both HPs and EVs in their base assumptions. Low Carbon London (LCL) has taken empirical data, derived by monitoring a substantial number of residential and domestic vehicles and HPs as part of the Project’s trials and examined the impact on actual networks in London. Based on this data, the project has been able to replace the representative networks and estimated load profiles used in previous work with a real network in South London and measure load profiles representing actual customer usage patterns as well as examining the impact of these new loads on power quality and provide evidence to support the previous anecdotal conclusions.

The project has also produced guidance on the impact of EV and HP loads on a distribution network and provides recommendations as to how to incorporate these into the forecasting, connections, planning and demand monitoring processes. A Cost Benefit Analysis (CBA) on the impact of a high uptake of EVs on required reinforcement spend across the distribution network was also undertaken. The trial outputs have validated UK Power Networks’ load forecasting projection processes and associated future planning activities; the same will apply to other DNOs. Both EV and HP loads are seen to have a minor impact on the overall network peak load for LPN and will impact the network at an LV feeder level. Of these two Low Carbon Technologies (LCTs), EVs are seen to be significantly less of an impact than HPs.

The effects on power quality from EVs and HPs could be pronounced where there is clustering of the load types. The identified significant contribution to low order harmonics could lead to high neutral currents, which would subsequently impact and influence LV network planning.

The new profiles developed for both EV and HP loads are considered to be an improvement on the existing modelled profiles used in load forecasting. It would be valuable to re-confirm the EV and HP load profiles with data from other Low Carbon Networks Fund (LCNF) projects, but both profiles should become part of the industry's standard tools and represents an advance on previous estimated or assumed profiles. It would also be progressive to ensure these profiles are updated with further modelling and trial results from the wider LCNF community.

Electric vehicles

The project found that the typical demographic profile of early adopters of EVs in London one of well-educated and affluent, with most being university-educated and either self-employed or in full-time employment. Most EV users are aged between 46 and 65 years of age and around 66% will primarily charge at home, using a 3kW home charge point to charge their EV and will charge their EV before it gets to less than 50% of charge remaining.

The measured load profile from EVs represents an additional 0.3kW contribution to residential peak demand per household, once averaged over 50+ households. This represents a significant increase on the current diversified residential peak load. EVs which are not for personal use, i.e. commercial vehicles have widely varying demand patterns depending on their purpose.

The profiles derived from the trial, using empirical data, were observed to be similar to the modelled profiles currently used in UK Power Networks planning tools. This validates the modelled profiles and has the effect of only minor dissimilarity between the load growth projections using the new set of derived profiles. The impact on London Power Networks' (LPN) load growth, across the distribution licence area, as a result of EV uptake (based on the UK Power Networks "accelerate" scenario) and applying the new LCL profiles, was shown to be minor in comparison to the effect of background load growth; with the contribution from EVs by 2050 to be 0.7% of the overall LPN load growth.

As EV uptake rises, there is an increase in the number of voltage violations with the additional EV load. However, it is anticipated that the majority of these will be fixed through local LV reconfiguration works, with only a handful of events triggering any investment works. Of the investment-triggering events, these would have occurred due to the background load growth and will need to be brought forward by 1 to 2 years due to the additional EV load. The EV charge point installation notification form developed by the Institution of Engineering and Technology (IET), or an equivalent, should be made mandatory to ensure that the DNO has visibility of where charge points are connected to the LV network. The trial showed that EV charging may cause a high harmonic current to flow on the network. This might be a consideration in the future when there is high uptake of EVs, particularly at clustered locations, with the effect of many EVs charging on the same feeder being manifest as distortions in the local supply network.

The EV charging CBA conducted in the project suggests that high EV uptake could lead to LV reinforcement spend increasing by a factor of four, relative to the current LV reinforcement spend of c. £1-2m p.a. across LPN. The analysis presented indicates that over time a high uptake of EVs could accelerate certain reinforcement investments, by increasing the peak load at primary substations. It is estimated that the NPV of the change in "Totex" resulting from the high uptake scenario presented in this report is £11,974k across LPN.

Heat Pumps

The new trial-derived profiles have a noticeably different pattern to that previously employed in UK Power Networks load growth modelling, particularly the overnight demand profile. The result is a flatter distribution of load over the day and a generally more uniform, less peaky aspect to its profile shape. This aligns more closely with anecdotal evidence from other trials that point to a more regular, load-flattened profile demand from heat pumps.

The anticipated impact of HP loads on the network was found to be minor; however, it was still significant and twice the expected contribution from EV charging. The contribution from HPs by 2050 is 3.6% of the LPN load growth, with non-domestic HPs being 2.4% and domestic HPs being 1.2% of load growth. HPs were found to contribute various levels of power quality disturbance, with different units having differing impacts. Using real network data, it was demonstrated that from the trial sample of HPs, a cluster of the “best performing” HPs showed no harmonic voltage distortions; however, the converse is true for the “worst performing” HPs. Further examination showed that an accumulation of HPs drawing significant harmonic current on local networks could lead to harmonic voltage distortion exceeding planning standard G5/4-1. Initiatives such as the ENA-developed HP installation notification forms should be mandatory to ensure that the DNO has visibility of where these units are connected to the LV network.

4.4 Residential and SME Demand Side Response

Aims and objectives:
The residential and SME sectors consume approximately half of the electricity produced in the UK. Reducing demand for electricity through energy efficiency and conservation measures, and decarbonising the electricity that is used by homes and workplaces is therefore essential to achieving both medium and long-term UK CO2 reduction targets. Over 75% of the energy that is used by UK homes is for space and water heating and meeting this demand accounts for 13% of the UK’s greenhouse gas emissions. Energy efficiency programmes are expected to bring benefits to the customer in terms of a reduction in energy bills and benefit to the wider UK due to a reduction in CO_2 emissions. It is also expected that energy efficiency will impact on electricity network power flows. LCL examines the impact of residential and SME energy efficiency and demand response programmes on the distribution network, by seeking to a) quantify the impact of conventional energy efficiency and conservation programmes on the residential and SME load profiles and network power flows in the trial areas and b) exploring the ability of price signals to shift demand for electricity by residential and SME customers to times that benefit distribution network operation. The shifting or management of electricity demand provides an opportunity to remove stress on the distribution network at times of peak demand, potentially avoiding or deferring the need for network reinforcement.

Outcomes:
The outcomes of the work are summarised in reports A1, A2, A3, A10, C2, and C3. Report A1 investigates if ToU tariffs and dToU tariffs in particular, offer benefits to the DNO, and if so, in what situations should the DNO deploy such tariffs, and what value is generated by their use. In addition it considers how such tariffs should be deployed and implemented and what level of customer uptake is required to ensure that the customer response meets the needs of the DNO. Imperial College’s Report A2 sets out to measure consumer’s willingness to engage with dynamic electricity pricing, while their report A3 analyses the residential/SME DSR trial in detail. The ICL report A10 examines the potential for DSR through optimisation of operation of domestic appliances. The report focuses on the ‘wet’ appliance category, including washing machines, dishwashers and tumble dryers. These appliances are responsible for a significant share of residential electricity consumption, while on the other hand offer best opportunities for demand shifting (unlike, for instance, lighting and entertainment loads).

Report C2 is another Imperial College report which quantifies the potential impact on peak demand in a typical section of a distribution network once domestic appliances are substituted with more energy-efficient alternatives. In order to develop planning assumptions, DNOs need to forecast the effects of energy efficiency measures as part of long-term demand forecasts, particularly the effects of replacement of appliances with more energy-efficient appliances. Most importantly, energy efficiency assumptions should be translated into impacts on peak demands, which represent the key input parameter for distribution network planning. Furthermore, impact on network losses should be considered given that the largest proportion of network losses is in Low Voltage (LV) networks.

Finally, report C3 is a DNO-focused report which outlines a higher resolution approach for evaluating the network impacts resulting from a range of possible domestic lighting and appliance energy efficiency improvements both at the household level and at scale for various future scenarios. This approach makes use of the comprehensive new smart meter and appliance ownership data collected in the Low Carbon London (LCL) project along with the latest data on appliance sales trends, efficiency performance and applicable legislation. The potential lighting and appliance energy efficiency savings quantified in this report are specific to various household types and, as such, can be applied to any geographic region within Great Britain, allowing Distribution Network Operators (DNOs) to apply the findings and methodology in this report to their specific networks. The possible reductions in future loads, and hence potential network reinforcement deferral, arising from improving lighting and appliance energy efficiency are also compared to the load reductions observed for static and dynamic Time of Use (ToU) tariff trials in Great Britain.

Residential Findings

In the residential dToU trial, consumers were incentivised to change their electricity consumption in reaction to changes in the electricity tariff. Over the trial year, 95% of households saved money relative to what they would have spent had they been on the standard flat tariff of the non TOU group. A household engagement ranking metric was developed to allow the stratification of results by responsiveness to the different price bands. In Figure 9 below (see also LCL ICL final report A3), the relationship between the responsiveness ranking and the mean observed demand response across all trials is illustrated. The panels depict the response to high (left), mid (centre) and low (right) price signals respectively, and each dot represents a single household. We expected a negative kW response on the chart (i.e. consumers turning-down or choosing not to use appliances) to the high price signal, no changes to the default price, and a positive kW response (i.e. consumers re-scheduling laundry cycles and energy usage) to the low price. The results show a large variance across the group, but the key outcome is that the high price response available from residential households is 56W of load reduction available during winter, which drops to 34W (or 0.034kW) during summer standard flat tariff of the non-ToU group.

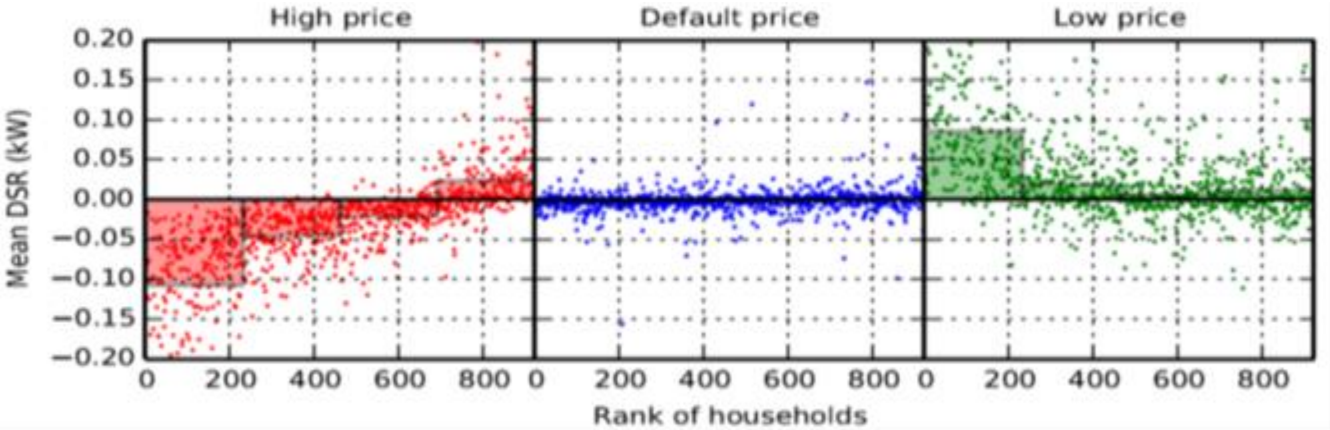


Figure 9 Responsiveness & mean DSR (see also Imperial College report A3)

Customer attitudes to Time of Use tariffs

In light of the LCL dToU trial being the first of its kind in the UK, as well as being one of the largest ToU trials to date in the UK, it was important to understand how receptive customers were to the trial. As well as measuring the response that could result from a dToU trial, analysis was therefore also performed seeking to understand customer's attitudes to the tariff. This analysis is presented in Low Carbon London Report A2. The analysis performed was largely based upon the survey data mentioned above, which was collected from most of the trial population, and 37 in-depth customer interviews. The objective of the survey and the interviews was to understand both the experience of households on the tariff and to understand better the observed patterns of demand response.

Table 7 below lists a number of positive statements about the dToU trial, and the percentage of survey participants that either agreed or disagreed to these statements. The responses shown indicate that the trial participants responded very positively to this set of statements on the tariff. Interestingly, the responses even indicate that trial participants did not view the tariff as too complex, which might have been expected to be a concern.

Table 7 attitudes to dToU tariffs

Positive statement on dToU tariff	% agree or strongly agree	% disagree/strongly disagree
Greater sense of control	71	24
Worth the hassle	67	28
Enjoyed some aspects	55	39
No reduction in quality of life	75	19
Do not find tariff complex	79	16
Effort sustainable long term	79	15
Good for motivating us to get chores/activities done	80	7
Helped planning/organising/remembering activities/chores	77	10
Taught young about the cost of energy	71	14
We miss some things about being on dToU	53	13
Some practices persisted beyond the end of the trial	70	30
Reduced overall energy consumption	63	30

Positive statement on dToU tariff	% agree or strongly agree	% disagree/strongly disagree
Renewables link would make me more likely to sign up	59	32
Renewables link would make me more likely to adapt behaviour	60	31
Would want to stay on dToU	77	18
dToU should be offered to everyone	91	5
dToU should be the standard tariff for everyone	81	14

The survey also collected data on the customer's appliances for which load was most commonly shifted. Load from wet appliances (e.g. washing machines etc.) was reported to be the easiest to shift, with lighting, cooking, and showering load being the least flexible load. This is supported by findings set out in Figure 10 below (see also LCL Report A2), which shows the appliances where households reported the most flexibility in reducing load in response to a high price. Responses were very similar when trial participants were asked which appliances were used more in response to low price periods.

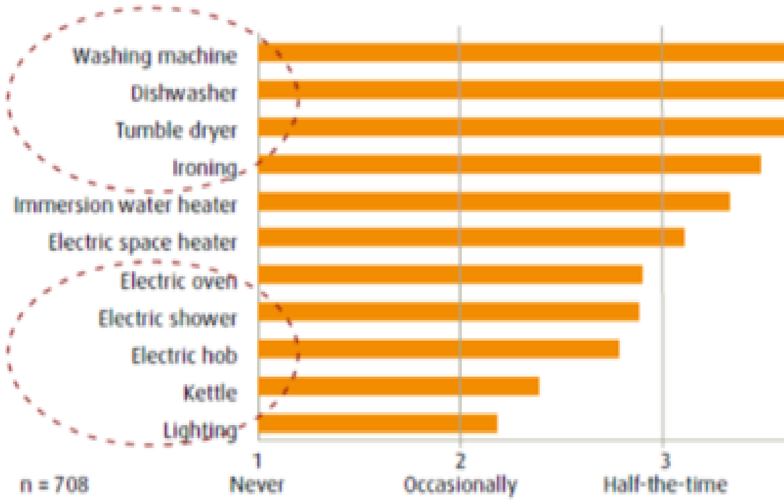


Figure 10 Flexible household loads

In most cases, the reported flexibility in the use of different appliances is related to the extent to which use of a given appliance is subject to a fixed routine (shown below in Figure 11 – also see LCL Report A2). For example, dishwashers are reported as being flexible, and are also reported as not being subject to a fixed routine. Conversely, lighting is reported as being inflexible, and also as being subject to a fixed routine. There are some exceptions to this general rule. Kettle load is reported as being inflexible, but is also not subject to a fixed routine.

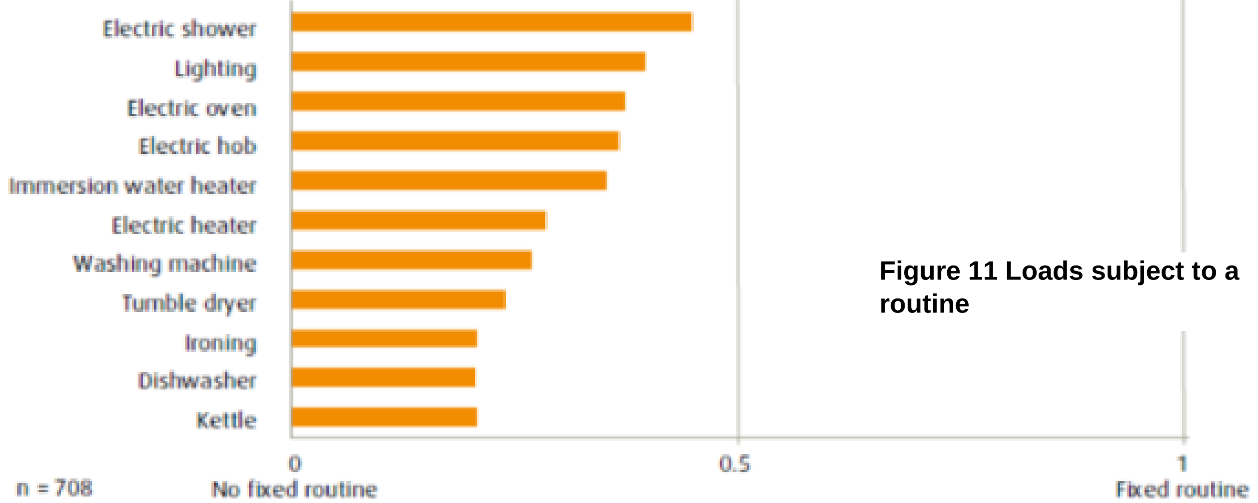


Figure 11 Loads subject to a routine

Main dToU trial findings

The trial's findings can be summarised as:

a) The introduction of smart meters facilitates Time of Use pricing, but to date such initiatives in GB have been driven by wholesale price benefits. The potential to reduce peak demand and shift load using ToU pricing has potential benefits for stakeholders across the value chain. However, most ToU tariff initiatives in GB have, to date, been led by energy suppliers, and based on potential wholesale cost savings rather than on the potential network benefits;
b) ToU initiatives in GB have been focused on static tariffs; this project is the first time a large scale dynamic ToU domestic tariff has been tested in GB;
c) If a dToU response were effective, reliable, and sufficient, it could potentially be used to defer the need to carry out reinforcement works on the distribution network. A response could also be used to help manage any capacity shortfalls in a particular network area. Customers on dynamic ToU tariffs might provide a response during a network outage. For example, if there is a capacity shortfall ahead of scheduled reinforcement works. The tariff tested through the Low Carbon London trial was the first to be designed to evaluate the benefits to both suppliers and the DNO;
d) There are challenges in realising DNO benefits from wholesale price-driven ToU initiatives. ToU tariffs rolled out by suppliers are likely to target either "traditional" peak hours through a supplier ToU tariff, or to be focused on periods with high wholesale prices. However, the peak hours that a DNO would benefit from being targeted vary by network location. Where the hours targeted coincide with the network peak then the network peak could be reduced. However, this does depend on high uptake of tariffs with a consistent specification across multiple suppliers. The analysis performed suggests that the potential to reduce demand using wholesale price-driven dToU tariffs is less than the sToU tariff, because the drivers of local network peaks are often not coincident with the drivers of peak wholesale power prices at a national level. A tariff targeting the top 5% of wholesale prices is shown to have the potential to reduce peak load at only 4 substations out of a sample of 19. Ideally, the DNO would require high prices to be targeted at periods when local network peaks occur, and only at substations that have no spare capacity;
e) The trial results suggest that on average dToU customers provided a response of c. 50W, and that the best responders provided a response of three times this size;
f) Customers appear to be keen to participate in Time of Use tariffs;
g) Cost-benefit analysis has been performed to evaluate the potential for a dToU tariff in case study areas, showing that a mandated ToU price signal would be required to achieve a sufficient response to realise network benefits;
h) Case study analysis suggests that £25/customer of benefits might be available through deferring reinforcement using dToU price signals at some substations, before the full costs of implementing such a tariff are taken into account;
i) Under existing market arrangements the network benefits that can be realised by GB DNOs as ToU tariffs are rolled out are likely to be minimal;
j) In future, the business case for DNO applications of dynamic ToU tariffs might be revisited, if at least some of the following criteria were met;
k) Uptake of dToU tariffs is close to 100%, and these customers are willing to sign up to dToU tariff specifications that meet DNO needs;
l) Regulation allows for cross-supplier coordination of DNO ToU price events;
m) In-home automation leads to higher levels of response – this could increase viability with a lower uptake;
n) Other stakeholders (e.g. the SO) are also able to apply ToU price signals through the tariff and customers are receptive to a higher number of high price events to accommodate multiple stakeholders; and
o) Suppliers already have dToU-ready billing systems in place such that the incremental costs to suppliers of administering such a tariff were negligible.

The project has also contributed to understanding that the dToU structure is multi-purpose, allowing multiple parties in the energy chain, including suppliers, to call off independent events. This will also be critical to establish a viable business case for time of use tariffs, once smart meters are rolled out, across the full energy chain.

4.5 I&C Demand side management

Aims and objectives:

The trial sets out to investigate the ability of commercial aggregators to provide demand response services tailored to the requirements of distribution networks through the control of I&C customers' demand. The services to be trialled provided varying magnitudes of demand response, over different time periods associated with specific LCL trial network locations. The project established multi-lateral DSR commercial arrangements with I&C customers, aiming to significantly reduce demand that is at risk from planned or unplanned network outages. The ability of I&C DSR to meet pre-fault and post-fault loading limits on the distribution network was also explored. It demonstrated the effectiveness of DSM of I&C customers as a tool available to DNOs to defer or avoid network reinforcement.

Outcomes:
The outcomes of the work are used to review and make recommendations regarding Engineering Recommendation P2/6 and the methods and modelling undertaken in ETR 130 and are summarised in reports A4, A5, A6 and A7. Report A4 outlines a robust deployment strategy for how DNOs can utilise DSR services in order to defer capital expenditure or to manage network constraints during construction and maintenance outages. This approach has been validated through real-world experience within the Low Carbon London (LCL) project and includes consideration of the risk weighted contribution of DSR to network security, compliance with the philosophy of the current network security standards (ER P2/6 and ETR130) and the DSR capabilities available from the I&C customer market. The report also demonstrates that the deployment of DSR has the potential to deliver financial benefits to both customers and DNOs and to provide network planning and control engineers with a new option to manage network constraints.

Report A5 presents the findings from the I&C DSR trials and considers the conflicts and synergies that may occur with existing and future market actors, through to 2030. Its key findings are that there is currently no commercial and market framework to optimise the value of DSR to various parties in the market in Great Britain (GB). The analysis has shown there are a number of potential conflicts and synergies in the use of DSR at both national and local levels. Conflicts arise when more than one party (the System Operator (SO), Distribution Network Operator (DNO), or Supplier) targets the same DSR provider and there is insufficient capacity to service the multiple requests. Synergies arise when the same demand is targeted by more than one party and there is sufficient capacity to service all requests. In particular, two important insights have been generated through the analysis:
a) there is a greater proportion of conflicts when information/dispatch is not shared between parties (information/dispatch sharing leads to a 60% to 85% decrease in conflicts depending on scenario and modelled year); and
b) the conflicts are much more significant in volume from the DNO's perspective (20% of the time) compared to the Transmission System Operator (TSO)'s perspective (1% of the time).

Report A6 examines the relative values of benefits that will motivate different buyers of DSR services and how the differences in DSR programmes will impact the distribution network, whilst report A7 is a report from Imperial College sets out to understand and characterise the performance of DSR services within the distribution network, in order to inform future smart distribution network operation and planning.

I&C DSR trials

Low Carbon London has pioneered the development of formal contractual arrangements for the provision of generation-led and demand-led demand side response (DSR) services to the DNO. The trials set out to understand and characterise the performance of I&C DSR services within the distribution network, in order to inform future smart distribution network operation and planning. The I&C DSR trials exercised both genuine demand-led and generation-led DSR and were designed to relieve network congestion at peak. By measuring compliance it was found that, for the most part, the resources performed as requested. Generation-led DSR was found to deliver 95% of the requested response for 30% of summer 2013 and winter 2013/14 events, and demand-led DSR was found to deliver 95% of the requested response for 48% of these events.

Considering generation-led DSR alone, performance was significantly better in summer than winter with sites delivering 95% of the requested generation in 42% of summer events, but only 18% of winter events. Similar 95% compliance figures for demand-led DSR are 62% for summer and just 8% for winter. The small winter figure may be driven by the lack of chiller load in winter and the predominance of gas in heating of buildings. Within the Low Carbon London trials, events were triggered in one of two ways: (1) in the first case, events were triggered manually, to simulate a control engineer reacting to existing SCADA alarms and then telephoning the demand-side aggregator or an individual site to trigger an event; (2) dedicated SCADA alarm was generated which was immediately shared with the aggregator or an individual site in order to request a response. The control engineer was notified rather than expected to intervene. This second case was enabled by 'Active Network Management (ANM2)' equipment. ANM triggered calls delivered the requested response for 86% of events, phone triggered calls, 93%.

The number of events trialled at each site was quite small and no site stood out as having a particularly poor response to calls. For these reasons it is not possible to differentiate between individual sites in terms of response to calls. The majority of events started on time or early, which is re-assuring for the DNO's considering DSR as a tool for managing network capacity. As expected, the ANM triggered events were somewhat timelier. Compliance for ANM triggered events during winter events was much worse on average than it was during the summer trials.

Trials included 11 hotels and these responded to calls to turn down during summer 2013 and winter 2013/14 in 83% of events - lower than average. Late starting was also a problem with 15% of these events starting late. However, the ability to maintain the required level of turn-down was much better than average, with this achieved in 78% of events.

Existing practice does not recognise the phenomenon of payback (or 'take-back'). Payback was, in fact, observed in most demand-led DSR events in the trials, producing sharp peaks that, in the case of the hotel sector, varied between 15% and 270% of the pre-event load. The amount of energy recovered during payback was wide-ranging, but quite small on average, showing that as much as 80% of energy demand was curtailed during events. It was also found that there was a good correlation between the payback peak height and maximum demand-led DSR turn-down for the hotel sector. The level of payback may therefore be predicted, within limits, for a given turn-down. Figure 12 below illustrates this phenomenon in practice (see also LCL ICL final report A7).

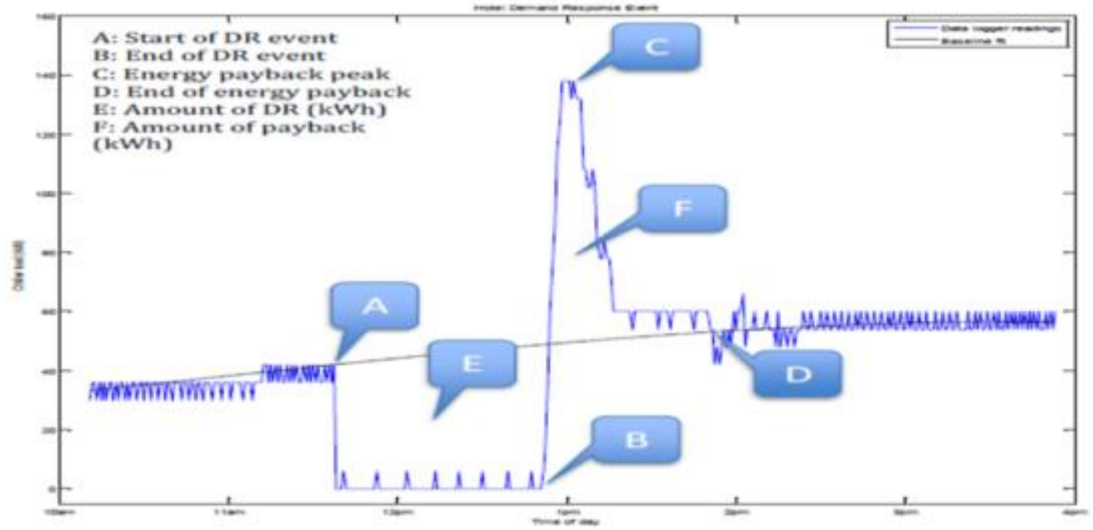


Figure 12 Demand led pay-back in hotels

Finally, a qualitative analysis of barriers to participation in DSR was made. It was found that the most significant barriers related to negative perceptions of potential risks to comfort and service levels, as well as fears around costs, time, equipment and other resources. These negative perceptions were found to outweigh technical and financial barriers to participation.

During the LCL trials UKPN contracted DSR services from several customers. Some provided DSR through generation facilities (such as CHP sites with sufficient technical and commercial flexibility, or backup diesel generators) while other customers provided the service through a 'turn-down' arrangement where they reduced their electricity demand on request. Although the trials were focused on understanding the reliability of DSR provided by each of these customers, there were examples in which real network constraints were managed with DSR.

The reliability of DSR facilities was evaluated using a methodology for assessing the contribution of DSR to security of supply, resulting in a new set of reliability factors, or 'F-factors', presented in Figure 13 below, derived using a similar approach to the Energy Network Association's technical report ETR130. These factors represent the ratio of the capability of DSR to the rated capacity of DSR and will provide DNOs an understanding of the amount of 'over-procurement' likely to be required to ensure the necessary response will be delivered.

DSR Type	Number of DSR facilities									
	1	2	3	4	5	6	7	8	9	10
Diesel	70%	72%	75%	77%	78%	79%	79%	80%	80%	81%
CHP	69%	72%	74%	76%	77%	78%	78%	79%	79%	80%
Demand Reduction	54%	58%	61%	62%	62%	63%	63%	63%	63%	64%

Figure 13 F-factors for DSR types

To maximise the potential DSR response, DNOs should seek to contract DSR services from as many sources as possible. For example, both demand and generation-led sources of DSR should be considered. Early customer engagement is required for DNOs to make DSR deployment decisions. These decisions will be based on the level and type of response that could potentially be contracted at each substation. This is especially important because DSR providers must be connected to the substation in question in order to provide capacity services.

I&C DSR conflicts and synergies

The project assessed the conflicts and synergies of I&C DSR based on the real-world experiences encountered in the trials. There is currently no commercial and market framework to optimise the value of DSR to various parties in the market in Great Britain (GB). The analysis has shown there are a number of potential conflicts and synergies in the use of DSR at both national and local levels. Conflicts arise when more than one party (the System Operator (SO), Distribution Network Operator (DNO), or Supplier) targets the same DSR provider and there is insufficient capacity to service the multiple requests. Synergies arise when the same demand is targeted by more than one party and there is sufficient capacity to service all requests. There is a greater proportion of conflicts when information/dispatch is not shared between parties (information/dispatch sharing leads to a 60% to 85% decrease in conflicts depending on scenario and modelled year); and the conflicts are much more significant in volume from the DNO's perspective (20% of the time) compared to the Transmission System Operator (TSO)'s perspective (1% of the time). Figure 14 below illustrates this situation and forecast the conflict and synergy trends to 2030.

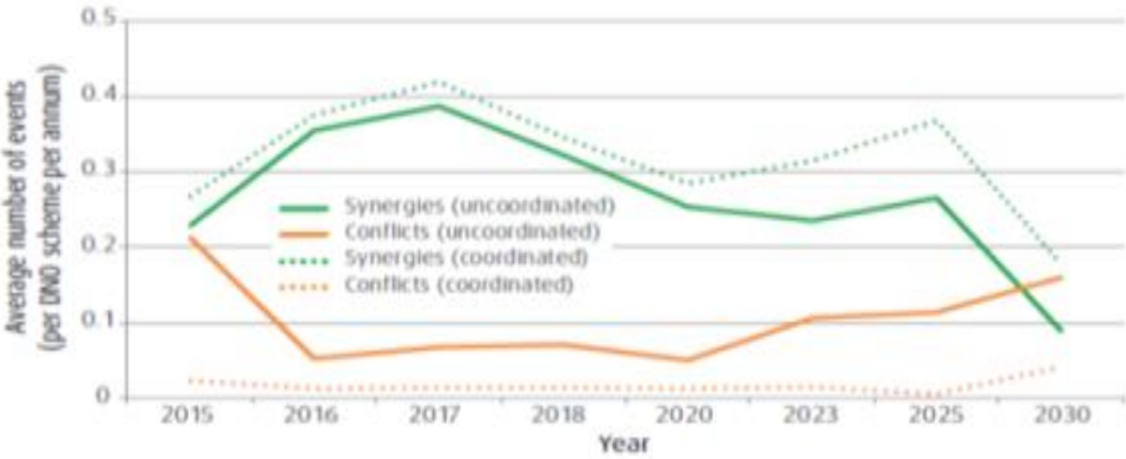


Figure 14 I&C DSR conflicts and synergies

Increased electrification, accompanied by the intermittency of many sources of low-carbon electricity and the challenges of decarbonisation, contribute to the need for additional operational flexibility. This in turn increases the use of DSR by multiple parties to efficiently match supply and demand in a low-carbon world. Low Carbon London has demonstrated that DSR can be implemented to successfully deliver financial benefits to both customers and the DNO. In addition, DSR provides planners and control engineers with another option to mitigate network constraints. The experience and findings from LCL have allowed UK Power Networks to adopt DSR as a business as usual activity. This has culminated in savings within the 2015 RIIO-ED1 business plan submission of £12m across the LPN licence and a total of £43.5m across all three of UK Power Networks' licensees during the period.

4.6 Wind twinning

Aims and objectives:

The UK Renewable Energy Strategy sets a goal of 34GW of wind generation to be available in GB by 2020. The intermittent and variable nature of wind energy will therefore impact at a national system operation level where there is likely to be a requirement for capacity reserve and balancing should renewable generation output deviate significantly from short-term forecast values. This trial investigated the ability of demand to follow local and national wind energy production and the corresponding impacts on distribution networks were identified and explored.

The twinning of demand with wind generation was trialled in two scenarios, a) a day ahead ToU wind twinning tariff, which was designed and offered within the dToU tariff trial to residential and SME participants, through specific pricing sequences, timings and durations of high and low tariff rates. This ToU tariff provided an incentive for customers to plan their use of non-time-of-day (or time-of-week) critical electrical appliances to coincide with times when the wind energy output would be expected to be high; for example by using washing machines and tumble driers on windy days. The second scenario focused on I&C customers in DSR contracts and tested the ability for them to provide localised demand response triggered by measured drops in wind generation, triggered on data and signals provide by Elexon and passed through to demand aggregators for action.

Outcomes:
The residential/SME wind twinning outcomes are described in report A1, which describes a number of ”wind twinning” events that sought to incentivise demand to follow supply (Supply Following (SF) events). These events included single high or low price events with a range of durations. The events were intended to evaluate the response available from customers as the output from intermittent generation fluctuates, and are most relevant to energy suppliers seeking to match their contracts with generators with customer demand. A combination of both high and low ToU prices were used to encourage customers to shift load away from periods where there is a shortfall in the supply of power to periods where there is surplus supply of power (e.g. periods of high wind generation). These events were demonstrative of the principle of “wind twinning”. While such events are likely to be correlated with the wholesale price-driven tariffs discussed earlier, they are not necessarily the same thing. The motivation for a SF tariff may partly be wholesale prices, but may alternatively be a reduction in exposure to intra-day markets or imbalance, or an operational constraint being managed by the System Operator.

The I&C wind twinning response is described in two reports A6 and A7. Report A6 examined the relative values of benefits that will motivate different buyers of DSR services and how the differences in DSR programmes will impact the distribution network. Report A7 set out to characterise the performance of DSR services, including wind twinning triggered DSR calls, within the distribution network, in order to inform future smart distribution network operation and planning.

5. Performance compared to the original aims of the project

Low Carbon London was an ambitious project with both a broad and deep scope. The scope included technical, commercial and social challenges with a mix that in many ways reflects the increased complexity and diversity of agents and actors operating in the evolving context of smart grids and carbon reduction in a large metropolis such as London. Due to the multi-faceted nature of the network, London has proved to be the ideal test bed for such a project. The city and Greater London area has the highest concentrations of electricity demand and CO_2 emissions in Great Britain, and the most demanding carbon reduction targets (60% reduction on 1990 levels by 2025). However, the trials and associated findings were designed in such a way as to be relevant and applicable to other urban networks across Great Britain, as well as being relevant to all major urban centres globally. The mix of partners involved in the project reflected the need to take an end to end energy supply chain perspective on smart grids in London.

The original aims of the project were articulated through four SDRC phases:

a) Build phase;
b) Initial trial phase;
c) Trial conclusion phase; and
d) Conclusion of final analyses.

Financially the project met its in-project benefits case, delivering £1.5m of network reinforcement savings through the successful application of I&C DSR at Ebury Bridge substation. The project’s findings also enabled a robust refresh of the business case to 2050. Finally, LCL completed all its objectives under budget, enabling a further £4.8m to be returned to LPN customers.

All SDRC were met within the required timescales. The expanded SDRC framework together with an explanation of how the project met all the individual SDRC evidence items is set out in Appendix 9.

5.1 Build phase

The build phase of the project was subdivided into three sub-phases:

a) “Preparation of solution implementation” for completion Q3 2011, comprising:
   - Logica smart metering Head End solution and Learning Laboratory commissioned; and
   - Complete preparation for c.5000 smart meter roll out, including address selection, acceptance surveys, privacy and security measures (working with GLA and Consumer Focus).
b) 1st stage of solution implementation for completion Q2 2012, comprising;

- Operational Data Store and interface to Logica head end commissioned; and
- Smart meter installation underway and "carbon impact tools" delivered.

c) Final stage of solution implementation for completion Q4 2012:
- Operational Data Store and interface to Logica head end commissioned; and
- Smart meter installation completed.

The build phase of the project occupied much of the activities in the initial 18 months. The solution preparation work completed by September 2011 saw significant effort going into the planning, engagement and recruitment of the pilot 500 residential/SME smart meter customers, despite being hampered by uncertainty about SMETS-compliant meter availability. The project has also reached agreement with two of its partners, Logica (CGI) and Siemens, for them to each establish a Low Carbon London learning and demonstration hub within their own facilities, to promote the project and its learning outcomes. These also served as test and pre-commissioning facilities to test the ODS and meter head-end data and communications interfaces. The Low Carbon London Learning Lab was successfully opened on schedule in September 2011, with a formal opening ceremony performed jointly by Basil Scarsella, CEO UK Power Networks, and Professor Goran Strabac of Imperial College London.

At this stage in the project, rumours of potential delays in the availability of a SMETS-compliant meter were first being mooted and the physical start of the pilot 500 smart meter deployment was delayed awaiting clarification on this. Eventually, in October 2011 a decision was taken to start the pilot exercise albeit with a non-SMETS meter, in the anticipation that a SMETS-compliant meter would be available for the main meter deployment. This delayed start meant that both the pilot and main meter deployment exercises were carried out successfully but in very tight windows to meet deadlines, with much weekend and out of hours work undertaken to install meters successfully in time for the Q2 2012 deadline. Once the pilot exercise was given the go-ahead, a comprehensive campaign, which had been readied and prepared in advance of the pilot scheme, was implemented immediately, encompassing targeted telephone recruitment, day and evening Low Carbon Zone local community drop-in centres supported by internet and postal campaigns.

Internally, in late 2011, a UK Power Networks low carbon business champions' forum was established to provide a focal point and platform for learning and discussion on the efficient sustainable distribution of low carbon electricity. An engineering governance group was also been created to bring together the Company's engineering community and provide a focal point for both the project and business as usual departments on smart grid and low carbon electricity distribution matters.

The first stage of the project solution implementation phase was completed on time by 30 June 2012. The testing of production release of the Operational Data Store (ODS) completed in May 2012 and by June 2012 nearly 4,000 smart meters had been installed with access to data from a further 500 smart meters commissioned and transferring data between the head-end and the ODS. The winter 2011-2012 I&C demand response trials completed and the summer I&C demand response trials commenced by end of June 2012. The project had developed a multipartite demand side response contract with two demand aggregators and both were in active use as part of the summer 2012 I&C DSR trials. Extensive dialogue was underway with National Grid, to identify conflicts and synergies in the operation of a demand response contract involving National Grid, but progress was slow due to the complexities involved. At this same time a cross-DNO-National Grid initiative was started encompassing this and other relevant scope, so the project took an active role in those meetings and discussions. The first CO_2 impact assessment reports were also completed by the end of June 2012.

The final stage of solution implementation was finished successfully by 31 December 2012. Deployment and installation of trial execution hardware, network monitoring and instrumentation equipment occupied much of the final months of this phase, including 30 secondary network substations in the Engineering and Instrumentation Zones (EIZs), as well as monitoring equipment at customers' premises and within customers' own low carbon installations. In addition, central control and monitoring systems have been installed within primary substations, along with Remote Terminal Unit Upgrades to 10 substation sites, and upgrades to network control applications such as ENMAC/Power-On Fusion. The ODS-head-end interface was fully commissioned and operational, with over 5,800 meters installed with EDF Energy customer by December 2012. Recruitment for the dToU trial was nearing completion, ready for the trial to start in earnest in January 2013.

This time period in the project also saw the work undertaken to prepare and submit the change request to Ofgem along with the preparatory work to create the three Engineering Instrumentation Zones, install monitoring and instrumentation equipment in over 30 primary substations and secure commitments on external heat pump data sources.

5.2 Initial trial phase

The initial trial phase sought to establish the mechanism for initial smart meter data collection and was to complete by Q2 2012:

- Implementation of initial trials based on data from the initial smart meters and half hourly industrial & commercial (I&C) customer meters with analysed results, for completion Q2 2012.

This initial trial phase, despite being subject to a delayed start due to uncertainties over SMETS meter availability, was completed on time with data from the pilot 500 residential/SME meters being collected by the head-end system and successfully transmitted to and stored in the ODS. It should be noted that at this time in the project the intention was to incorporate a SMETS meter into the smart meter trials should one have become available in time (which subsequently did not happen). In February 2012 the project held an event to present the learning and findings from the initial smart meter deployment and in May held a further event to both present the findings from the winter 2011/12 demand response trial and outline the rest of the project's activities in the I&C demand response sector.

5.3 Trial conclusion phase

This phase was to carry out and complete all the main trials of the project by Q3 2014.

a) Conclusion of "Using Smart Meters and Substation Sensors to Facilitate Smart Grids" trials, comprising;
    a. Understanding customer behaviour and potential network impact;
    b. Use of smart meter information to support distribution network planning and design; and
    c. Use of smart meter data to support network operations.
b) Conclusion of "Enabling and Integrating Distributed Generation" trials, comprising:
    a. Facilitating connections to LV and HV distribution networks;
    b. Active management of DG to address security of supply concerns and postpone network reinforcement; and
    c. Exploring the impact of LV, G83 connected generation.
c) Conclusion of "Enabling Electrification of Heat and Transport" trials, comprising:
    a. Exploring impact of electric vehicle charging; and
    b. Exploring the impact of heat pump demand.
d) Conclusion of "Residential and SME Demand Side Response" trials, comprising:
    a. Energy efficiency programmes and technologies; and
    b. Consumer behaviour demand response and responsiveness to TOU tariffs" trials.
e) Conclusion of "I&C Demand Side Response" trials, comprising
    a. Demand side response with I&C customers; and
    b. Demand side response conflicts and synergies.
f) Conclusion of "Wind Twinning" trials, comprising:
    a. Wind twinning through ToU tariffs with suppliers; and
    b. Wind twinning through responsive demand contracts with commercial aggregators.

This phase represented the bulk of the project's substantive work, covering the full year of the smart meter and dToU trials for over 4,500 and 1,000 residential and SME customers respectively. The project has produced a comprehensive set of final reports that describe the work undertaken and the results obtained across all the trials. The following table identifies the relevant reports against the SDRC sub-phases a) to f) above, together with the respective project direction SDRC evidence references.

Table 8 - SDRCs and outputs - project trials conclusion phases

SDRC	Project direction SDRC evidence references	Relevant LCL final reports
Conclusion of "Using Smart Meters and Substation Sensors to Facilitate Smart Grids" trials: • Understanding customer behaviour and potential network impact • Use of smart meter information to support • distribution network planning and design • Use of smart meter data to support network operations **Complete Q3 2014**	1-1 Accessibility and validity of smart meter data 2-1 Network state estimation and optimal sensor placement 2-2 Accessibility and validity of substation sensor data DNO learning report on the use of smart meter information for network planning and operation	LCL Report C5 – Accessibility and validity of smart meter data LCL Report C4 – Network state estimation and optimal sensor placement LCL Report C6 – Accessibility and validity of substation sensor data LCL Report C1 - Use of smart meter information for network planning and operation
Conclusion of "Enabling and Integrating Distributed Generation trials: • Facilitating connections to LV and HV distribution networks • Active management of DG to address security of supply concerns and postpone network reinforcement • Exploring the impact of LV, G83 connected generation **Complete Q3, 2014**	3-1 Impact of LV connected DER on power quality 4-2 Impact of LV DERs on network utilisation 7-1 Opportunities for DG in the distribution network DNO learning report for DG addressing security of supply and network reinforcement requirements DNO learning report for facilitating DG connections	LCL Report B3 - Impact of Low Voltage – connected low carbon technologies on Power Quality LCL Report B4 - Impact of Low Voltage – connected low carbon technologies on network utilisation LCL Report A7 – Distributed Generation and Demand Side Response services for smart Distribution Networks LCL Report A8 – Distributed Generation addressing security of supply and network reinforcement requirements LCL Report A9 - Facilitating Distribution Generation connections
Conclusion of "Enabling Electrification of Heat and Transport trials Exploring impact of electric vehicle charging Exploring the impact of heat pump demand **Complete Q3, 2014**	3-1 Impact of LV connected DER on power quality 5-1 Impact of opportunities for wide-scale electric vehicle deployment 4-2 Impact of LV DERs on network utilisation DNO learning report on the impact of EV and HP loads on network demand profiles DNO learning report on opportunities for smart optimisation of new heat & transport loads	LCL Report B3 - Impact of Low Voltage – connected low carbon technologies on Power Quality LCL Report B1 - Impact and opportunities for wide-scale Electric Vehicle deployment LCL Report B4 - Impact of Low Voltage – connected low carbon technologies on network utilisation LCL Report B2 - Impact of Electric Vehicles and Heat Pump loads on network demand profiles LCL Report B5 - Opportunities for smart optimisation of new heat and transport loads

SDRC	Project direction SDRC evidence references	Relevant LCL final reports
Conclusion of "Residential and SME Demand Side Response trials • Energy efficiency programmes and technologies • Consumer behaviour demand response and responsiveness to ToU tariffs" trials **Complete Q3, 2014**	6-1 Residential consumer attitudes to time varying pricing 6-2 Residential consumer responsiveness to time varying pricing 6-4 Smart appliances for residential demand response 4-1 Impact of energy efficient appliances on network utilisation DNO learning report on network impacts of energy efficiency at scale DNO guide to residential DR for outage management and as an alternative to network reinforcement	LCL Report A2 – Residential consumer attitudes to time varying pricing LCL Report A3 – Residential consumer responsiveness to time varying pricing LCL Report A10 Smart appliances for residential demand response LCL Report C2 - Impact of energy efficient appliances on network utilisation LCL Report C3 – DNO Learning Report on Network impacts of energy efficiency at scale LCL Report A1 – Residential Demand Side Response for outage management and as an alternative to network reinforcement
Conclusion of "I&C Demand Side Response trials • Demand side management with I&C customers • Demand side management conflicts and synergies **Complete Q3, 2014**	7-1 Distributed generation and demand response services for the smart distribution network DNO guide to I&C DR for outage management and as an alternative to network reinforcement Conflicts and synergies of DR DNO impacts of supply-following DR report	LCL Report A7 – Distributed Generation and Demand Side Response services for smart Distribution Networks LCL Report A4 – Industrial and Commercial Demand Side Response for outage management and as an alternative to network reinforcement LCL Report A5 – Conflicts and synergies of Demand Side Response LCL Report A6 - Network impacts of supply-following Demand Side Response report
Conclusion of "Wind Twinning trials • Wind twinning through ToU tariffs with suppliers • Wind twinning through responsive demand contracts with commercial aggregators **Complete Q3, 2014**	7-1 Distributed generation and demand response services for the smart distribution network DNO impacts of supply-following DR report	LCL Report A1 - Residential Demand Side Response for outage management and as an alternative to network reinforcement LCL Report A7 - Distributed Generation and Demand Side Response services for smart Distribution Networks LCL Report A6 - Network impacts of supply-following Demand Side Response report

5.4 Conclusion of final analyses

This final phase of the project completed by the end of Q4 2014 and comprised two elements:

a) New network design and operational practices; and
a) New network planning and operational tools.

The following table sets out the SDRCs, project direction evidence and the project outputs for this final phase of the project.

Table 9 SDRCs and outputs - final analyses phase

SDRC	Project direction SDRC evidence references	Relevant LCL final reports
Conclusion of final analyses: • New network design and operational practices • New network planning and operational tools **Complete Q4 2014**	11-1 Design of smart distribution networks 11-2 Resilience performance of smart distribution networks 12-1 Novel commercial arrangements and the smart distribution network 14-2 Carbon impact of smart distribution networks 14-3 Overall summary report DNO design and operations learning report DNO tools and systems learning report Final Report - DNO Guide to Future Smart Management	LCL Report D3 - Design and real-time control of smart distribution networks LCL Report D4 - Resilience performance of smart distribution networks LCL Report D5 - Novel commercial arrangements for smart distribution networks LCL Report D6 - Carbon impact of smart distribution networks Incorporated into LCL Report SR - DNO Guide to Future Smart Management of Distribution Networks LCL Report D1 Development of new network design and operation practices LCL Report D2 DNO Tools and Systems Learning LCL Report SR - DNO Guide to Future Smart Management of Distribution Networks

In total the project delivered 27 final reports, grouped into three logical themes for easier reading. These themes are a) DSR and DG; b) the electrification of heat and transport; and c) network planning and operation.

6.Required modifications to the planned approach during the course of the project

The recruitment of participants proved challenging in some trials, due largely to a variety of factors outside of the project's control.

EVs

The post banking-crisis economic climate prevailing during the early years of the project undoubtedly had a real dampening effect on previous forecasts in EV sales and ownership. This presented challenges to the project in recruiting EV owners, due to the small pool of potential participants in London. This availability was further impacted by the relatively common availability of old-style low cost lead-acid battery vehicles (e.g. G-Whizz) which are popular in London in part due to the attractive parking concessions available to EVs and which are charged at home from domestic 13A sockets rather than through private or public EV charging posts and so were unsuitable for the LCL trials. However, the project successfully mitigated this in part through a very active and well-advertised recruitment campaign but also by working in conjunction with Nissan UK to develop a short-term EV leasing scheme to increase trial participant numbers.

DG market research

The recruitment of I&C participants with installed DG proved particularly testing. As mitigation to this, the project commissioned a market research specialist to conduct a survey of potential DG trial recruits to determine the issues behind the reluctance to participate. The findings shaped the later recruitment and built upon the insights gained around a simpler offering as well as targeting the actors in the DG service chain – e.g. building facilities management companies and CHP development consultants.

ANM equipment streamlining

The project also streamlined its required ANM equipment requirements as the project adjusted its configurations to reflect the mix of ANM monitoring and active trials. This was achieved in agreement with Smarter Grid Solutions (SGS), the project's ANM partner; the reduced equipment requirements enabled additional ANM technical resources from SGS to be used in the project at no additional cost.

Improved forward visibility of I&C loads for DSR trials reducing project costs

As the I&C DSR trials progressed, securing DSR loads for inclusion in trials became more predictable and hence the forward visibility of I&C loads for later trials was good; this enabled the project to re-balance the UK Power Networks resources on this workstream to utilise lower costs resources, reducing the outturn project budget.

Paying demand aggregators for outcomes not effort

The increased predictability of I&C DSR loads was also improved by the decision to pay demand aggregators against outcomes and not effort; this increased the robustness of committed loads and reduced trial issues when response was called for.

Additional I&C demand aggregator

UK Power Networks also increased the competitive climate within aggregators to deliver cost-effective demand into trials by bringing in an additional demand aggregator, KIWI Power, an aggregator regarded as a particularly innovative and emerging DSR player. This additional aggregator focused on hotel-sourced building turn-down demand that provided new insights into sources of flexible demand in London.

Smart meter – Landis & Gyr 5236

The project had originally intended to use a SMETS-compliant smart meter in all its trials where a smart meter was required. The choice of a SMETS-compliant meter would have enabled energy consumption data together with voltage and power flow information all to be gathered within the one device.

However, the project had to mitigate the delayed availability of a SMETS-meter and select an alternative. The meter selected by the project was the L&G 5236, which was readily available in the marketplace and used by most energy suppliers who were offering a smart meter at the time, notably EDF Energy, the project's energy supply partner and British Gas, who the project later made arrangements to receive data for an additional 10,800 meters. It was also certified for use with CGI's metering head-end system. This decision was borne out by subsequent further delays in the availability of a SMETS meter, unknown at the time the decision to use a Non-SMETS meterwas made.

The project mitigated the absence of a SMETS smart meter with the establishment of the three EIZs as areas of intense instrumentation and measurement in Brixton, Merton and Queens Park, with a comprehensive voltage and power flow measurement framework established from 11kV substation to LV endpoints in all three EIZs.

Smart meter - EDMI MK7B and MK10A

The project was able to select a different smart meter for those trials where the participants were recruited directly by LCL (i.e. not through EDF Energy), for example, for I&C and residential EV monitoring trials and also to provide endpoint instrumentation on the LV ways in three EIZs. The data could also be collected via an alternative head-end system. The project selected two smart meters from EDMI, a single and a three phase meter, both capable of capturing voltage data and other power flow characteristics. The data from these meters was transmitted via SIM cards and collected directly from EDMI's own secure meter head end system.

EDF Energy customer rewards

The project increased the original amount provisioned for customer rewards to participate in the dToU trial. This was based on insights from EDF Energy's customer service experts on suitable reward amounts to trigger a response in London.

Project change request

During the initial 18 months of the project three particular challenges arose, which culminated in a formal change request being submitted to Ofgem in July 2012. There had been changes in material circumstances outside of the project's control in the following areas:

a) Heat Pumps

The project encountered very low demand for heat pumps in London. This was potentially due at the time to delays in the establishment of the Renewable Heat Incentive. In response to this, the project proposal was to cease further active recruitment of residential and I&C participants for the heat pumps trial, due to the high costs of recruitment and to develop an alternative approach, developed jointly with Imperial College, based on supplementing the existing sample with empirical data from other suitable external sources. This work was subsequently carried out in conjunction with the Energy Savings Trust, who had access to a large portfolio of heat pumps and heat pump data, which was further enhanced by the project deploying power quality analysers to enrich the external data being collected and input to the project.

b) Geographic location of trials - LCZs to EIZs.

The project had originally intended to link its trials to locations within London that were participating in the Mayor of London's Low Carbon Zone (LCZ) initiative. These were 10 defined geographic areas of London, announced in March 2010, which had each been awarded a share of £3million by the Mayor of London to cut carbon by over 20% by 2012.
The initiative closed in September 2012 and the LCZs were then discontinued as defined entities. As part of the 2012 change request, the project took the opportunity to redefine its geographic focus to a smaller number of specific zones, defined as three Engineering Instrumentation Zones (EIZs) coupled with, in particular the cases of the smart metering and dTou trials, a carefully managed demographically balanced recruitment process to ensure that participant pools were representative of London and able to be easily extrapolated to a national level or applied to other city or urban contexts.

The EIZs were also established as areas of more intense low carbon activities than would have been seen in the LCZs, and this was augmented by the project installing a full range of trial monitoring equipment across all three EIZs.

c) Carbon impact measurement and reporting tool

This element of the change request was driven by the fact that the third party software provider who was to deliver the original carbon tool was acquired by new owners. The new owners were unable to commit to the necessary modifications required to meet the project's exacting carbon measurement requirements at the previously indicated price. As an alternative approach, the project contracted with one of its project partners CGI (at the time Logica), to develop a bespoke tool tailored to meet LCL's specific carbon impact measurement and reporting requirements.

The project timescales were also proposed to be extended for a further six months, to end 31 December 2014, to reflect the additional time to absorb the changes into the project.

The change request was reviewed in detail by Ofgem's appointed consultant TNEI, who had also reviewed the project during the bid submission process. In addition, the project sought views from all other DNOs on impacts the change request may have had on the envisaged learning from the project. As a final check, the project's academic partner, Imperial College, were asked to provide written assurances that the project would continue to deliver the benefits outlined in the original submission.

Following these steps, Ofgem were satisfied that the material changes in circumstances had been successfully mitigated and approved the change request in December 2012, allowing the project to progress across all of its trial at the start of 2013.

The reduced geographic spread enabled cost reductions, totalling £350,000 to be identified. In addition, the project committed to deliver further cost reductions of £1.2m, derived from having identified more efficient methods of delivering some elements of the project. These savings were independent of the change request and would have been delivered without the change request being approved and at the end of the project.

As a mark of its continued commitment to the project, the DNO increased its contribution to the project by a further £2m and committed to delivering all of the savings, totalling £3.5m within the lifetime of the project, in the financial year 2013-14, including those savings that technically need not have been delivered back to customers until after the end of the project.

Additional DNO reports

UK Power Networks committed to provide a number of additional final reports a within the revised timescales, with a sharp focus on DNO-centric perspectives from the projects trials and findings. These additional reports were to be delivered in two tranches, one by September 2013 and the final set by 31 December 2014.

7. Significant variance in expected costs

The project worked proactively throughout to manage all costs. As a result, variances at the Project Direction "Box" level and as detailed below are all outturn underspends, with the project as a whole completing all its SDRC and objectives with a summary outturn underspend of £4,837K.

Box 6 (Employment costs)

At outturn, employment costs are £124k underspent which was 3% of the budget. The underspend was a result of the use of lower cost resources and resource efficiencies leading to savings against the budget.

Box 7 (Equipment costs)

Equipment costs were £1.888K less than budget, a 43% underspend. The principal sources of the underspend were due to reduced costs within EV trials, unused provision for stranded smart meter assets, avoided expenditure on I&C demand aggregator equipment by using existing infrastructure already in place and savings made on substation instrumentation through negotiation of better pricing.

Box 9 (Customer and user payments)

Aggregator payments to I&C customers were £877K less than budget, a 36% underspend, achieved through improved contractual pricing by the project as the I&C DSR trials progressed.

Box 10 (Other costs)

Other costs were underspent by £2.490K, a 15% saving against budget, achieved through project efficiencies through the re-use of existing IT equipment, the delivery of additional savings from project partners and manipulation of the project plan to deliver the same outputs for less expenditure than originally budgeted.

Summary of the bank account movements

	£	£
Balance as at 23rd March 2015		8,161,476
Payment due to UKPN for completed work		(2,655,327)
Bank balance following final invoice settlements		**5,506,149**
Total costs anticipated in Project Direction		28,305,000
Total spend for work completed		(22,937,389)
LCL Project Balance		**5,367,611**
Interest assumed in Project Direction (rounded figure)	1,052,000	
Actual interest realised	(521,490)	
		(530,510)
LCL Project underspend		**4,837,100**
LCNF – Overfunding		**669,049**
Funding to be returned to customers		**5,506,149**

£k	Total Project Budget	<- Spend to March 2015 -> Actuals	Variance	%
Box 6 (Employment costs)				
Programme Director	512	335	(177)	-35%
PMO	310	315	5	1%
Communications & Commercial Managers	468	309	(159)	-34%
Administrative Support	154	75	(79)	-51%
Technical Lead	630	397	(233)	-37%
Network Operations Staff	2,520	3,048	528	21%
	4,594	**4,479**	**(115)**	-2%
Box 7 (Equipment costs)				
5 ANM schemes	736	736	0	0%
40 aggregator equipment/devices	650	19	(631)	-97%
Smart Metering	693	-	(693)	
Plugged in Places contribution	1,125	822	(303)	-27%
Substation works	1,186	926	(260)	-22%
	4,390	**2,504**	**(1,886)**	-43%
Box 8 (Contractor costs)	-	-	-	
Box 9 (Customer and user payments)				
Aggregator payments to I&C customers	**2,440**	**1,563**	**(877)**	-36%
Box 10 (Other costs)				
IT costs – operational data store	2,001	2,193	192	10%
IT costs – Carbon Tool licensing	110	110	-	0%
IT costs – SGS support & software licence	465	163	(303)	-65%
IT costs – Aggregator IT costs	163	8	(156)	-95%
IT costs – comms, infrastructure, environment and interfaces	640	569	(71)	-11%
IT costs – CGI head end	394	314	(81)	-20%
Contingency	2,997	1,669	(1,328)	-44%
Travel and expenses	20	41	21	107%
Public engagement/learning dissemination	1,728	1,721	(7)	0%
Inflation	747	-	(747)	-100%
Partner/Collaborator labour costs	6,336	6,565	229	4%
Other solution/implementation costs	380	338	(42)	-11%
Programme Management Other		-	-	
Accommodation	750	444	(306)	-41%
Training	-	-	-	
Communication	150	256	106	71%
	16,881	**14,391**	**(2,490)**	-15%
Total	**28,305**	**22,937**	**(5,368)**	-19%
Allowance for change in interest calculation	(531)			
Total	**27,774**	**22,937**	**(4,837)**	-17%

8. Updated Business Case and lessons learnt for the Method

As part of the original proposal submitted to Ofgem, an assessment of the potential benefit of flexible demand to the DNOs and the network more generally was prepared, covering the period between 2010 and 2050.[2] Against estimated roll-out costs of £2.3bn, the gross benefit is divided into three parts:

1. Direct benefits arising from conducting the LCL trials (£1.5m);
2. Benefits that might be expected to accrue to DNOs from their making use of flexible demand (£15.0bn); and
3. Carbon benefits that might accrue to the electricity system more broadly as a result of flexible demand (£25.8bn).

The original business case has been re-reviewed and a number of changes have been made to the LCL business case since the original LCL bid submission was made. The full detail of this review can be found in Appendix 10. Many of the changes, particularly in relation to carbon benefits, are the results of revised grid scenarios, including the carbon intensity of the electricity system and the value of carbon abatement.

The most significant change in benefit accruing directly to DNOs, however, relates to smart Electric Vehicles. At the time of bid submission, at least two different assessments were in the industry around the potential reinforcement that might be associated with EVs: the LCL bid submission assumptions, and the report carried out by Imperial College and the Centre for Sustainable Energy and Distributed Generation (SEDG) for the Energy Networks Association (ENA)[3]. In retrospect the LCL business case was at the extreme high end of estimates, and estimated a £52.0bn present value of reinforcement associated with EVs out to 2050, whereas the SEDG estimate was at the lower end of estimates around £16.3bn. Subsequent estimates using the Transform model and slightly different scenarios and assumptions also estimated the cost of supporting EVs, micro-generation and heat pumps via conventional reinforcement in the order of £18-24bn.

The LCL trials were able to demonstrate a considerable degree of diversification between individual EV peaks, lower than either the SEDG report or the LCL business case had assumed. As such, the cost of conventional reinforcement is now estimated to be £10.3bn, representing at least £6bn lower cost to the GB than any of the original estimates in the industry, and significantly less when compared with the original business case of **£52.0bn**. The corresponding benefit of shifting EV load in a smart way is consequently reduced, but the **£12.6bn** drop in expected benefits is outweighed by the **£41.7bn** reduction in underlying EV cost to DNOs.

DNO benefits.

This section considers the gross benefit that DNOs could receive from controlling flexible demand, taking into account, where possible, the learnings from the Low Carbon London (LCL) trials, and using DECC's and National Grid's latest projections for the composition of the electricity system and the value of carbon. Whilst some secondary benefits of demand flexibility were explored (e.g. reduced line losses), the business case focuses only on the primary benefit of reinforcement deferral. The projected benefit is estimated in two parts:

- The benefit of dToU tariffs and DSR contracts to reduce the cost that residential and commercial demand growth impose on DNOs via the need for substation reinforcement; and
- The benefit that similar commercial arrangements could have if they can be applied to new Low Carbon Technologies such as Electric Vehicles, which are expected to place additional burdens on the networks.

Residential & Commercial load: Benefit of dToU tariffs and DSR contracts

The LCL project assessed the benefits of residential dToU tariffs and commercial DSR arrangements separately:

- The gross benefit of using dToU tariffs across the LPN area to defer ED1 & ED2 reinforcement was estimated[4] to be £1.96m, but only on the assumption that such tariffs could be made mandatory[5].
- The gross benefit of DSR contracts in LPN over ED1 & ED2 was determined[6] to be £13.1m, requiring £7.5m of availability payments to be made to DSR providers, along with costs associated with system changes.

[2] Corrections to the original analysis gave a revised 2010/11 Net Present Value (NPV) of smart-enabled flexible demand of £38.6bn (compared to £39.1bn originally quoted).

[3] 'Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks', April 2010, available at: http://www.energynetworks.org/modx/assets/files/electricity/futures/smart_meters/Smart_Metering_Benerfits_Summary_ENASEDGImperial_100409.pdf

[4] LCL report A1: *Residential Demand Side Response for outage management and as an alternative to network reinforcement*

[5] Note that based on the dToU trial, for the voluntary case it was estimated that only an uptake of 24% would be achieved

[6] LCL report A4: *Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement*

An estimate has been made of how these benefits extrapolate outside LPN and beyond ED2. The gross benefit of these two schemes to all DNOs between 2010 and 2050 is £0.12bn. This compares with the initial estimate of £0.22bn made in the original bid submission.

Electric Vehicles: cost to DNOs and the benefit of Time of Use tariffs

It was assumed in the original bid that EV uptake had the potential to impose significant costs on DNOs by requiring substantial additional investment. In calculating the cost, the assumption was made that the EV peak loads combine with little or no diversification. In practice, EV peaks do not always coincide with each other, meaning that some diversification that can be assumed when combining multiple EVs.

As Table 10 shows, whilst the apparent benefit of making EVs "smart" has reduced considerably since the bid stage, the most significant driver for this has been the realisation that the underlying cost of EVs on the network is likely to be lower than originally anticipated.

Table 10 Changing assumptions of EV network impact and benefit of smart

Assumption	Reason for assumption change	Average EV peak	EV uptake scenario	Flex-ibility	Underlying EV cost	NPV of smart EVs
Original bid (corrected)	Original bid did not assume any diversification between EV peak loads and between EVs and other sources of demand.	3kW residential/ 4.5kW commercial	DECC 2050 pathways	60%	£52.0bn	£14.8bn
Pre-LCL diversity view	**At the time of the bid submission, Imperial College and SEDG had produced a parallel report in which a diversified residential EV profile was assumed, and which was significantly lower.[7]**	**0.6kW/ 4.5kW**	**DECC 2050 pathways**	**60%**	**£16.3bn**	**£4.6bn**
EV diversity applied	LCL project determined that the average contribution of residential EVs to the peak demand is just 10% of the individual EV peak. Commercial EVs are less diversified.	0.3kW/4kW	DECC 2050 pathways	60%	£10.3bn	£2.2bn
Lower EV uptake	Revised EV uptake projection based on National Grid's Future Energy Scenarios (FES) "Gone Green" case	0.3kW/4kW	FES Gone Green	60%	£6.4bn	£1.7bn
Revised flexibility & attribution	dToU trial suggested 30% of EV load could be shifted from the peak. Range of benefit depends on how much of the EV flexibility can be exploited to defer DNO reinforcement.	0.3kW/4kW	FES Gone Green	30%	£6.4bn	£0.9-1.9bn

Both the original bid and this revised estimate exclude benefits from smart Heat Pumps. Imperial College London's carbon impact report[8] notes that where EVs and HPs are able to be flexible, EVs will tend to be preferred. This is because heating a space earlier than required results in losses to the environment, whereas there is no corresponding loss associated with changing the timing of EV charging.

Whole system carbon benefits

Carbon benefits were assessed directly as part of the LCL project at a 'per intervention' level. The revised NPV estimate of carbon benefits is £8.6bn, a reduction from the original estimate of £25.8bn, reflecting a reduced contribution anticipated from Heat Pumps, a fall in DECC's estimate of carbon abatement costs, and most significantly a fall in the underlying forecast of grid carbon intensity.

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[8] M. Aunedi, F. Teng, G. Strbac, (2014) "Carbon impact of smart distribution networks", Report 14-2 for the "Low Carbon London" LCNF project: Imperial College London, 2014.

This estimated carbon benefit is for the system as a whole, rather than just DNOs. It also does not limit itself to DNO-led actions, and therefore implicitly includes "smart" actions that might be taken by suppliers, National Grid or other market participants with interests other than deferring distribution substation reinforcement.

Numerous adjustments were made to the projected carbon benefits, which can be seen in more detail in Appendix 10. However the likely sources of carbon reduction can broadly be placed into one of two categories:

1. **Displacement**

   Smart solutions can allow additional Low Carbon Technologies to be added to the system, displacing more carbon intensive options. Electric vehicles, heat pumps and renewable generation all displace more carbon-intensive alternatives. The extent to which smart solutions facilitate more of these technologies being added to the network was not studied directly as part of LCL. However, a number of possible mechanisms for this exist:

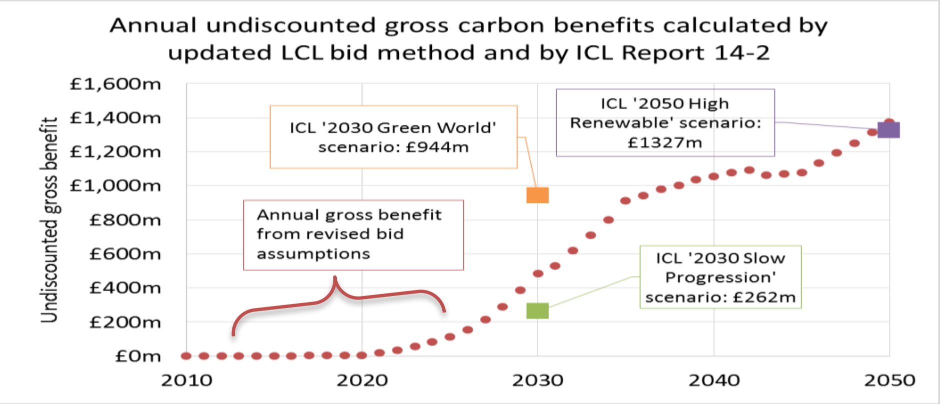
   - A certain level of flexible demand may be required to allow EVs and HPs onto the system (e.g. avoiding network constraints).
   - Some renewable generation projects might not be viable without assurances that they will not suffer excessive curtailment. Smart grids might make viable projects that would otherwise not have gone ahead.

   The carbon benefit of "smart" solutions will depend on the extent to which these mechanisms drive LCT uptake and the cost of carbon abatement. In the case of EVs and HPs, the underlying carbon intensity of the electricity system is a key driver. Whilst they displace petrol, diesel and natural gas, their uptake increases the overall consumption of electricity.

2. **Efficient dispatch**

   Smart technologies can be used to manage the grid more efficiently. This encompasses a number of mechanisms, including avoiding curtailment of low carbon generators ("wind twinning") reducing line losses and providing less carbon intensive options for balancing the system.
   Imperial College London (ICL) has conducted analysis[9] looking at the carbon benefit that can be associated with using smart appliances on a distribution network. The report considered two scenarios in 2030 and one in 2050 to estimate the additional carbon reduction that arises from allowing EVs, HPs, residential and commercial demand to be used flexibly to avoid wind curtailment and provide balancing services.

   A comparison of the revised LCL bid and the ICL analysis is shown in below.



Comparing estimated gross carbon benefit with ICL report 14-2

Costs

Cost estimates exist for specific "smart" applications, and can be found in the CBAs carried out as part of the LCL learning reports. The net benefit of applying the methods studied under LCL will depend on the way in which they are implemented. Some key findings include:

- Whether schemes are voluntary or mandated will affect the overall cost and the distribution of those costs amongst electricity market actors

[9] M. Aunedi, F. Teng, G. Strbac, *ibid.*

- The upfront costs associated with putting in place the technology, systems and process required for the smart grid could be substantial. It may, however, be possible to share those costs between the market actors that might benefit (DNOs, suppliers, National Grid, etc.)
- The way in which smart measures are used is important. For example, using DSR on a post-fault basis incurs minimal utilisation costs, but has little carbon reduction effect. The sustained DSR actions required to have a material effect on overall energy use is likely to be much more costly to implement.

Benefit case summary

Summary of original and revised LCL benefit case

Benefit of "smart"	Original bid	Revised
Benefits		
Direct benefits	£1.5bn	£1.5m (corrected figure – error in original bid)
DNO benefits (residential dToU & commercial DSR)	£0.22bn	£0.12bn
DNO benefits (EV & HP flexibility)	£10.4bn	£0.9-1.9bn
DNO benefits (other)	£1.7bn	-
System carbon benefits	£28.9bn	£8.6bn
Gross benefit	***£42.7bn***	***£9.5bn***
Costs	**£3.6bn**	**£2.3bn**
Net benefit	**£39.1bn**	**£7.3-8.3bn**

Lessons learnt for the method

LCL did not experience any significant or major issues with the project's methods. The timescales necessary to finalise commercial arrangements associated with trials on some occasions took much longer than originally anticipated, primarily to due to the pace at which decisions can be made in large and complex London-wide agencies, the large number of different parties required to be consulted and the fact that many of these arrangements were new and had not previously been through a legal and commercial process.

The reluctance of prospective I&C trial participants to place their often regarded flagship London-based assets into a trial has already been discussed earlier in the report. Obtaining some form of NIC submission commitment via, for example, a letter of intent is recommended to secure I&C interest without the necessity of becoming a project partner.

The project undoubtedly encountered many uphill tasks during its lifetime, but these were largely mitigated by the project taking a proactive and forward-looking approach to ensuring identified risks were actively managed and mitigated to prevent real issues arising. The only risks that became significant issues were those driven by material changes in circumstances outside of the project's control and were dealt with in the project change request to Ofgem.

The project investigated three methods; new commercial arrangements, new network operational practices and new network planning practices and the opportunities LCTs afford these methods. During the lifetime of the project these three methods remained at the centrepiece of the efficient development and operation of smart grids, however, it is recognised that the non-technical dimensions of smart grids, both in a trial and in a business as usual context, are growing in importance. This puts a more complex dimension into any analysis and applies both in residential/SME and I&C contexts. Network visibility for smart grids now requires a much better understanding of why energy is being consumed, in addition to just the traditional load profile factors, is a good example of this issue.

Such understanding will in turn aid a much better appreciation of how flexible and amenable to change any energy demand may be, as well as gaining knowledge of the value of energy to a particular user at different times of the day or week, which may then drive how any commercial arrangements could be shaped to manipulate that energy demand via DSR, time of use tariffs, use of heat pumps, charging EVs and interaction with DG installations.

The insights provide by the in-depth demographic characteristics of trial participants, particularly in the smart metering trials, has generated some real learning around affluence and energy consumption and energy efficiency that can be applied in future load planning. Early awareness of these factors from LCL also assisted UK Power

Networks in its subsequent LCNF project on investigating energy consumption in the Vulnerable Customers and Energy Efficiency (VCEE) project.

9. Lessons learnt for future innovation projects

Trial participant recruitment

The table below summarises the participant recruitment on the programme. Note that since Low Carbon London paid aggregators on the basis of outcomes, it does not have information on the response rate achieved in their discussions with potential sites. Projects such as Northern Power Grid's Customer Led Network Revolution and Electricity North West's Capacity to Customers have published findings on this.

Participant	Recruitment period	Number recruited	Response rate	Recruitment method	Incentive	Subjective assessment
Smart Meters	12 months	5,533	6%	Mailshot + phone call	None	Straightforward but with low response rate
ToU	6	1,119 (drawn from the smart meter pool of 5,533)	16%	Mailshot + phone call	£100 for signing up £50 for staying on to end of trial	Straightforward once explained Low response rate
ToU entry paper survey	10 weeks	722	68%	Mailshot	£20 cash collected from Post Office	Good level of engagement
ToU exit paper survey	4 weeks	421	40%	Mailshot	Prize draw	Good level of engagement
Household appliance survey	12 weeks	2,830	51%	Mailshot and online	£20 cash collected from Post Office	Good level of engagement
ToU meter interviews	26 weeks	37	Not collected	Mailshot	None	Good level of engagement – interview was 40-80minute face to face or telephone
EV residential	18 months	72	Not collected	Targeted advertising	25 participants were recruited through a Nissan (UK)/LCL subsidised EV leasing scheme	Difficult due to low available EV numbers
EV commercial	18 months	54	Not collected	Mailshot	None	Difficult due to low available EV numbers
EV paper survey	10 weeks	41	57%	Email Mailshot EV leasing recruitment (21 from this route)	None	Difficult
Heat pumps	24 months	18	Low	Energy Savings Trust (10) Passiv Systems (8) Canvassing at Heat Pump Association	None	Very difficult

Participant	Recruitment period	Number recruited	Response rate	Recruitment method	Incentive	Subjective assessment
Existing DG	Up to 36 months	13 CHP and 2 PV sites for monitoring trials 2 sites – Bunhill Energy Centre and Greenwich Power for active DSR trials + undeclared number through demand aggregators	Low	Mailshots Canvassing at CHP Association conferences; Meetings with CHP consultants; Meetings with Facilities Management companies; and Market research exercise In conjunction with demand aggregators Project partner networking	Monitoring trial - none DSR payments for those recruited onto those trials	Most difficult

The recruitment of I&C DG trial participants took an extended period to complete. Much of this was down to the multi-layered approvals required in prospective participant organisations, particularly where DG installations were managed by an outsourced facilities management organisation and the approval process factored in numerous separate technical agencies and potential trial participants' external consultancy organisations. Similarly, the negotiations of trial commercial arrangements took extended time, in part due to the novelty of the proposals and the time needed to understand and assess the ramifications from the trial participants' perspective. It is suggested that in any future projects, commercial organisations are required to document a level of participation, perhaps through a Letter of Intent, as part of the bid process. In addition, trial recruitment processes should identify contingency options as part of the initial solution design submitted to Ofgem.

Another factor in play when dealing with flagship London installations as potential trial participants was precisely because of their prestigious and high-profile position for example, within the company concerned, or London Borough, there was detectable reluctance at times to consider any proposition that was termed a "trial", as it was deemed as an unacceptable risk, sometimes without understanding any of the detail of the proposition.

The project undertook specialist market research as part of the DG recruitment mitigation. The insights gained from that helped shape the remaining recruitment activities. These ranged from the need to simplify the offering to participants to recognising the need to sharpen the financial attractiveness to potential participants. The market research also drew out interesting insights about a general and widespread lack of understanding on a range of related issues from carbon issues in London to smart grids and the need to de-carbonise the electricity delivery supply chain in potential participants.

Tight central project management and control by the DNO

The deliberate decision by the UK Power Networks to actively lead and manage all aspects of LCL undoubtedly paid dividends in enabling it to work proactively to manage risks and to ensure that all the project's various activities remained true to the original aims and objectives. It ensured the DNO had detailed oversight of the entire project's work at all times. This required the DNO to place a number of its own personnel in key positions in the project, e.g. in the solution design and architecture office or in leading key project workstreams. It also placed an obligation for comprehensive reporting to be adhered to throughout the project by all project team members, whether from the DNO or from a partner organisation.

The large-scale scope and innovative ground-breaking nature of LCL could have exposed it to a multitude of risks around scope creep and diversions into irrelevant areas of related interest, but the philosophy of central DNO leadership and control successfully mitigated this risk.

This approach needed to be balanced with the partnership ethos of LCL and the DNO had to work diligently ensuring that partners were involved at all times and also most importantly , that partner capabilities were fully identified and leveraged into the project. This required the Programme Director to be significant amounts of time working with project partners to ensure they were fully contributing all their potential capabilities into LCL and that they felt they were a partner in LCL.

Optimum partner size and mix

LCL was a project led by UK Power Networks with 11 other partners. This diverse mix reflected the broad canvas of interests in smart grids in London, ranging from large national and international organisations such as National Grid, EDF Energy, Siemens and CGI, through to nascent smart grid technology players such as Smarter Grid Solutions. The projects partners also comprised key London-wide agencies such as Transport for London and the Mayor of London's office. The emerging DSR market-place was represented by three demand aggregators, Flexitricity, EnerNOC and EDF Energy. The project's academic partner was Imperial College London, one of the world's leading authorities on electricity smart grids. The Institute for Sustainability is an active player across a number of low carbon initiatives in London's, enabling the LCL project to interact with these through the project's lifetime.

Such a large and diverse range of interests presented unique challenges to the project in keeping partners engaged over the four years of the project. The general nature of London's high levels of economic activity meant that several key partner project personnel changed through the project due to individuals changing jobs and employers, which at times presented additional risks and opportunities to the project.

It is recommended that future LCNF projects in London are carried out with fewer partners, narrower scope and shorter timescales.

Solution design and development

LCL required significant further solution design and development may be required once the bid has been approved by Ofgem. This activity occupied the first 12-15 months of the project and meant that the project was in "heads-down" mode during that time with little outward sign of progress.

Future projects should recognise that maturity of the submitted design at the bid stage and should indicate the remaining work envisaged to turn the submitted design into a workable detailed solution and suggest within the bid, suitable solution design and development milestones in that period to provide Ofgem with assurance that the project is still running to schedule.

Project replication and smart gird technologies

Smart grid technologies are by and large still at the early stages of development, with low TRLs. Many areas are also subject to rapid technology refresh and innovation. For projects that have a lifespan of several years, as was the case with LCL, this can have implications for how the project's findings and outcomes could be replicated, as much of the technology may either be obsolete or have been subsequently replaced with a more advanced and more recent version or alternative. LCL has seen this at first hand with the ANM technology selected for the project, which was leading-edge in 2010 and 2011, but now is obsolete, no longer available and replaced by more advanced technology.

10. Project Replication

The LCL project used a wide range of physical components. In the relatively fast-moving world of smart grids, new equipment is coming onto the market-place every year and much of the equipment used in LCL would now be regarded as obsolete. Notable examples of this include the smart meters, the ANM technology used in the project's trials as well as the central ODS database used to collect most of the project's empirical data. The IT infrastructure was provided through UK Power Networks IT service, which is largely delivered through outsource contracts, using shared, rather than dedicated services. Equipment configurations are provided in the appendices; for the ANM trials

(Appendices 4-7 inclusive) and the overall IT architecture (Appendix 2). Further details of any equipment model numbers or configurations used can be provided on request.

Conversely, the commercial arrangements trialled as one of the project's key methods have proved to be very current, lending them to straightforward replication elsewhere.

The following describes the main elements of infrastructure needed to replicate the outcomes of LCL.

SMETS smart meter

A SMETS-1 compliant smart meter, appropriately configured, will be able to capture the required range of energy consumption, voltage and other power flow characteristics needed for the detailed analysis LCL undertook and outcomes delivered. These devices would need to be deployed in all trials – residential smart meter and dToU trials, EV and heat pump monitoring. The use of a SMETS-compliant meter would avoid the need for power quality analysers in heat pump trials, although these could be fitted at points on the system to collect additional information.

Smart RTU

The project deployed a range of substation measurement devices from 11kV downwards to enable an end to end measurement framework within the distribution network. This is still an emerging area of technological development with new products coming onto the market at regular intervals.

Trial recruitment

Trial recruitment costs would need to be provisioned to replicate LCL trials. The level of expenditure would be very sensitive to ease or difficulty in recruiting the required numbers.

dToU Trial recruitment

For network benefits to be realised by GB DNOs as ToU tariffs are rolled out, the value through the whole industry supply chain needs to be maximised. Throughout LCL, EDF Energy administered the recruitment of residential smart meter participants onto the dToU trial. To achieve this, roughly two thirds of the implementation costs were associated with recruitment, cash incentives, and handling additional customer queries and would only be incurred in the first year of a tariff being applied. Incentives of c. £143/customer, as presented throughout LCL are unlikely to reflect the actual rollout of ToU tariffs. However, for the trial results, incentives have directly influenced the observed trial uptake (24%) which will be important when understanding the expected response to manage network constraints.

While a network benefit-driven dToU could be used to realise network benefits in some cases, such as deferring reinforcement or improving outage management, the benefits must outweigh the costs of implementation. Therefore, a coordinated industry approach to implementing ToU tariffs could help maximise the value through the supply chain, enabling network benefits. This would be largely facilitated by a dynamic tariff as opposed to a static one. There are also other practical challenges in a DNO focused approach, such as managing customer expectations if their network area was targeted with a dToU tariff, and making changes to industry processes to allow for half-hourly DUoS charging.

EV and Heat Pump recruitment

EV and heat pump recruitment costs are almost wholly driven by any incentives offered to participate. In LCL, heat pump recruitment was one element of the change request and alternative approach was adopted using data from other sources and avoiding recruitment costs. EV recruitment costs were negligible apart from the incentives offered as part of the EV leasing scheme carried out in conjunction with Nissan UK, in which both LCL and Nissan UK made contributions to subsidise the EV lease cost to trial participants.

IT Infrastructure

Global IT organisations for some years now have targeted energy smart grids as a focus for strategic development and investment, however, real-world developments have been thin on the ground and if anything, the earmarked funds have been moved to other emerging areas of envisaged expenditure. A more realistic synchronising of IT smart grid technology to actual business requirements may see a slower pace of development but one that sees more concepts making it through into production offerings and in a more incremental and evolutionary rather than revolutionary way.

The IT infrastructure used by LCL was a complex, highly bespoke one. The core was two databases, the ODS and the PMS. The ODS was provided by Siemens and was an extract from a now-defunct energy management suite. However, the underlying design was based on PI, a real-time data infrastructure and architecture from OSIsoft, which could be used to replicate the ODS under a new system. The key feature was the ability to configure and describe distribution network components within the system. The various file transfer and data interfaces were specific to LCL and any DNO seeking to replicate the outcome would build in their own bespoke file and data interfaces; this is a straightforward task. The second core database, the PMS, held details of trial participants. This system is akin to a simple customer relationship management (CRM) system and could easily be replicated either using the same design or a DNO may already have access to alternative CRM facilities within its organisation, which would fulfil the required role.

UK Power Networks IT infrastructure is provided through a number outsource contract (e.g. Data centre, desktop, wide-area communications etc.). The equipment used is particular to the service providers concerned; furthermore, the LCL IT infrastructure was largely provided through the use of shared-service and virtualised IT environments, to keep overhead costs low.

ANM infrastructure

The ANM infrastructure used in the project’s trials to monitor, manage and control DG was leading-edge in 2010-2011. It was provide by Smarter Grid Solutions (SGS), one of the project’s partners. SGS have continued to develop and innovate their infrastructure offerings such that the equipment used in LCL is now no longer available and considered obsolete in the market-place (e.g. SGS declined an offer to buy back the actual trial equipment due to its obsolescence). However, SGS would be able to provide any DNO looking to deploy ANM to replicate LCL outcomes with current versions of the technology.

Commercial arrangements

The project developed a set of contracts used to carry out I&C DSR trials. These contracts evolved from each trial, with learning from earlier trials applied to subsequent contracts. These are available to all DNOs.

Business as usual costs

The ongoing running costs of the project are relatively small compared to the initial capital outlay of deploying smart meters, RTUs. The amount of data collected is primarily determined by number of remote devices collecting and transmitting information (e.g. number of smart meters, EVs and heat pumps). There would be ongoing data communication costs and a service fee from any smart meter head-end operator, both again determined by data volumes and frequencies. Depending upon the ODS and PMS solutions put in place, there may be ongoing licence fees to be paid to software vendors. Data storage costs would nominal although these would increase over time as stored data volumes grew. In general, BAU costs would exclude any ongoing incentives to participants and be focused on the IT costs of the service.

11. Planned implementation

The projects findings have been carefully assessed in terms of the three methods LCL set out to trial.

I&C DSR and distributed generation

The project has already successfully implemented learning and outcomes from LCL into its distribution system. The project worked closely with the UK Power Networks RIIO-ED1 submission team to develop ED1 proposals based on the I&C DSR trials in LCL. This work has resulted in committed savings in network investment of £12m within LPN and £43.5m across the DNO within the ED1 business plan period.

The project has also identified that DSR has value to both network planning and operations. This includes developing tools and approaches to assist the appraisal, procurement and contractual agreements to implement DSR. Implementing DSR will be beneficial in managing planned and unplanned faults as well as enabling the deferral of network reinforcement investments.

Values for contribution or 'F-factors' which can be used in the existing network planning processes laid out in Energy Networks Association documents ETR130 and P2/6 have been derived for different types of demand response sites. For example, a diesel generator's contribution can vary from 70% to 81%, depending if it's a single site versus a portfolio of up to ten sites. These values have also been calculated for CHPs (69%-80%) and 'turn down' sites (54%-64%) respectively.

It is recommended that DNOs adopt the values derived in LCL, and available in LCL report A4, when assessing the contribution of DSR to security of supply.

However, it should be noted that DSR involves a marginally increased risk than relying on traditional electrical plan and assets. Both DNOs and Ofgem have acknowledged through the RIIO-ED1 settlement that DSR has the potential to provide significant economic value, but involves a marginally increased risk since it relies on assets and customer behaviour outside of the DNO's immediate control. As such, it does not perform as well on a score of predictive reliability as a network strengthened with real assets.

The project has provided significant new understanding of the operation of distributed generation on the distribution network. This work has been presented in forms of typical operating profiles and describes the value of incorporating the ETR130 assessments into planning assumptions in the future. Importantly, the projects trial of automated despatch of distributed generation, via the ANM system both direct to sites and aggregators, has given confidence to UK Power Networks to consider this approach for the I&C DSR which is being implemented.

Residential and SME DSR

As described above in section 4.4, and also in the LCL output reports (A1, A2 and A3), DSR derived from smaller Residential and SME customers is not currently planned for implementation by UK Power Networks. DSR derived from these smaller customers may be considered in the future should the value to customers improve similarly to I&C DSR. This is likely to involve multiple parties acting together, increasing the value to customers or increased home automation providing greater response to price signals.

Planning load forecasting and Transform Model

LCL has validated the DNOs load forecasting methodology and has replaced the final few assumptions in the methodology with real, measured values.

The purpose of load forecasts is to anticipate large-scale trends and to prioritise regions of high growth on the network. Their resolution is typically of the level of the 5,500 primary substations across the GB, each serving typically 10-11,000 customers. Since 2011, DNOs have developed sophisticated tools to support their load forecasting processes, which include to a greater extent than previously a bottom-up assessment of new demand drivers such as electric vehicles (EVs), heat pumps (HPs), and the growth in small-scale embedded generation (SSEG), communally known as Low Carbon Technologies (LCTs), and domestic consumer load.

Whilst the tools are designed to ingest the latest and most current data on the housing stock, and residential background demand, these factors will only change over the longer term. The main drivers for change over the next period, which must be monitored annually, are likely to come from any adjustments in the forecast uptake of LCTs. LCL has further strengthened this bottom-up approach by replacing assumed charging profiles of EVs with measured profiles from a daily average of 44 vehicles and showing good stability out to 95% percentile/2 sigma, and update current heat pump assumptions with measured profiles from the trials.

The revised forecasts closely align with the outcomes of the original assumptions, and re-validate that the vast majority of the forecast impact from LCTs is on the secondary distribution network. Specifically, from the load forecast an estimated 4,600 secondary substations will require reinforcement due to LCT uptake; this means that 25% of the stock in London will require reinforcement for this reason alone in the LPN licence area by 2050. It is recommended that these new profiles, which will be made available via the project website, are adopted by the other DNOs and are being submitted for inclusion within the GB Transform model.

Classification of network types

LCL has helped inform how to improve current design practices and help the classification of network types. The key need for network designers and planners, particularly for the secondary distribution level, is to be able to rapidly collate key parameters for an area of the network under review, either as the result of a connection request or as part of the capital investment plan. Specifically, the key parameters are the amount of embedded generation, maximum demand net of generation and the voltage profile. Particularly useful are approaches which classify networks into a reduced number of 'generic' network types around which engineering policy can be developed. Also vital are the profiles and demand characteristics of the load being added to the network.

Existing classification approaches for residential profiles can be improved with publically-available data. The LCL data has demonstrated that the vast majority of the information related to residential demand can be determined from household occupancy (single occupancy, couple or 3+ residents) and a relatively crude indicator of affluence ("affluent", "comfortable", "adversity") both based on publicly available datasets. The evening peak is driven by multiple occupancy homes and affluent single occupancy homes, whereas the majority of single occupancy homes demonstrate a flat load profile.

Updated profiles for EVs, heat pump and CHP

Up-to-date load profiles of heat pumps and electric vehicles, CHP are now available. The data presented in this report represents a population of over 5,533 residential load profiles, 72 domestic EVs, 54 commercial EVs, 1,408 public EV charge posts and 21 heat pumps. UK Power Networks recommends that the new profiles are agreed between the DNOs, taking into account data from other LCNF projects, and integrated into ENA standards for connection assessments, and are augmented with an up-to-date view of residential demand in electric-heated homes.

11kV investment and smart meter data

Smart meter data could inform investments in the 11kV distribution network by estimating the aggregated Maximum Demand (MD) where there is no current remote monitoring available. Smart meter data allows for an assessment of LV network utilisation; aggregating this data could enable a network-wide load growth report for secondary substations.

The only equivalent at the moment would be to aggregate the Estimated Annual Consumptions (EACs) and load profile classes used for financial reconciliation across the industry as part of the balancing and settlement arrangements, administered by Elexon. There will never be a 100% correlation between aggregated smart meter data and measured maximum demand, but calculations in this report demonstrate a potential correlation of over 80% between the smart meter data and measured substation demand, compared with 64% and 74% respectively from balancing and settlement data. DNOs will need to evaluate whether this has the potential to significantly improve classification approaches discussed above and warrant the investment in data storage and ICT systems.

Smart meter data privacy in sparse networks

The benefits from aggregating smart meter data could be restricted in certain rural networks. DNOs have a duty to maintain data privacy, and, as such, there are discussions within the industry on the implications of requiring DNOs to have smart meter data in aggregated volumes, i.e. not being able to see smart meter data from individual customers.

To inform that discussion, UK Power Networks estimates that over 10% of the substations within London have fewer than 10 customers. In the South East region which has a significantly higher proportion of rural substations, approximately 30% of the substations, including pole-mounted transformers, have less than 10 customers. This indicates that the minimum number of customers over which smart meter data is aggregated should be carefully considered, especially for rural networks, in order to draw on the benefits of the data. It is therefore important that the minimum level be defined such that networks with a low volume of consumers by substation can adequately be monitored, or their data can be accessed. It should be noted that Smart Meter data privacy is undergoing industry wide discussion via a number or forums including the ENA Smart Meter working group and also the Smart Grid Forum Workstream Six subgroup.

Localised growth

Identification of localised load growth and changes in load patterns will allow DNOs to determine a range of network options early on. Building on the approach discussed for smart meter data aggregation, a view of the capacity on the network can be derived at identified 'aggregate nodes'. This simply means that the higher level of network visibility will provide information on network capacity at these nodes, enough to inform planning and new connection design. Smart meter data and this method of analysis will be fundamental for identifying LCT uptake in certain parts of the network, which would not be otherwise captured.

Heat pump uptake

DNOs should maintain a close eye on heat pump uptake, primarily via the RHI register, and particularly installations grouped in clusters. Visibility will allow adequate consideration on the MD contribution and associated risks of clusters to a network. In the case of networks with heat pumps, the MD could be adversely affected by 'extreme cold' weather conditions. The LCL trials showed that for an average temperature of -4^{0} C and a penetration level of 20% of household owning heat pumps, the peak daily load increases by 72% above baseline. There is therefore a risk during periods of extended cold spells where heat pumps present no diversity, which DNOs must consider accordingly in their planning assumptions.

Smart meter data, LV outages and voltage management

Smart meters will improve the DNOs visibility of LV outages and therefore offer opportunities for improving service levels. DNOs will no longer be reliant on customers calling in to report outages, or restoration of supply as this information will be available automatically from smart meters. By using the information from the last gasp, first breath and energisation check functionalities, smart meters will benefit DNOs by allowing them to identify outages more promptly and optimise resources to restore the network while providing better customer service.

Smart meters will also improve the DNOs approach to managing voltage issues on the network. DNOs currently take a reactive approach to measuring voltage on the LV network following calls from concerned customers and investigating sites specifically by installing temporary monitoring equipment. With the installation of smart meters, voltage data will be available to improve voltage management; however, the volume of alerts and data should be filtered effectively. LCL has informed on the voltage reading configurations on smart meters to allow better management of voltage alerts volumes and constraints. Using LV network feeder voltages from the LCL engineering instrumentation zone trial as a proxy for voltage alerts, UK Power Networks undertook sensitivity analysis in order to define suitable configuration settings for managing voltage alert volumes. For this purpose, the duration of the voltage excursions, as well as the threshold for an excursion was defined. The analysis concluded that the volume of alerts would be disproportionately high for voltage limits set below the statutory limits (e.g. the +8/-5% scenario).

The recommended configuration is for excursion thresholds at the statutory voltage limits (+10%/-6%), with duration 10+minutes. At this configuration, the volume of high and low voltage breaches improves. However, when comparing the volume (1,624 excursions) in the EIZs to the estimated 210 power quality complaints that were received from across the LPN network (over 2m customers) during 2014, it can be noted that there will still be a significant challenge managing power quality events in London, and presumably for all DNOs. Besides the voltage alert configuration, identifying clusters of voltage alerts will further improve the management of the alerts and therefore should be designed into the system that manages the incoming alerts. This can be achieved by overlaying alerts with a corresponding MPAN topology to form a picture of when these voltage breaches are due to network conditions and, informed by the location, correlate voltage problems to potential faults or other network issues.

UK Power Networks recommends that DNOs consider adopting the voltage alert parameters and settings proposed in this report.

Regulatory Barriers

Throughout the programme, UK Power Networks has reviewed the potential to deploy or utilise all of the techniques investigated as part of the LCL project. This review has included consideration of any regulatory barriers to deployment. From a regulatory perspective, there have been no identified barriers to direct deployment of any techniques or commercial arrangements at the date of this report.

By design, LCL has always strived to ensure that the outputs of the project ensure that the products do not introduce artificial barriers, for example;

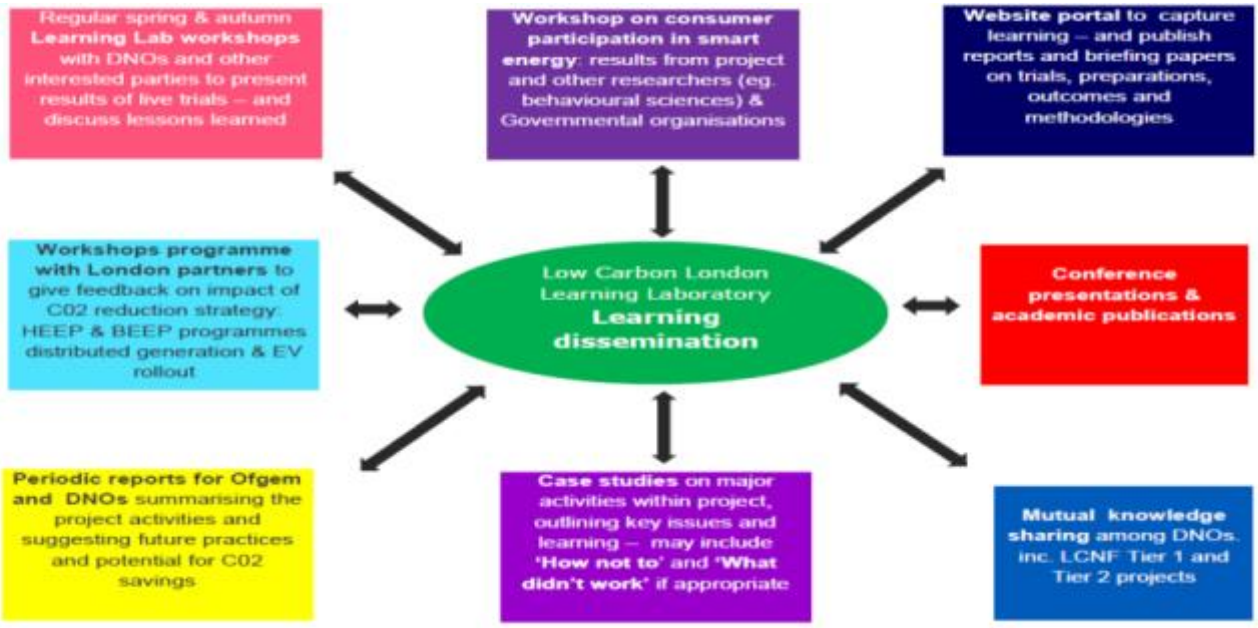
- Industrial and Commercial DSR. The technique used to assess reliability (f-factors), and thus levels of operational procurement, used the techniques adopted within ER P2/6 and specifically ETR130. This has been presented in the same format as the existing documents and thus maintaining compliance within existing licence conditions.

- Smart meter voltage considerations. The assessment of required voltage alerts and settings was made and presented in line with the available voltage alarms that will be recorded by the SMETS smart meters and made available to DNOs via the DCC.
- Presentation of new loads, load profiles and diversity assessments are easily adopted into any DNO's connection policy updates. These would however need to be approved as part of the connection charging methodologies.

It should be noted that whilst there are no regulatory barriers standing in the way of deployment, as demonstrated above, the output reports note that some techniques, for example residential ToU (DSR), will require multiple parties, including Suppliers, to participate thus enabling benefits to be aligned to trigger the benefits to be realised.

12. Learning dissemination

Low Carbon London took a structured and comprehensive approach to learning throughout the project, both in terms of capture and dissemination. Project workstream leads maintained a learning log during the development and execution of trials, the contents of which provided valuable candidates for wider learning dissemination. The project appointed a learning dissemination manager who worked actively throughout the project to develop, review, consolidate and disseminate learning. The diagram below sets out the project's learning dissemination framework which has been in place since the project's inception.



The project leveraged the skills and experience in several of the partner organisations through a regular partner communication steering group, where best practice used elsewhere was brought into and used in LCL. The project has a dedicated space in The Crystal in London, a sustainable cities initiative by Siemens exploring the future of cities and home to the world's largest exhibition focused on urban sustainability and a world-class centre for dialogue, discovery and learning.

Project Innovation Portal

The project has developed and maintained a comprehensive internet presence to encourage learning dissemination, access to which has been continuously monitored to gauge interest from around the world. The project has also established other social media channels to encourage interest and learning dissemination (e.g. Twitter and a dedicated LinkedIn group).

Low Carbon London newsletter

The project issued a newsletter each quarter, communicating the latest progress, trials, trial findings etc. It was sent out to a mailing list of over 300 stakeholders, as well as to internal staff. This included a number of press agencies who then used material in the news letters for articles and news items.

Internal learning within project

The project ran weekly team meetings in which immediate learning was initially discussed and captured. This was then consolidated and presented at monthly project steering meetings where all learning points arising were presented and discussed.

Learning dissemination within UK Power Networks

The LCL project ran a small number of internal learning forums that served to provide a useful vehicle to both update the wider business of the project's work and progress, but also to garner useful feedback on potential project implementation into the DNO. A notable example of these was the internal learning event held on I&C DSR in 2012, where representatives from all interested aspects of the business attended a full-day session on the progress on I&C demand response trials and how they could be taken forward and implemented into the business. This forum provided useful input to the shaping of the DSR commitments made in the ED1 business plan. The project for a period of intense activity in trial development ran a regular monthly technical forum with senior engineering representatives from across the operational business to present and discuss approaches to trial design and development. In the latter stages of the project, it was a regular active attendee at the monthly UK Power Networks engineering standards forum, with the project regularly providing input on progress, talking points and emerging learning.

"Brown bag lunches"

The project hosted a series of "brown bag lunches" across UK power Networks – these were informal sessions, open to all employees, held at various locations across the DNOs offices in the lunch hour. It was an opportunity for employees to attend a relaxed and informal learning event to hear about LCL and ask any questions. Feedback was regularly taken at these events to continuously improve them based on comments and views from attendees.

External learning events

A number of dedicated Low Carbon London learning dissemination events have been held on a range of topics throughout the project. These have been held in London with a wide variety of stakeholders attending, including other DNOs, DECC, Ofgem, press, energy suppliers, CHP operators, energy consultancies, EV public charge post operators etc.

External conferences

The project featured prominently both at national and international conferences on sustainable energy, smart cities and low carbon technologies, regularly presenting papers and operating an exhibition stand at a number of UK exhibitions.

DNO roadshows

The project has held a series of roadshows with other DNOs in late 2014, to facilitate detailed learning dissemination of the project's trial findings and outcomes. The project designed a series of bespoke sessions, local to each DNO, to enable an opportunity for detailed discussion on the project's trials, findings and outcomes. Each DNO was contacted in advance to discuss any requirements to cover particular aspects or topics within LCL. On the day, a series of presentations about the project gave each DNO a good opportunity to discuss in detail and question any aspect of the project within their own surroundings.

The roadshow structure comprised a series of presentations by LCL, covering all the project's trials, results, findings and outcomes. The format was deliberately informal with questions and challenges to the project encouraged from local DNO personnel throughout the day. The format was designed to give attendees a good in-depth insight into the project's work and findings in an open and candid style with the latter part of the day focusing on how the findings could apply or be applied to the local DNO.

The DNOs were asked to rate the usefulness of individual roadshow components as well as the overall value; the average overall rating was 4.15 out of 5 with no DNO rating lower than 4 out of 5. A consistent aspect of feedback was that all DNOs felt that the ability to use LCL's findings within their own organisation as challenging, with that consideration being rated lowest in three out of four DNO roadshows. Northern Powergrid was not included due to the LCNF peer review agreement in place with them – the roadshow material will be covered with NPG as part of that process. A full list of all the project's learning documents is contained in Appendix 11.

WPD DNO roadshow

The LCL roadshow for WPD was held at their offices in Tipton on 1 September 2014. Overall, WPD rated the roadshow 4.5 out of 5. They felt the most useful aspect of the roadshow was the "opportunity to discuss LCL's findings and results" which was rated 4.9 out of 5; however two aspects a) the "ability to use the findings and results" and b) the "potential benefits to the industry" were rated slightly lower at 3.9 out of 5.

The WPD questions covered the range of the project's findings with particular emphasis on the DSR findings as being the most useful and relevant. They also shared some of their own findings on EV charging, in particular how the location of a residential charge point (e.g. in a garage) and poor weather can impact charging behaviours. LCL also took WPD through the EV charging diversity curves (residential and commercial users) derived from the project's trial data and how that might impact future network planning assumptions.

WPD rated the DSR project outcomes as the most useful and the dToU outcomes as the least useful in terms of replicating the outcomes within the DNO.

ENW DNO roadshow

LCL's roadshow for ENW was held at their Preston office on 15 September 2014. They rated the roadshow overall at 4 out of 5, with two considerations a) "Insights into LCL findings and results" and b) "Potential benefits to the industry" both being rated at 5 out of 5; however, they rated the "ability to use LCL findings in your own organisation" lowest at 3 out of 5.

The main focus of the roadshow was on DSR with emphasis on the need to explicitly consider the procurement costs of DSR into any benefits calculations. The LCL project also demonstrated how the project's findings had been used to refresh and update some of the Planning Load Estimate (PLE) tool assumptions used within the UK Power Networks operational business. Other issues discussed in relation to DSR trials during the roadshow included:

- Cost of recruiting customers;
- Procurement concerns relating to fairness of offering;
- DSR for an Independent Distribution Network Operator (IDNO);
- Response rates;
- Operating / planning standards; and
- Defining the correct amount of DSR to procure.

Feedback from ENW on the replication of the projects' outcomes rated the outcomes from the smart meter data and the electrification of heat and transport as the most useful, with both DSR and dToU outcomes less useful.

Scottish Power Energy Networks roadshow

The LCL roadshow arrived at the IET's offices in Glasgow on 25 September 2014. It was particularly well-attended, with 22 people from SPEN at the roadshow. SPEN rated the roadshow overall at 4.1 out of 5, with two aspects rated highest at 4.5 out of 5; a) insights into LCLs results and findings and b) the opportunity to discuss the findings and results. The ability to use the findings and results within their own organisation was rated lowest at 3.8 out of 5.

In terms of the ability for the DNO to replicate the project's outcomes, the use of smart meter data for network planning and operation was rated the most useful, with dToU tariffs rated the least useful.

Much of the questioning focused on the dToU trials, with SPEN comparing the LCL findings with those from previous ToU tariff trials involving SPEN. The discussions also considered whether the DNO or the supplier should be responsible for taking the dToU tariff forward and the conflict and synergies of vested interests within the overall energy chain when considering dToU tariffs, wholesale price volatility, hedged positions and DNO network considerations. Questions were also asked around the trial governance structure in order to give participants the opportunity for structured monthly feedback, with a preference to see 'pence per kw hour' on their in-home display (IHD). As well as seeing the variations of price at different times of day through IHD messaging. The discussion also considered the wider topic of in-home automation and the fact that LCL trial was a completely un-automated i.e. customers had to physically turn off their appliances

The roadshow also spent considerable time reviewing the project's outcomes around smart meter data and diversity, specifically the approach to diversity e.g. grouping according to perceived wealth, as well as modelling assumptions and how this is translated to and influenced business planning. The project's monitoring of the Engineering Instrumentation Zones (EIZs) was also discussed in detail, and how the data showed imbalances across the network having an impact on losses, with the three EIZs of the London network having 27 distribution substations being monitored as part of the LCL trials.

SSE Energy Power Distribution roadshow

The LCL roadshow for SSE Power Distribution was held at their Reading office on 29 September 2014. The DNO rated the dToU outcomes as the most useful with I&C DSR and smart meter data the least useful project outcomes. Overall, the roadshow was rated at 4 out of 5.

On the dToU trial outcomes, there was discussion around the value of the 50W average demand shift; although it was pointed out that some participants had achieved shifts of over 200W. As with other roadshows, there was some in-depth discussion on how a DNO could use dToU tariffs within the wider energy supply chain and how the various actors within that chain could work collaboratively to use dToU tariffs.

The project's outcomes on EV charging were covered in detail; in particular, the regularity of charging, where LCL showed that if a vehicle had 75% charge remaining customers were less likely to charge, whereas if the battery dropped below 50% then they would charge it. There was also discussion on the peaks during different days of the week, with LCL data indicating that there was a Tuesday / Thursday charge cycle for most trial vehicles and a marked difference between Saturday / Sunday with Sunday charging being particularly popular as people prepared for the next working week. The DSR outcomes were also presented in detail with much discussion on how the project had derived updated F factors for input to network planning.

Final reports

The project has created a portfolio of 27 final reports. They document in detail the project's trials, findings outcomes, cost benefit analyses, recommendations and conclusions. They also consider some of the wider policy and strategic issues emanating from the project. They are grouped into four separate themes to aid the reader; the themes are a) Distributed Generation and Demand Side Response; b) Electrification of Heat and Transport; c) Network Planning and Operation and d) Future Distribution System Operator. An overall report DNO Guide to Future Smart Management of Distribution Networks accompanies these four themed groupings. A comprehensive reference list detailing the structured learning is contained in section 13 below. The project has created a similarly colour-coded themed box set of final report volumes to go to key stakeholders.

13. Key project learning documents

Project reports

The table below details all the project's 6 monthly progress reports and final reports. A confidential register of potential intellectual property assets has been maintained throughout the project and if requested will be made available to appropriate DNO personnel.

All reports, as well as further information on the project, can be accessed via the UK Power Networks innovation web portal at:
http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/

6 monthly progress reports (PPRs)	Location
June 2011	http://tinyurl.com/nf7y62x
December 2011	http://tinyurl.com/oqakopl
June 2012	http://tinyurl.com/nwla7m3
December 2012	http://tinyurl.com/oy25m9n
June 2013	http://tinyurl.com/oa5blvg
December 2013	http://tinyurl.com/qez3nv3
June 2014	http://tinyurl.com/pt7wocl
December 2014	

FINAL REPORT	DESCRIPTION	LINK
A1 Residential Demand Side Response for outage management and as an alternative to network reinforcement	Presents the impact on the distribution network of a wider scale roll out of a dynamic Time-of-Use tariff	http://tinyurl.com/ofe5u2s
A2 Residential consumer attitudes to time varying pricing	Outlines the results from the quantitative and qualitative assessment from the survey and interviews of customers on the dToU trial	http://tinyurl.com/ogf78vh
A3 Residential consumer responsiveness to time varying pricing	Explicitly describes the quantitative results in terms of load reduction and load shifting	http://tinyurl.com/njuruh4
A4 Industrial and Commercial Demand Side Response for outage management and as an alternative to network reinforcement	Presents the results from the I&C DSR trials and outlines the key considerations for DNO implementation of DSR and P2/6 planning assessments	http://tinyurl.com/pr7btc7
A5 Conflicts and synergies of Demand Side Response	Analyses the impact of multiple parties contracting DSR and potentially accessing the same resource	http://tinyurl.com/pelxeko
A6 Network impacts of supply-following Demand Side Response report	Focuses on the impact of low carbon led generation and the DSR market as DNOs will experience it in the years ahead	http://tinyurl.com/nl8p8zf
A7 Distributed Generation and Demand Side Response services for smart Distribution Networks	Presents the quantitative analysis of the I&C DSR trials and introduces alternative baselining techniques	http://tinyurl.com/np7kkov
A8 Distributed Generation addressing security of supply and network reinforcement requirements	Looks at the impact of having more DG connected to the distribution network and the potential improvement on security of supply	http://tinyurl.com/nn86eln
A9 Facilitating Distribution Generation connections	Determines how smart technologies such as Active Network Management can facilitate more capacity on the urban network for generation	http://tinyurl.com/o976jg5
A10 Smart appliances for residential demand response	Outlines potential response from smart appliances	http://tinyurl.com/pm7q3cn
B1 Impact and opportunities for wide-scale Electric Vehicle deployment	Focuses on presenting the results from the EV monitoring trials and the analysis on diversity and profiles for the observed loads.	http://tinyurl.com/phfdcqa
B2 Impact of Electric Vehicles and	Considers and models the expected impact of	http://tinyurl.com/one8k5o

Heat Pump loads on network demand profiles	EVs and HPs at a wider scale based on the trial findings	
B3 Impact of Low Voltage connected low carbon technologies on power quality	Connected low carbon technologies on Power Quality – covers the detail of the power quality of LCTs and the impact on the LV network	http://tinyurl.com/qeb9ym3
B4 Impact of Low Voltage connected low carbon technologies on network utilisation	Connected low carbon technologies on network utilisation – analyses the direct impact of high EV and HP uptake on the network at scale	http://tinyurl.com/qjpyguy
B5 Opportunities for smart optimisation of new heat and transport loads	Outlines the potential smart solutions such as Time-of-Use tariffs and ANM to address the impact of EVs and HPs on the network	http://tinyurl.com/oluu3es
C1 Use of smart meter information for network planning and operation	Presents the analysis of domestic customer's profiles as well as the voltage assessment from the engineering instrumentation zones	http://tinyurl.com/nvfcxra
C2 Impact of energy efficient appliances on network utilisation	Outlines the potential for reduction on energy use by efficient appliances	http://tinyurl.com/oqay4rq
C3 DNO Learning Report on Network impacts of energy efficiency at scale	Models the impacts and benefits of appliance efficiency on the distribution network	http://tinyurl.com/pwqaphf
C4 Network state estimation and optimal sensor placement	Describes a new approach to calculate the status of the networks without having full visibility of the network using a state estimation technique.	http://tinyurl.com/qxqfvh3
C5 Accessibility and validity of smart meter data	Assesses the validity of the smart meter data gathered throughout the trials	http://tinyurl.com/no9rsgn
D1 Development of new network design and operation practices	Outlines the key changes and considerations required for implementing the LCL findings into planning and network operation processes.	http://tinyurl.com/npttz9h
D2 DNO Tools and Systems Learning	Describes the Information Systems and Operational telecom systems required for the integration of smart meters and smart grid solutions	http://tinyurl.com/nryu73r
D3 Design and real-time control of smart distribution networks	Considers the potential new planning approaches including Option Value of DSR and Min/Max regret investment	http://tinyurl.com/ocauo2g
D4 Resilience performance of smart distribution networks	Develops the assessment of reliability for DSR and introduces an alternative approach to network reliability consideration	http://tinyurl.com/o739mqr
D5 Novel commercial arrangements for smart distribution networks	Defines some of the key considerations for the electricity industry on how dynamic networks will require more commercial flexibility	http://tinyurl.com/pye5e3o
D6 Carbon impact of smart distribution networks	Quantifies the carbon impact of deploying a full smart network and presents the impact of LCLs trials	http://tinyurl.com/osyoxoh
SUMMARY REPORT		http://tinyurl.com/nj7gth7

Project data

Where possible, data collected during the project will be made freely available to any interested party. This rich dataset will include;

- Domestic half hourly (HH) consumption complete with socio-demographic metadata
- Dynamic Time of Use HH consumption complete with price signal schedule
- Domestic surveys associated with Smart Meter and dToU trials
- Electric Vehicle charging data

Once collated, links to the data will be available via the Low Carbon London webpage available in section 14 below.

14. Contact details

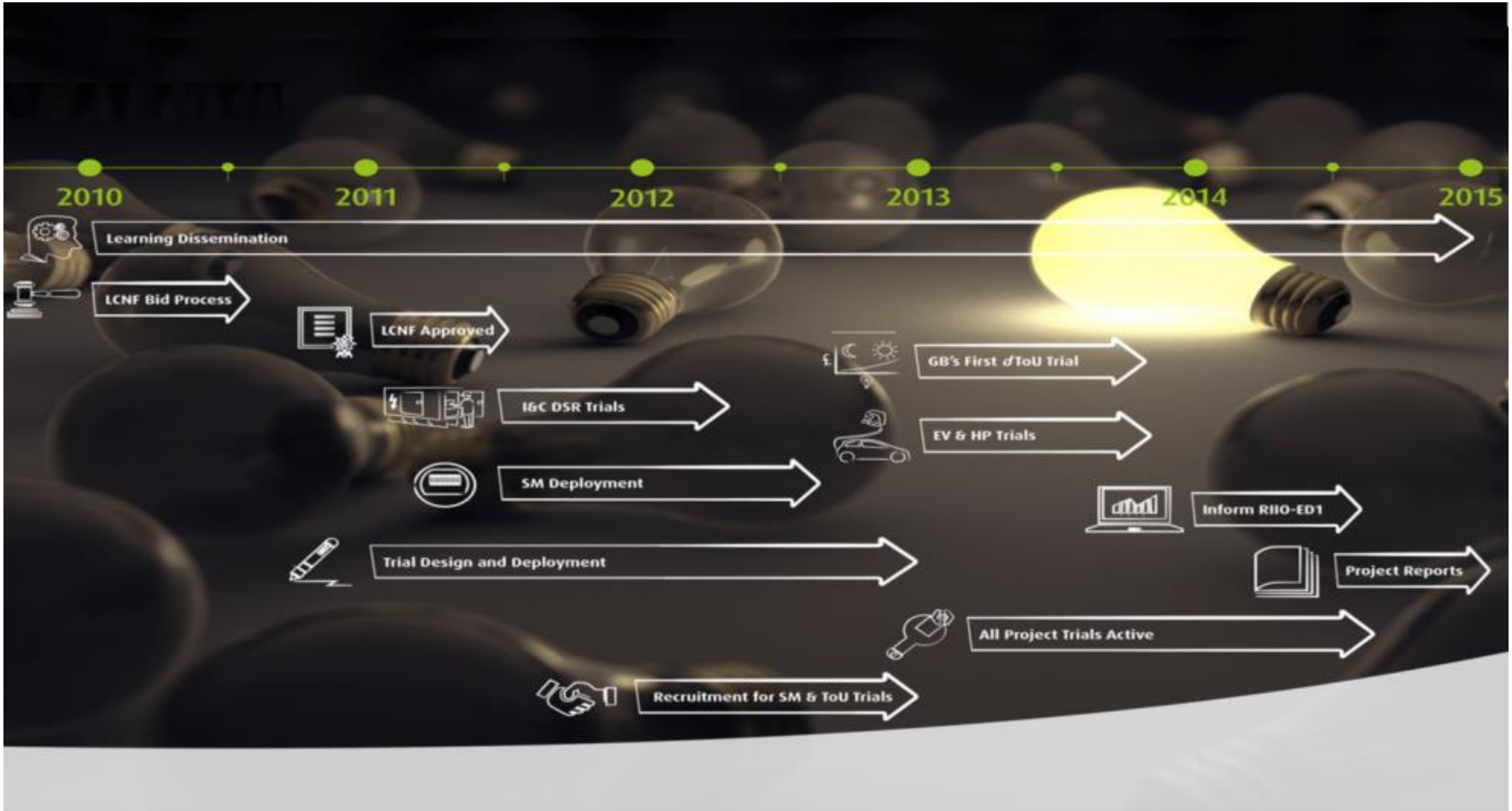
To obtain further information on learning from Low Carbon London please go to:
http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/

Or contact us at innovation@ukpowernetworks.co.uk

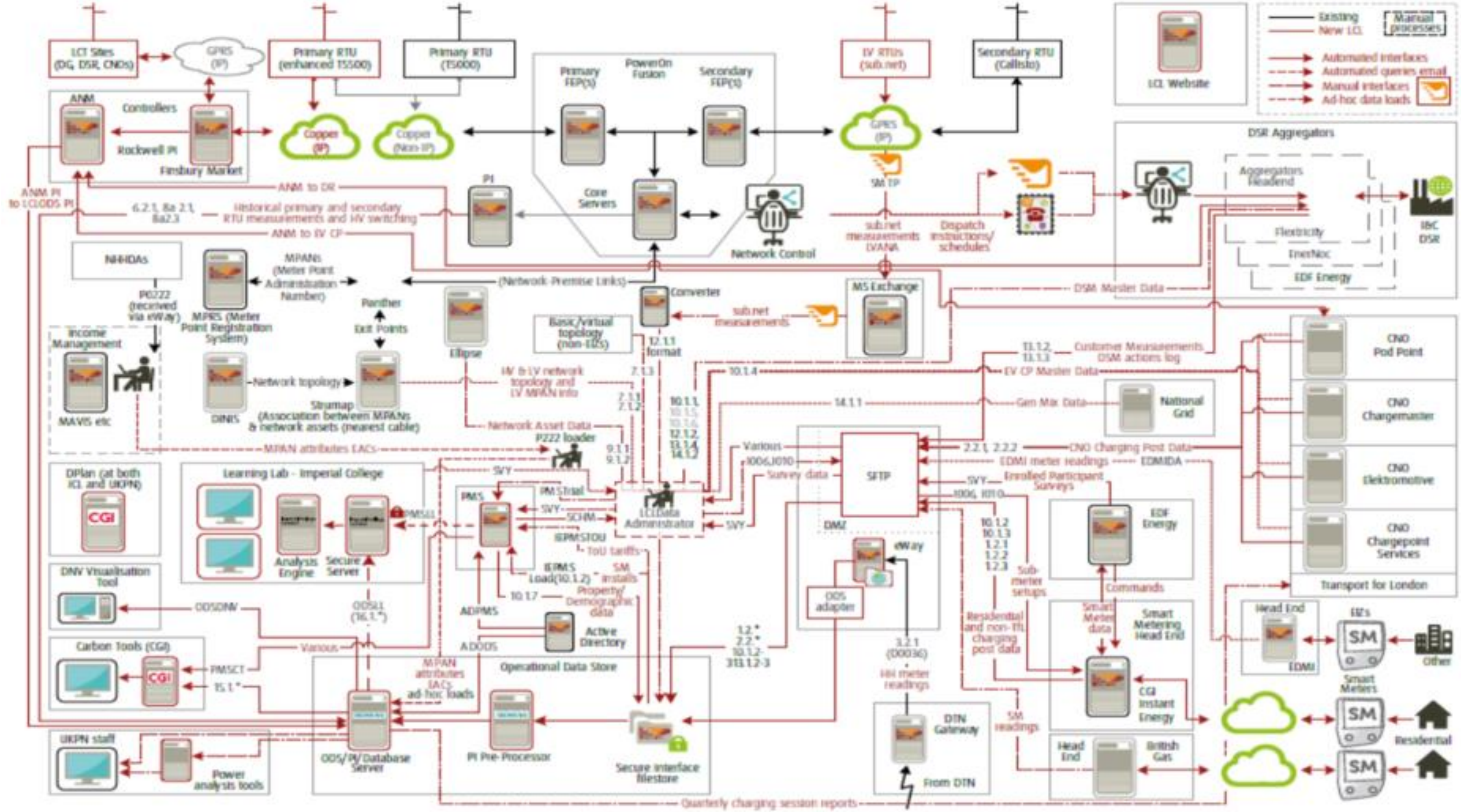
Low Carbon London, C/O Future Networks, UK Power Networks, Newington House, 237 Southwark Bridge Road, London SE1 6NP

List of appendices

Appendix 1 Project timeline



Appendix 2 IT architecture

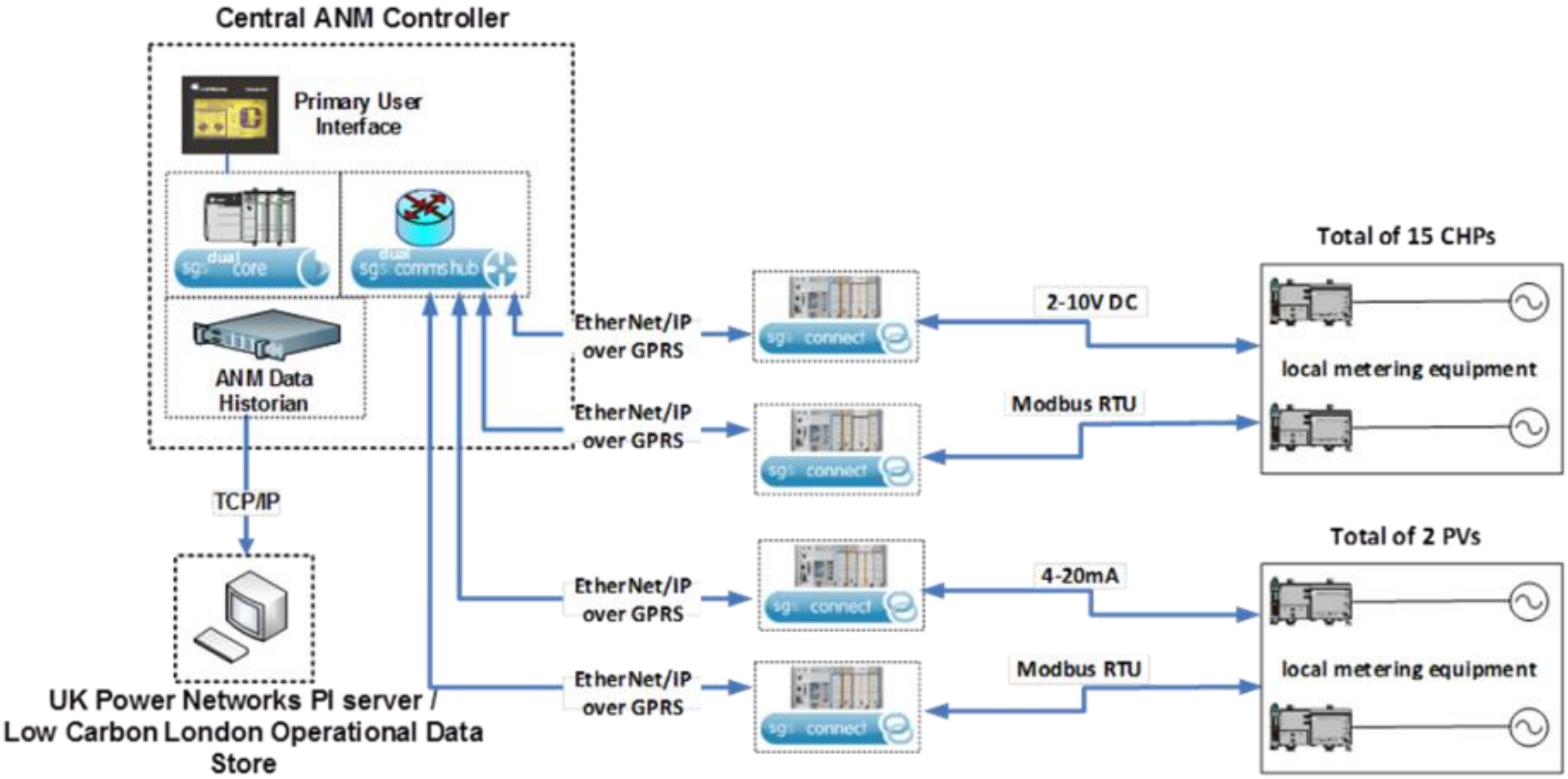


Appendix 3 Instrumentation and measurement framework

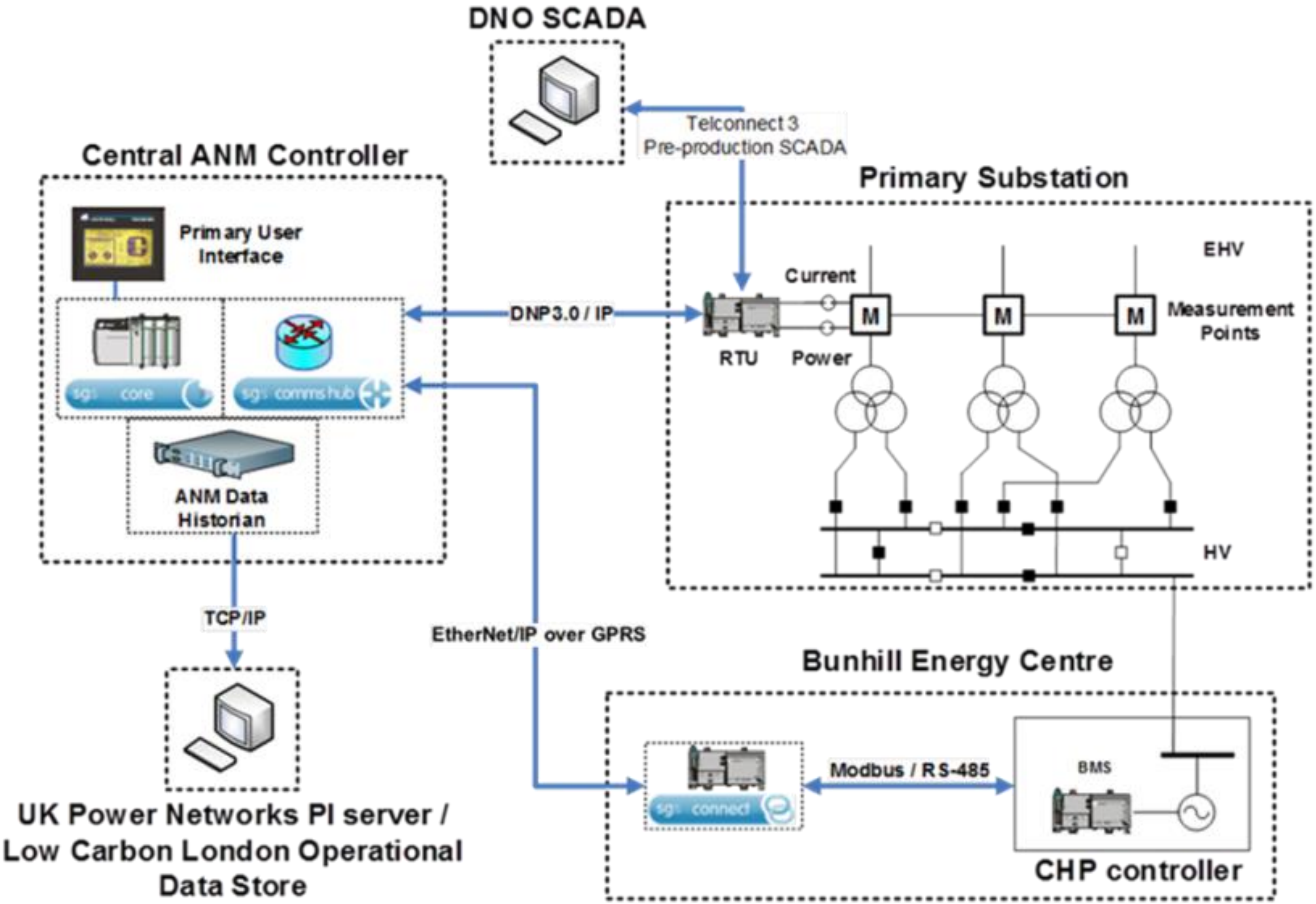
Monitoring Equipment	Measurement	Statistic	Units	Phase
EDMI MK7B Single phase smart meter	Real power	avg.	W	Single
	Reactive power	avg.	VAR	Single
	Apparent Power	avg.	VA	single
	Phase Angle Main	avg.		single
	Current	min, max, avg.	A	single
	Voltage	min, max, avg.	V	Single
	Voltage THD	avg.	%	Single
	Current THD	avg.	%	Single
EDMI MK 10A 3 phase smart meter	Real power	avg.	W	A,B,C
	Reactive power	avg.	VAR	A,B,C
	Voltage	min, max, avg.	V	A,B,C
	Voltage THD	avg.	%	A,B,C
	Current THD	avg.	%	A,B,C
HV Substation Monitoring Device Remsdaq Callisto 1 RTU	Current	avg.	I	A,B,C
	Voltage	avg.	V	A,B,C
	Real Power	avg.	kW	A,B,C
	Reactive power	avg.	kVAR	A,B,C
	Apparent Power	avg.	kVA	A,B,C
	Power Factor	avg.	n/a	A,B,C
	Voltage THD	avg.	%	A,B,C
	Air temperature	avg.	degrees	A,B,C
	Current THD	avg.	%	A,B,C
	Harmonic Content (1st-50th)	avg.	%	A,B,C
Primary Substation Monitoring Device GE Converteam T5000 or 5500 RTU	Current	avg.	I	A,B,C
	Voltage	avg.	V	A,B,C
	Real Power	avg.	kW	A,B,C
	Reactive power	avg.	kVAR	A,B,C
	Frequency	avg.	Hz	A,B,C
	Power Factor	avg.	n/a	A,B,C
LV Substation Monitoring Device EMS Sub.net LV	Current	Max, min, avg.	I	A,B,C
	Current THD			
	Voltage	Max, min, avg.	V	A,B,C
	Voltage THD			
	Real Power	Max, min, avg.	kW	A,B,C
	Reactive power	Max, min, avg.	kVAR	A,B,C
	Apparent Power	Max, min, avg.	kVA	A,B,C
	Voltage Harmonic Content (1st-50th)	Max, min, avg.		A,B,C
	Current Harmonic Content (1st-50th)	Max, min, avg.	%	A,B,C
LV Feeder Monitoring Device - 3 phase connections EDMI MK 10A 3 phase smart meter	Current	Max, min, avg.	I	A,B,C
	Voltage	Max, min, avg.	V	A,B,C
	Real Power	Max, min, avg.	kW	A,B,C
	Reactive power	Max, min, avg.	kVAR	A,B,C
	Apparent Power	Max, min, avg.	kVA	A,B,C

Monitoring Equipment	Measurement	Statistic	Units	Phase
	THD	Max, min, avg.	%	A,B,C
LV Feeder Monitoring Device - single phase connections Outram PM100	Voltage	Max, min, avg.	V	A
	Voltage THD	Max, min, avg.	%	A
	Current THD	Max, min, avg.	%	A
	Harmonic Content (1st-50th)	Max, min, avg.	%	A
LV Feeder Monitoring Device - Temporary installations Outram PM7000	voltage	Max, min, avg.	V	A,B,C,N
	Voltage THD	Max, min, avg.	%	A,B,C,N
	Current THD	Max, min, avg.	%	A,B,C,N
	Harmonic Content (1st-50th)	Max, min, avg.	%	A,B,C,N
	Real Power	Max, min, avg.	kW	A,B,C,N
	Reactive Power	Max, min, avg.	kVAR	A,B,C,N
	Apparent Power	Max, min, avg.	kVA	A,B,C,N

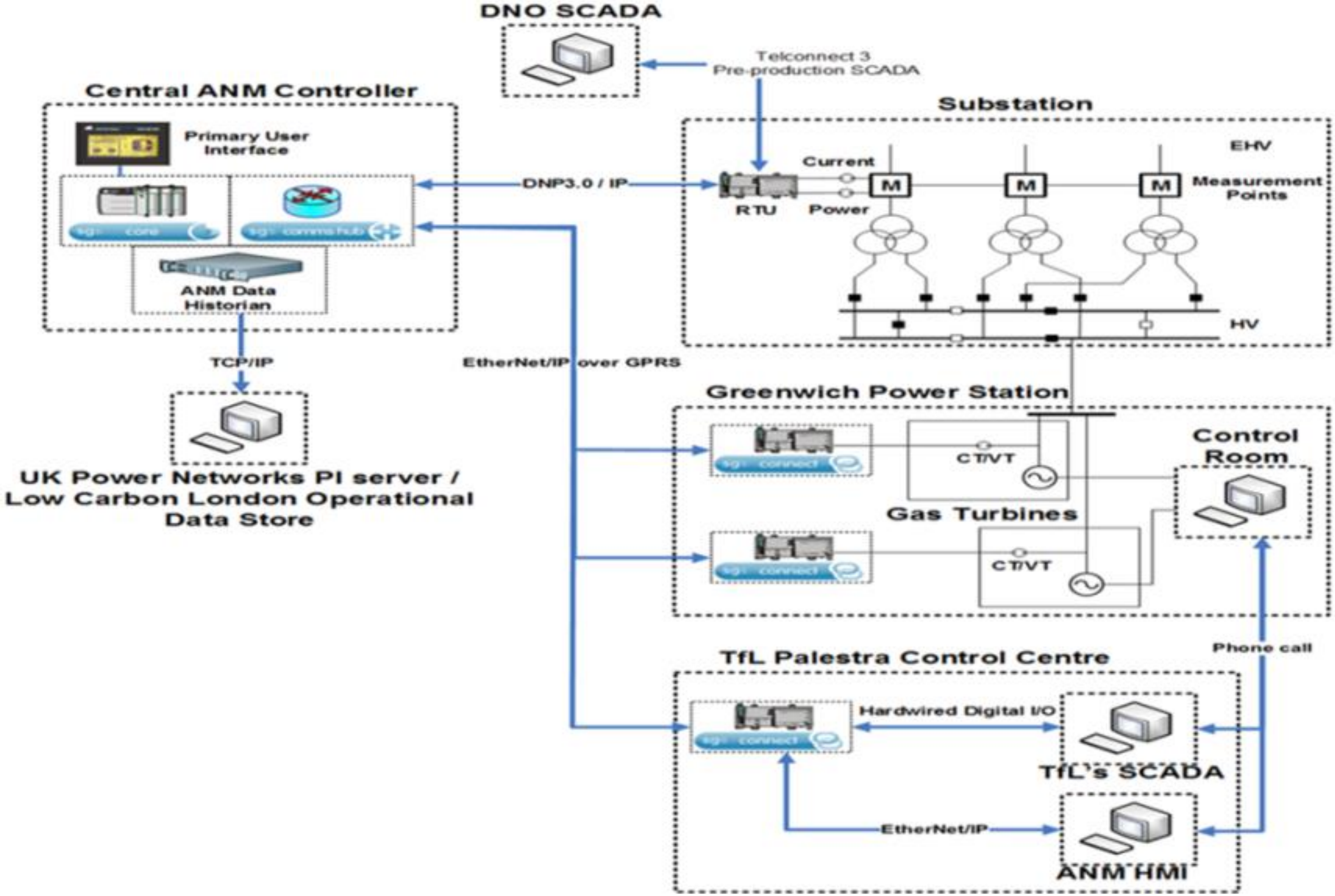
Appendix 4 Architecture used to monitor DG



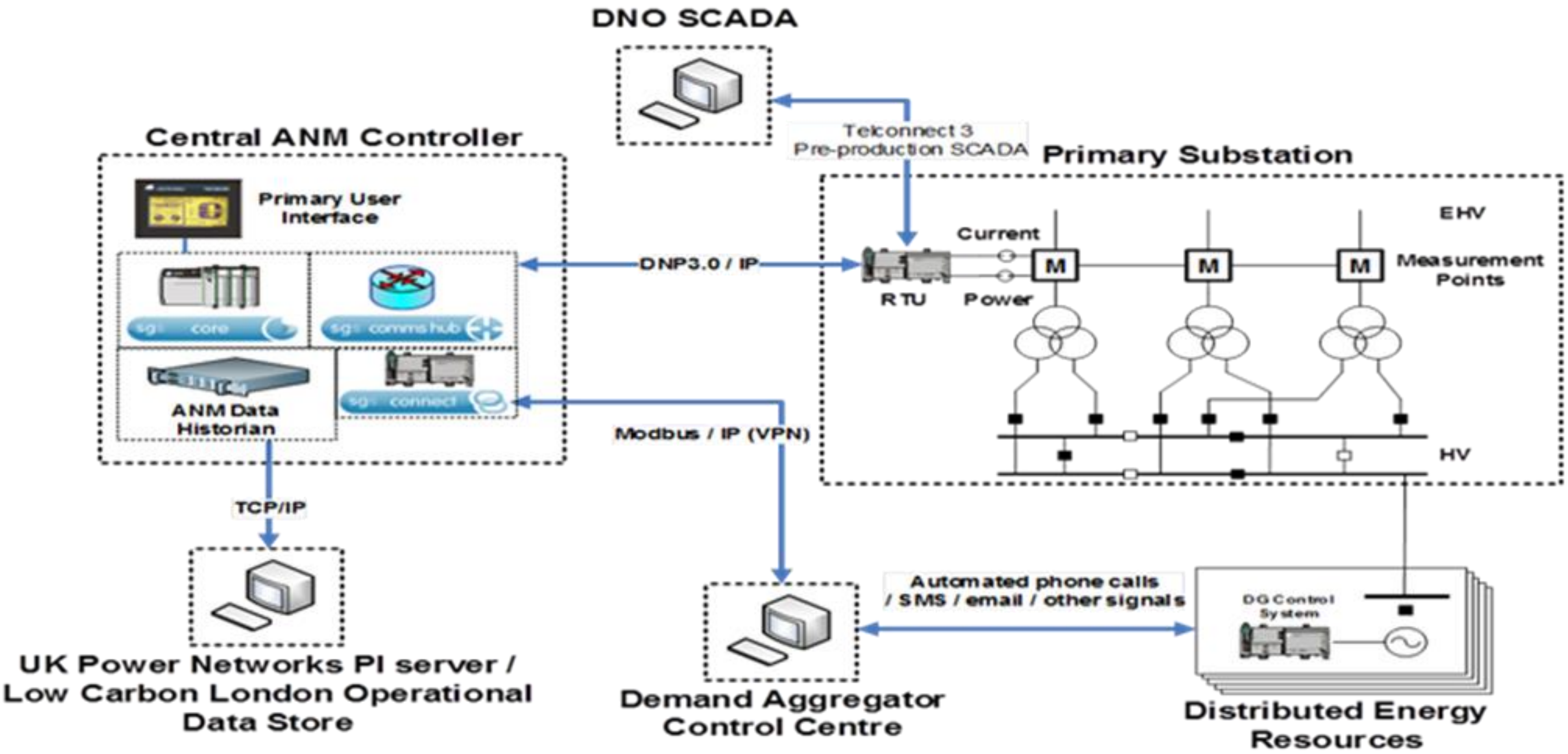
Appendix 5 Architecture used at Bunhill Energy Centre



Appendix 6 Architecture used at Greenwich power



Appendix 7 Architecture used for indirect ANM DSR trials



Appendix 8 IHD tariff message

Appendix 9 Expanded SDRC framework

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
Build Phase: • Preparation of solution implementation complete: Logica smart metering Head End solution and Learning Laboratory commissioned (Appendix 2, Use Case U07.1 and U07.2) • Preparation for c.5000 smart meter roll out complete, including address selection, acceptance surveys, privacy and security measures (working with GLA and Consumer Focus) **Completed Q3, 2011**	Evidence – Outputs and Learning • Demonstration of the Learning Laboratory facilities at Imperial College with documented schedule of trials ○ Clear visibility of scope of work packages ○ Clear alignment to Use Cases ○ Clear identification of project deliverables • Results of customer smart meter acceptance surveys ○ Overall quantification of acceptance ○ Identification of key concerns ○ Actions to improve level of acceptance • Documented Privacy and Security strategy ○ Overall risk assessment ○ Identification of pinch points ○ Scope for risk mitigation through data aggregation ○ Risk minimisation plan • Statistical analysis of smart meter trial sample size ○ To ensure statistical validity for extrapolation ○ Ensure samples sufficient to address variables (e.g. method of home heating / socio-economic consumer groupings / etc.) • Demonstration of initial functionality of Head End ○ Ability to (two-way) communicate	*Learning Lab at Imperial College was in constant use by LCL from early March 2011. Bespoke IT equipment was installed in May and June 2011. Following redecoration, it was officially opened on 5 October 2011 by Basil Scarsella, CEO UK Power Networks.* *The trial description documentation provided clear scope of work packages, alignment to use cases and deliverables.* *The use of PRINCE2 product descriptions ensured a clear focus on project outcomes and objectives.* *EDF Energy were fully mobilised in preparation for the pilot smart meter deployment, with telephone and mailshot recruitment (i.e. smart meter acceptance surveys).* *Learning from EDF Energy's pilot deployment of 500 smart meters was used to feed into main deployment (e.g. Saturday and evening appointments).* *Formal Privacy and Security assessment undertaken by external security expert, supplied by CGI. The reports produced provided risks assessment, pinch points, use of data anonymisation where*

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
	with smart meters ◦ Data volume capability proven	*appropriate and a full risk mitigation plan* *EDF energy and imperial College worked closely on targeted recruitment to deliver a fully demographically balanced recruitment pool.* *The design of the energy usage and appliance survey captured home heating methods* *CGI produced test and volumetrics data to prove 2-way head-end capability and data volume capability*
Build Phase: • 1st stage of solution implementation complete: Operational Data Store and interface to Logica head end commissioned, smart meter installation underway and "carbon impact tools" delivered Trial Phase: • Implementation of initial trials based on data from the initial smart meters and half hourly industrial & commercial (I&C) customer meters with analysed results **Completed Q2, 2012**	Evidence – Outputs and Learning: • Functioning Operational Date Store and head end accessing/processing smart meter information • Multipartite Demand side management (DSM) contracts between Aggregators, I&C customers, and EDF Energy Networks (documented contract implementation) • Initial CO_2 impact assessments	Siemens delivered the ODS Release 1 in March 2012 following extensive testing. Imperial College made additional functionality and user requirement changes. These were then incorporated into later releases. ODS training courses held for LCL and Imperial College LCL personnel at Siemens' training offices in York I&C DSR trial contracts in place between UK Power Networks, demand aggregators and their demand customers Development, testing and first production use of in-house carbon tool by CGI, data from initial I&C trial used as input data.

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
Build Phase: • Final stage of solution implementation complete: Operational Data Store and interface to Logica head end commissioned, smart meter installation completed **Completed Q4, 2012**	Evidence – Outputs and Learning: • Functioning Operational Date Store and head end accessing/processing smart meter information ○ Proven capability to process data from head end, undertake event processing to identify key data, aggregate and map data to network nodes	*June-December 2012 saw data flows demonstrated from source (EDF Energy smart meters), through head-end and into ODS.* *ODS network configuration and mapping data loaded routinely into ODS* *Mechanism established with EDF Energy to manage key events (change of tenancy, supplier switch etc.)*
Trial Phase: Conclusion of "Using Smart Meters and Substation Sensors to Facilitate Smart Grids" trials: • Understanding customer behaviour and potential network impact (Appendix 2, Use Case U04.1) • Use of smart meter information to support distribution network planning and design (Appendix 2, Use Case U04.2) • Use of smart meter data to support network operations (Appendix 2, Use Case U04.3) Complete Q3, 2014	Evidence – Learning: • Assimilation of network voltage and load profiles from smart meter data (up to 6,500 smart meters) to validate ADMD assumptions and determine critical design criteria as a guide to the more efficient planning of LV networks (for example with regard to thermal limits, losses, power quality and voltage optimisation) Evidence – Outputs: Learning Lab reports (Q2, 2014): • 1-1 Accessibility and validity of smart meter data • 2-1 Network state estimation and optimal sensor placement • 2-2 Accessibility and validity of substation sensor data DNO learning reports (Q3, 2014): • DNO learning report on the use of smart meter information for network planning and operation	*Smart meter and dToU trial ran through 2013. 5,533 participants, of which 1,119 were on the dToU trial. In addition, agreement reached with British Gas for a further 10,800 smart meters in London to be input to the project, making a total of 16,333 smart meters, with data for the full 2013 calendar year, all with CACI Acorn demographic profiles.* *EDMI meters at LV pot ends provided power quality and voltage data.* *ADMD analysis provided in conjunction with data analyst from PA Consulting.* *LCL final reports C1, C4, C5 and C6 provide the required report outputs.*
Conclusion of "Enabling and Integrating Distributed Generation" trials:	Evidence – Learning:	*Active network management schemes achieved at Bunhill Energy Centre DSR*

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
• Facilitating connections to LV and HV distribution networks (Appendix 2, Use Case U02.1) • Active management of DG to address security of supply concerns and postpone network reinforcement (Appendix 2, Use Case U02.2) • Exploring the impact of LV, G83 connected generation Complete Q3, 2014	• Proven capability of technical and commercial dispatch / curtailment of generation (est. 5 Active Network Management Schemes) with beneficial impact on network utilisation, voltage, load factor and/or fault level • Validation of ER P2/6 / ETR130 assumptions including Tm and F factors for specific generation technologies and applications • Guidance on successful approaches to, and value of, managing SSEG connections in order to preserve network operation and power quality while best enabling their connection Evidence – Outputs: Learning Lab Reports (Q2, 2014): • 3-1 Impact of LV connected DER on power quality • 4-2 Impact of LV DERs on network utilisation • 7-1 Opportunities for DG in the distribution network DNO learning reports (Q3, 2014): • DNO learning report for facilitating DG connections • DNO learning report for DG addressing security of supply and network reinforcement requirements	*trial, Greenwich Power DSR trial, POD Point EV active management trial, and numerous direct ANM events through Flexitricity using SGS equipment.* *P2/6 and ETR130 assumptions validated against LCL findings. New F Factors for continuous generation (Tm) also produced based on LCL findings.* *LCL recommendations and guidance on SSEG connections contained in final reports A7, A8, A9, B3 and B4.*
Conclusion of "Enabling Electrification of Heat and Transport" trials: • Exploring impact of electric vehicle charging (Appendix 2, Use Case U03.1) Exploring the impact of heat pump demand (Appendix 2, Use Case U03.2)	Evidence – Learning: • Evidence of real changes in load patterns due to: () ○ Heat pumps ○ Electric Vehicles ○ Micro-generation • Guidance on successful approaches to, and	*Load pattern analysis and diversity curves produced for EVs (private and I&C EV charging scenarios)* *Heat pump data was subject to Ofgem change request and external data provided PQA analysis of voltage.*

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
Complete Q3, 2014	value of, smart optimisation of EV charging to minimise peak demand and losses impact (maximising load factor) and to minimise need for reinforcement (maximising utilisation) Evidence – Outputs: Learning Lab Reports (Q2, 2014): • 3-1 Impact of LV connected DER on power quality • 5-1 Impact of opportunities for wide-scale electric vehicle deployment • 4-2 Impact of LV DERs on network utilisation DNO learning reports (Q3, 2014): • DNO learning report on the impact of EV and HP loads on network demand profiles • DNO learning report on opportunities for smart optimisation of new heat & transport loads	*PV loads analysed from EDF Energy customers and RTU data analysis from community PV projects in EIZs (Brixton and Queens Park)* *LCL final reports B1-B5 inclusive provide detailed analysis on EVs heat pumps and micro-generation.*
Conclusion of "Residential and SME Demand Side Management" trials: • Energy efficiency programmes and technologies (Appendix 2, Use Case U05.1.a) • Consumer behaviour demand response and responsiveness to TOU tariffs" trials (Appendix 2, Use Case U05.1.b) Complete Q3, 2014	Evidence – Learning: • Quantified impact of DSM and energy efficiency measures in terms of reduced peak demand • Effectiveness of TOU tariffs and analysis of price elasticity and hence necessary level of tariff incentive to deliver effective response Evidence – Outputs: Learning Lab Reports (Q2, 2014): • 6-1 Residential consumer attitudes to time varying pricing • 6-2 Residential consumer responsiveness to time varying pricing6-4 Smart appliances for residential demand response	*Detailed quantitative analysis by Imperial College through smart meter data and energy survey results.* *dToU effectiveness assessed through detailed analysis of consumption changes* *Price elasticity analysis from differences in shifts between low and high tariffs.* *LCL final reports A1, A2, A3, A10, C2 and C3 provide detailed analysis.*

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
	• 4-1 Impact of energy efficient appliances on network utilisation DNO learning reports (Q3, 2014): • DNO learning report on network impacts of energy efficiency at scale • DNO guide to residential DR for outage management and as an alternative to network reinforcement	
Conclusion of "I&C Demand Side Management" trials: • Demand side management with I&C customers (Appendix 2, Use Case U05.2) • Demand side management conflicts and synergies (Appendix 2, Use Case U05.3) Complete Q3, 2014	Evidence – Learning: • Real examples of DSM contracts with I&C customers covering highly utilised networks with clear benefits of peak demand shifting capability under unplanned outage conditions • Quantification of risk and benefit of using I&C DSM as an alternative to network reinforcement - as a guide to more efficient planning for network security and as an input to an expanded version of ETR 130 (for example deriving equivalent F and Tm factors) Visibility of synergies (and/or method of resolving conflicts) between NG and EDF Energy Networks requirements for responsive demand Evidence – Outputs: Learning Lab Reports (Q2, 2014):	*DSR contracts in place during all DSR trials; UK Power Networks committed to £43.5 of DSR savings in ED1 period based on LCL learning.* *Detailed quantitative analysis by Imperial College of I&C DSR trial results to provide ETR130 analysis including F Factors with persistency (Tm) of generation.* *LCL participated actively in discussions with National Grid both with the wider DNO-National Grid conflicts and synergies workshops as well as preceding that initiative with individual LCL consultations with National Grid.* *LCL final reports A4, A5, A6 and A7 provide detailed analysis*

Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
	• 7-1 Distributed generation and demand response services for the smart distribution network DNO learning reports (Q3, 2014): • DNO guide to I&C DR for outage management and as an alternative to network reinforcement • Conflicts and synergies of DR • DNO impacts of supply-following DR report	
Conclusion of "Wind Twinning" trials: • Wind twinning through ToU tariffs with suppliers (Appendix 2, Use Case U01.1) • Wind twinning through responsive demand contracts with commercial aggregators (Appendix 2, Use Case U01.2) Complete Q3, 2014	Evidence – Learning: • Identification of scope for manipulating demand (through commercial incentivisation) to follow wind output • Assessment of potential for: ○ optimisation of system level real time demand to minimise CO_2 emissions; ○ reducing cost of system residual balancing; ○ minimising requirement for generation plant margin; and ○ minimising price volatility Evidence – Outputs: Learning Lab Reports (Q2,2014): • 7-1 Distributed generation and demand response services for the smart distribution network DNO learning reports (Q3, 2014): • DNO impacts of supply-following DR report	*Residential wind twinning achieved through use of specific dToU tariff changes, determined by EDF Energy and Imperial College and deployed as part of the year-long dToU trial.* *Analysis includes assessment of incentive levels required to deliver required shifts.* *I&C wind twinning achieved in conjunction with real data from Elexon on actual wind generated grid mix changes and triggering DSR events on that basis.* *LCL final reports A1, A6 and A7 provide detailed analysis*
Conclusion of final analyses: • New network design and operational practices (Appendix 2, Use Case U08)	Evidence – Learning: • Consolidation of outputs from all trials as a comprehensive guide to the future smart	*LCL final reports D3, D4, D5 and D6 provide detailed consolidated analysis* *LCL final report D1 provides analysis of*

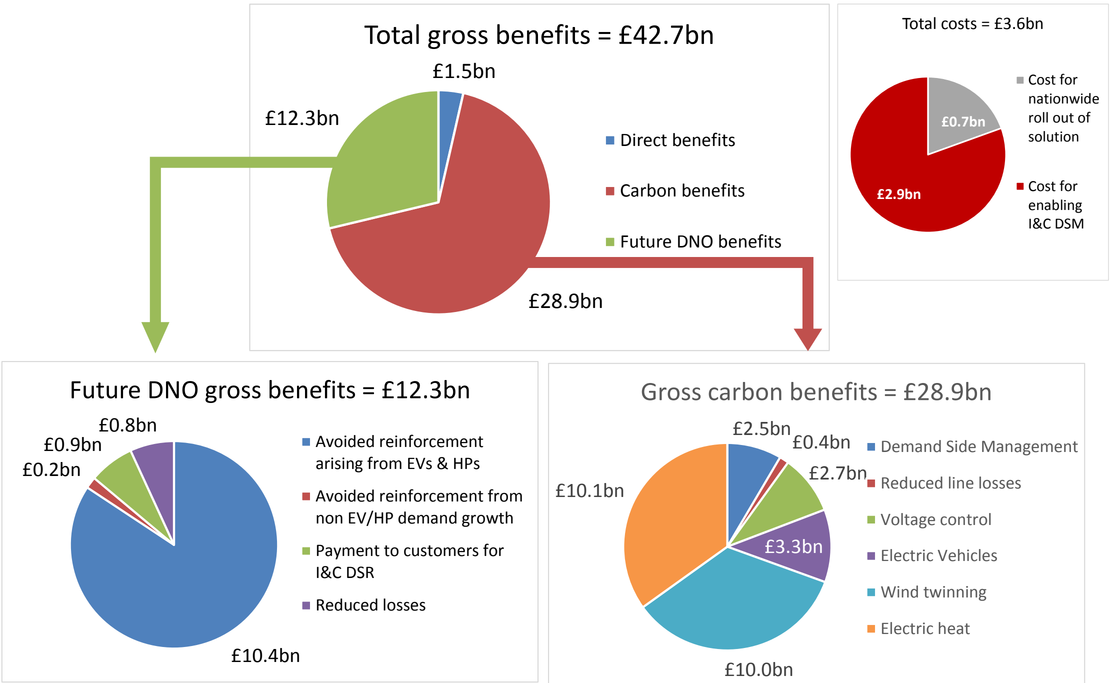
Successful Delivery Reward Criterion	Evidence	How LCL met the SDRC
• New network planning and operational tools (Appendix 2, Use Case U06) Complete Q4, 2014	management of distribution networks with high penetrations of DERs and low carbon applications, including the applicability of commercial contracts and incentives to encourage smart management of demand and generation • Quantified overall CO_2 savings and LCTP contributions Evidence - Outputs: Learning Lab Reports (Q4, 2014): • 11-1 Design of smart distribution networks • 11-2 Resilience performance of smart distribution networks • 12-1 Novel commercial arrangements and the smart distribution network • 14-2 Carbon impact of smart distribution networks • 14-3 Overall summary report DNO learning reports (Q4, 2014): • DNO design and operations learning report • DNO tools and systems learning report • Final Report - DNO Guide to Future Smart Management of Distribution Networks	*new network design and operation practices* *LCL Report D2 provides analysis of DNO Tools and Systems Learning* *LCL Report D3 combines reports 9-1 and 11-1 for ease of reading* *LCL Report SR provides a consolidated DNO Guide to Future Smart Management of Distribution Networks*

Appendix 10 Business case review and update

As part of the proposal submitted to Ofgem, an assessment of the potential benefit of flexible demand to the DNOs and the network more generally was prepared, covering the period between 2010 and 2050. The benefit case was divided into four parts:

1. Direct benefits arising from conducting the LCL trials (**£1.5bn**)
2. Benefits that might be expected to accrue to DNOs from their making use of flexible demand (**£12.3bn**)
3. Carbon benefits that might accrue to the electricity system more broadly as a result of flexible demand (**£28.9bn**)
4. Costs associated with rolling out the measures considered under LCL to all DNOs (**£3.6bn**)

Figure 15 Benefit case in the original LCL bid



Revised CBA approach

This report is intended to review and update the original benefit case, assessing the approach that was taken, correcting calculations where necessary, incorporating LCL trial findings and updating assumptions on exogenous variables, such as carbon intensity of the electricity system, to reflect latest projections.

The distinction originally made between DNO benefits and wider system benefits is retained. However, it is important to note the philosophical distinction between the two. The benefit that arises from smart grids depends on how flexible demand is used and, crucially, which market participant has control.

- When considering the ***DNO benefits***, it is assumed that the DNO has control of the flexible demand, and can use it to mitigate local constraints, and thereby defer reinforcement or manage outages. It is assumed that the DNOs are the sole direct beneficiaries of this flexibility, although customers would ultimately share this benefit through a reduction in their Distribution Use of System (DUoS) charges. In principle there could be some associated carbon reduction from the DNO actions, but this is likely to be small given that load management events would be infrequent. This benefit is therefore ignored.

- The assessment of ***carbon benefits*** assumes that the DNOs do not have sole control of the flexible demand. Rather, the flexible demand may be used to avoid periods of high prices, shift consumption to lower priced periods (thus reducing wind curtailment), or to provide balancing services to the transmission grid. In this world, DNOs could benefit to the extent that local network peaks coincide with wider system actions, but this coincidence is not guaranteed, and may be insufficient for DNOs to defer capital expenditure.

Report structure

- The first section is intended to correct the original claimed net benefit, changing only those parts of the calculation that should have been different when the bid was submitted. This includes correcting calculation errors, but also involves removing claimed benefits that were not addressed as part of LCL.
- The next section focuses on the DNO benefits that can arise from DNO-led flexible demand. The benefit is calculated as follows:
    - Retaining the original bid approach, but updating the relevant parameters to reflect learnings from the LCL trials, and updating electricity system assumptions (e.g. generation mix and LCT uptake) to reflect more recent projections
    - Using the Cost Benefit Analysis (CBA) that was carried out as part of the LCL project to provide a revised estimate of the DNO benefit
- The following section focuses on the wider system carbon benefits that can arise from flexible demand. This assumes that flexibility can be exploited by multiple market participants (i.e. not only DNOs), and so can be thought of as the total carbon benefit that flexible demand can provide. This benefit is calculated as follows:
    - Projections relating to LCT uptake, grid carbon intensity and carbon values are updated. Otherwise, the underlying approach taken in the original bid submission is left unchanged
    - Carbon reductions are compared with a report by Imperial College London[10] that uses a modelling approach to assess the carbon reduction that flexible demand could enable in the future. For the years modelled, the value of the carbon is estimated for comparison with the original bid approach
- The final section brings together the corrections and exclusions, the revised DNO and carbon benefits to give and overall indication of the benefit of flexible demand to DNOs and to the wider system.

Revising the bid-stage benefit

The scope of this section of the report is relatively narrow: it is not intended to critique the overall approach taken, or to revise assumptions made about the future electricity grid. Rather, it focuses on:

- Correcting those line items that contained calculation errors
- Removing those line items that reflect benefits, but that fall outside the scope of the LCL project
- Updating using better assumptions that were available at the time of the bid.

Revising the net benefit

The corrections to the original analysis are summarised in the following section. After these corrections the Net Present Value (NPV) of smart-enabled flexible demand to 2050 falls from **£39.1bn** to **£38.6bn**.

[10] M. Aunedi, F. Teng, G. Strbac, "Carbon impact of smart distribution networks", Report 14-2 for the "Low Carbon London" LCNF project: Imperial College London, 2014.

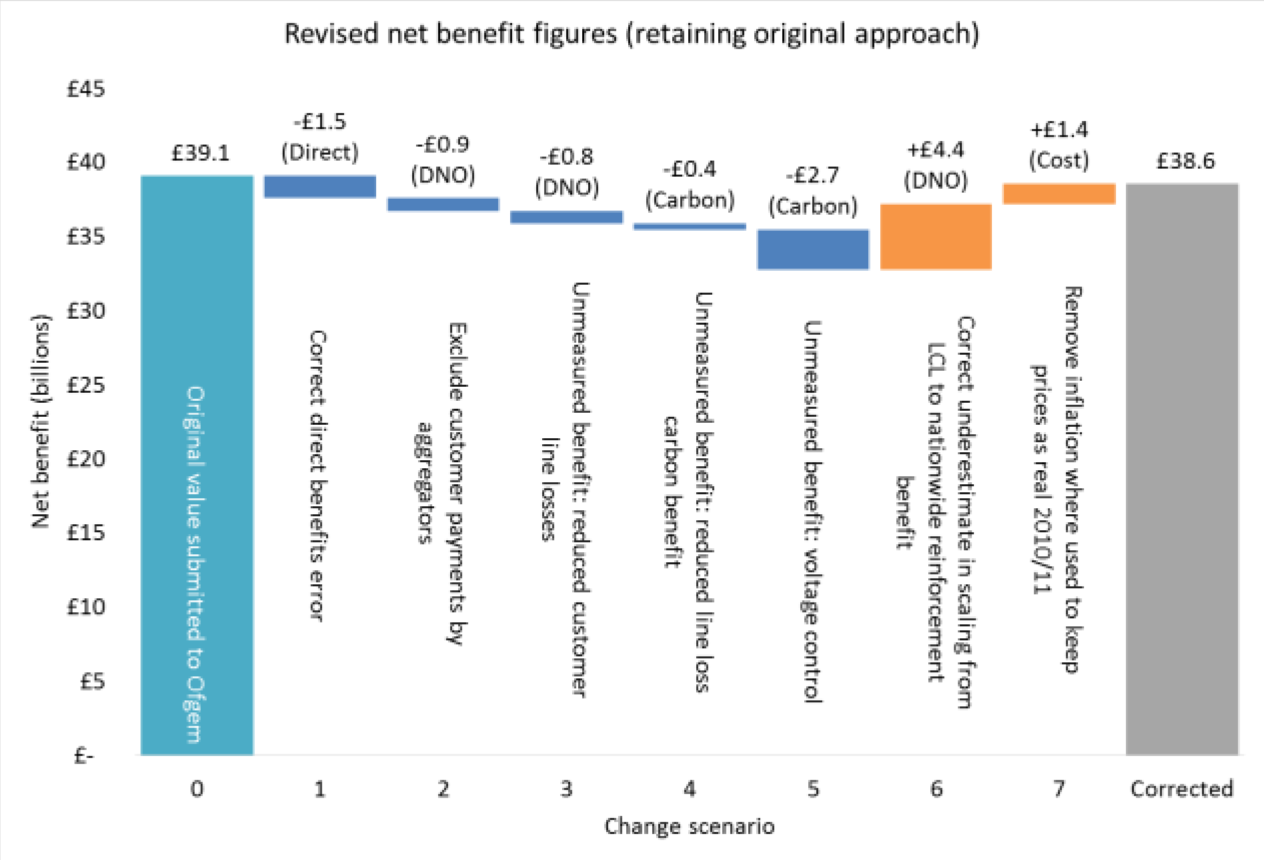


Figure 16 Net benefit corrections from the original LCL bid

A more detailed explanation of each change is given below:

1. **Direct benefits attributable to the project:** Direct benefits were expressed in billions rather than millions. The £1.5m direct benefits are relatively small compared with the other benefits, and are not investigated further.
2. **Customer payments:** Customer payments by aggregators for Industrial & Commercial Demand Side Response (I&C DSR) were given as a DNO benefit. These should more properly be treated as a sharing of the payment made by the DNO to the aggregators, and hence have no bearing on the net benefit of DSR.
3. **Loss reduction (DNO benefit):** The LCL trials did not explicitly measure loss reductions. What estimates were made for the LCL CBAs showed negligible reductions, primarily because DNO-led DSR and dToU interventions were made infrequently. This line has therefore been removed.
4. **Loss reduction (Carbon benefit):** Similarly, a reduction in line losses was assumed to contribute to a carbon reduction for the system as a whole. Whilst it is true that flatter profiles arising from flexible demand should reduce losses, since this benefit was not considered as part of LCL this line is excluded.
5. **Voltage control:** This may provide carbon benefits, but this was not investigated under LCL
6. **Overly conservative attribution of smart benefits to project:** In a number of cases, an assumption is made about the proportion of an overall benefit that can be attributed to the LCL project. In this case, this scaling factor was applied before extrapolating from LPN to nationwide and after this extrapolation had been done. Without addressing whether scaling the benefit in this way is appropriate, it is thought that it should only be done once.
7. **Apply real prices consistently:** The Retail Price Index (RPI) was used to scale some of the cost items, which was overstating these costs. All cash flows have now been expressed in 2010/11 real terms.

Gross benefit and the treatment of costs

The costs behind the net benefit figure were based on an extrapolation from the LCL trials, and on an estimate of availability and utilisation payments required to enact DSR. With the exception of removing RPI (step 7 above), which reduced costs from **£3.6bn** to **2.3bn** as shown below, the approach towards calculating these costs has not been altered from the original analysis.

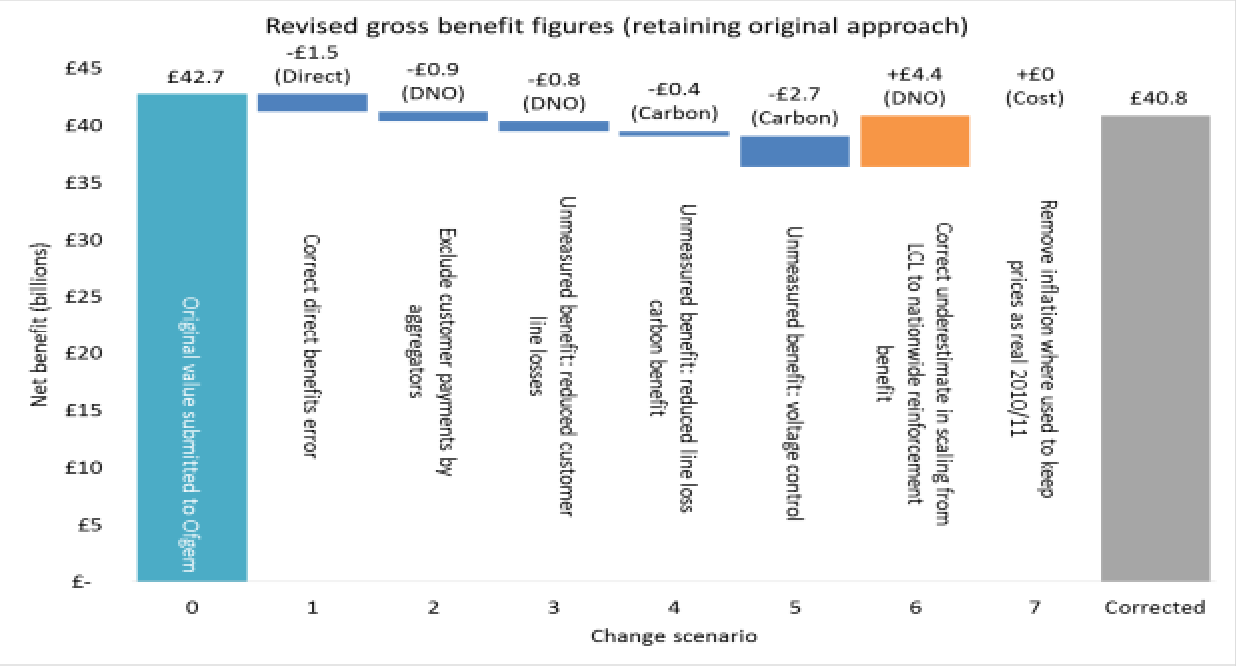
Figure 17 Impact of correction on cost estimate

However, the costs of implementing and enacting "smart" behaviour are not straightforward to calculate, and depend heavily on how this roll-out is carried out. A full discussion of these costs can be found in the CBA sections of reports A1 (dToU), A5 (I&C DSR) and B5 (smart EVs), but some of the issues include:

- There is undoubtedly a cost associated with rolling out either residential dToU or EV ToU systems. If the DNOs have to pay suppliers to pass through dToU signals, these costs could be prohibitively high if they cannot be shared with other market participants. It may be, however, that these tariffs are mandated, in which case some costs could be avoided, such as customer recruitment. A mandated scheme could also remove the burden from DNOs, although ultimately there would still be substantial costs faced by suppliers, who would then presumably attempt to pass these through to customers.
- DSR costs for DNO-led actions can be more robustly estimated. Report A5 estimated that £5.7m of net benefits could be derived from DSR in LPN over ED1 & ED2, taking into account £7.5m of costs to set up the systems and processes, and to make availability and utilisation payments, amounting to 57% of the gross benefit. This figure is for the specific case in which DSR can be used by DNOs on a post-fault basis to defer reinforcement or manage outages. The relationship between costs and benefits of using DSR for delivering carbon benefits has not been studied.

For the remainder of this report, therefore, the focus is on the gross benefits of smart grids. Where figure 17 showed the evolution of the net benefit, figure 19 shows the same evolution but only for the gross benefit. The resulting "corrected" gross benefit figure of **£40.8bn** forms the basis of the subsequent sections.

Figure 18 Gross benefit corrections from the original LCL bid



This **£40.8bn** "corrected" estimated of gross benefits comprises:

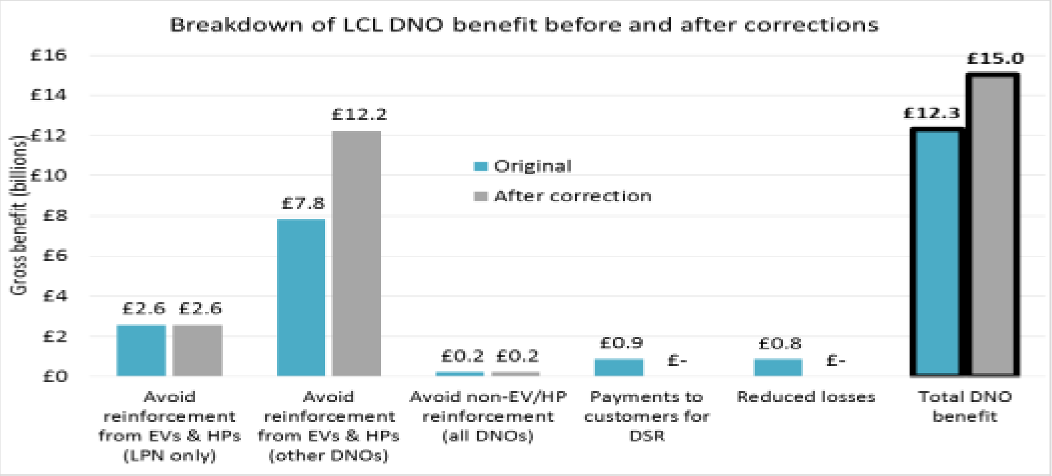
- **£15.0bn** of DNO benefits from using "smart" to defer reinforcement and manage outages. This compares to **£13.8bn** estimated from the original bid, which included £1.5bn of direct benefits[11].
- **£25.8bn** carbon reduction from using "smart" to benefit the electricity system more widely, compared to **£28.9bn** in the original bid.

These two categories of benefit are investigated further in sections 3 and 4, respectively.

DNO gross benefits from DNO-led demand flexibility

This section considers the gross benefit that DNOs could receive from controlling flexible demand, taking into account, where possible, the learnings from the LCL trials, and using DECC's and National Grid's latest projections for the composition of the electricity system and the value of carbon. Having carried out the update detailed above the originally quoted gross benefit accruing to DNOs is increased from **£12.3bn** to **£15.0bn**, as shown in figure 19 below.

Figure 19 Corrections to DNO gross benefits in the original LCL bid



[11] Note that having corrected the £1.5bn direct benefits down to £1.5m, these are minimal when compared with the other benefits and are ignored for the remainder of this report

By excluding customer payments and reduced losses, all the benefit of flexible demand under this approach comes from avoiding reinforcement. Reinforcement costs are incurred for two reasons under the original approach:

- In addition to the baseline growth rate, it was assumed that the uptake of Electric Vehicles (EVs) and Heat Pumps (HPs) would contribute to DNO reinforcement costs. However, because these forms of demand could be flexible, the DNO could reduce their impact on reinforcement costs by exploiting that flexibility to manage peak load. Considering only EVs, an estimate was made for cost of EV uptake to UKPN in the LPN region, and the subsequent benefit that flexibility would give. This was then scaled up to the whole of the UK based on the relative load-related reinforcement costs between the network areas. Over the period from 2010 to 2050, the "corrected" Present Value was calculated at **£2.6bn** for LPN and **£12.2bn** for the other network areas.
- Annual load-related reinforcement spend by all DNOs between 2010 and 2015 was estimated by Ofgem[12] to be £275m. The same report referenced a Brattle Group study[13] suggesting that 10% peak reduction could be achieved through a combination of load reduction and load shifting. These assumptions were used as the basis of the benefit calculation, although the overall benefit was reduced by assuming that DSR uptake ramped up over seven years. The claimed benefit was further reduced by assuming that only a proportion of this benefit could be attributed to the DNO. The Present Value of these benefits between 2010 and 2050 were calculated at **£0.2bn** (2010/11 prices).

The LCL trials and subsequent analysis allow these two figures to be revised, giving the revised reinforcement benefit estimates arising from the LCT-driven growth and more organic growth of existing demand.

Updated EV/HP-related reinforcement costs & benefit

It was assumed in the original bid that EV uptake had the potential to impose significant costs on DNOs by requiring substantial additional investment. In calculating the cost, the assumption was made that the contribution of EVs to the network peak load could be determined by simply summing the individual EV peaks. In practice, EV peaks do not always coincide with each other, meaning that some diversification that can be assumed when combining multiple EVs. Because this diversity had been ignored, the cost of integrating EVs into the network had been overstated.

The benefit of "smart" EVs to the DNO can be broken down into 3 elements:

- What is the average contribution of an EV to the network peak (**Average EV peak**)?
- How many EVs are expected to be added to the network (**EV uptake scenario**)?
- By how much can "smart" measures reduce the contribution of the EV to the network peak (**Flexibility**)?

As the table below shows whilst the apparent benefit of making EVs "smart" has reduced considerably since the bid stage, the most significant driver for this has been the realisation that the underlying cost of EVs on the network is likely to be lower than originally anticipated.

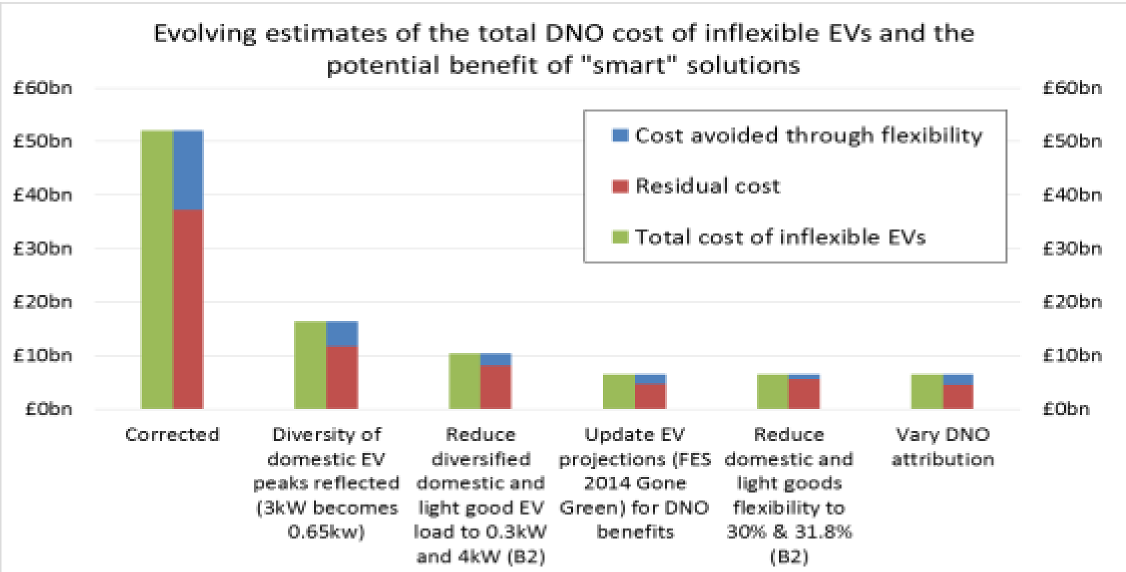
[12] https://www.ofgem.gov.uk/ofgem-publications/57026/dsr-150710.pdf
[13] http://www.brattle.co.uk/system/publications/pdfs/000/004/721/original/Unlocking_the_EU53_Billion_Savings_From_Smart_Meters_in_the_EU_Oct_2009.pdf?1378772124

Assumption	Reason for assumption change	Average EV peak	EV uptake scenario	Flex-ibility	Underlying EV cost	NPV of smart EVs
Original bid (un-corrected)	Of the total benefit of smart EVs, the amount to attribute to the project was under-stated. Some EV peak diversification should also have been assumed.	3kW residential/ 4.5kW commercial	DECC 2050 pathways	60%	£52.0bn	£10.4bn
"Corrected" bid	Gave a consistent view of the attribution of smart benefits to the LCL project, but diversification still not included.	3kW/4.5kW	DECC 2050 pathways	60%	£52.0bn	£14.8bn
Pre-LCL diversity view	At the time of the bid submission, Imperial College had produced a parallel report in which a diversified residential EV profile was assumed, and which was significantly lower.[14]	0.6kW/ 4.5kW	DECC 2050 pathways	60%	£16.3bn	£4.6bn
Post-LCL diversity view	Trials showed some variation between the days of the week, but the average contribution from residential EVs to the diversified residential peak demand is 0.3kW. Commercial EVs have higher capacity, are estimated to be fewer in number, more concentrated on the network, and with more correlation in charge times, so a diversified peak of 4kW is assumed.	0.3kW/4kW	DECC 2050 pathways	60%	£10.3bn	£2.2bn
Lower EV uptake (Gone Green)	The EV uptake assumption around this benefit was based on a scenario in the DECC 2050 pathways report which indicated that 50% of vehicles could be electric by 2050. A number of different projections exist, but the revised assumption is based on National Grid's Future Energy Scenarios (FES) "Gone Green" case (extrapolating linearly from 2035).	0.3kW/4kW	FES Gone Green	60%	£6.4bn	£1.7bn

[14] 'Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks', April 2010, available at: http://www.energynetworks.org/modx/assets/files/electricity/futures/smart_meters/Smart_Metering_Benerfits_Summary_ENASEDGImperial_100409.pdf

Assumption	Reason for assumption change	Average EV peak	EV uptake scenario	Flex-ibility	Underlying EV cost	NPV of smart EVs
Lower flexibility	The LCL dynamic Time of Use (dToU) trials gave an indication of the reduction in peak that can be achieved in practice. On average 48W of reduction could be achieved by dToU in a residential setting. Of a household winter peak load of 800W, 160W was estimated to be discretionary. This suggested that 30% of discretionary load could be shifted. On the broad assumption that all EV load is discretionary, it was assumed that 30% peak reduction could be achieved.	0.3kW/4kW	FES Gone Green	30%	£6.4bn	£0.9bn
Fully exploit flexibility for benefit of DNOs	A conservative view had been taken, whereby only a proportion of the benefit of smart EVs was deemed to be attributable to the project. If this scaling factor is removed, the apparent benefit of "smart" is increased, although this represents the upper limit of DNO benefit, and would assume that all EV flexibility could be used solely to defer network reinforcement.	0.3kW/4kW	FES Gone Green	30%	£6.4bn	£1.9bn

Figure 20 Cost of EV as assumptions evolve and the corresponding benefit of flexibility



The relative financial impact of changing each of the main drivers of "smart" EV value depends on the order in which those changes are applied. Nevertheless, the most significant reason why the benefit is expected to be lower than at the bid stage is that the underlying cost of EVs to the DNOs is likely to be lower.

It is worth noting that both the original bid and this revised estimate exclude benefits from smart Heat Pumps. LCL trials did not test HP flexibility directly. Also, Imperial College London's carbon impact report[15] suggests that where EVs and HPs are able to be flexible, EVs will tend to be preferred. This is because heating a space earlier than required results in losses to the environment, whereas there is no corresponding loss associated with changing the timing of EV charging. So whilst there is potential flexibility from HPs it seems reasonable to exclude this from the benefit case.

Updated non-EV/HP related reinforcement benefit

The non-EV-related reinforcement benefit of **£0.22bn** used in the original LCL bid was driven by an assumption given by Ofgem[16]. Using an estimate of near-term annual DNO reinforcement spend (i.e. before EV uptake becomes significant), it was assumed that 10% could be avoided through load reduction and shifting using DSR.

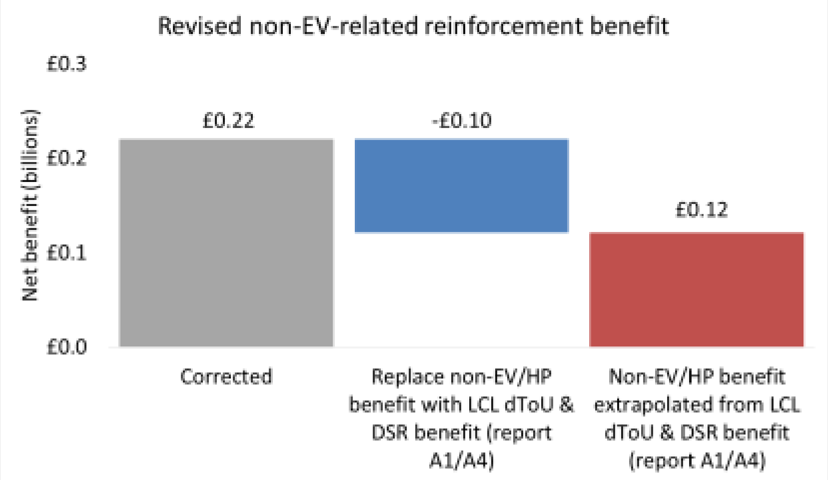
Rather than revising each part of this assumption step-by-step, the LCL project findings can be used to estimate this benefit directly. Two learning reports are relevant here:

- Learning Report A1[17] estimated the gross benefit of using dToU tariffs across the LPN area (on the assumption that such tariffs could be made mandatory, meaning the uptake could be 100%[18] and the DNO costs could be minimal). This estimation was based on actual LPN substation profiles and took account of the fact that dToU will only defer reinforcement if the substation's peak is sufficiently low and short-lived. The total estimated LPN benefit over ED1 & ED2 was **£1.96m**, achieved by deferring the reinforcement of a number of primary substations.
- Learning Report A4[19] made a similar assessment of the useful benefit that I&C DSR could deliver given the shape of substation profiles and some realistic commercial constraints. The LPN net benefit was determined to be £5.6m. However, for comparability we need to consider the gross benefit, for which we should exclude upfront process and system costs (£100k) and the £7.5m cost of availability payments required for DSR. The gross benefit for LPN over ED1 & ED2 is therefore determined to be **£13.1m**.

LCL did not assess how costs and benefits would scale from the LPN area to the UK's DNOs overall. Therefore, the same scalar is applied as was used in the original bid submission. This was based on the relative DPCR5 general reinforcement spends declared by the DNOs. This may be an overestimate, particularly given that demand-constrained regions such as London are more likely to benefit from DSR constraint management. Nevertheless, this scaling factor (x6.6) is applied to determine the non-LPN combined benefits of dToU and DSR. By extrapolating beyond ED2 to cover the period out to 2050, the overall benefit of these two schemes to all DNOs comes to **£0.12bn** (discounted and priced in 2010/11 terms), a reduction of £0.10bn, as shown in figure 21 below.

[15] M. Aunedi, F. Teng, G. Strbac, (2014) *ibid.*
[16] https://www.ofgem.gov.uk/ofgem-publications/57026/dsr-150710.pdf
[17] LCL report A1: *Residential Demand Side Response for outage management and as an alternative to network reinforcement*
[18] Note that based on the dToU trial, for the voluntary case it was estimated that only an uptake of 24% would be achieved
[19] LCL report A4: *Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement*

Figure 21 Revising non-EV-related reinforcement gross benefit in light of LCL

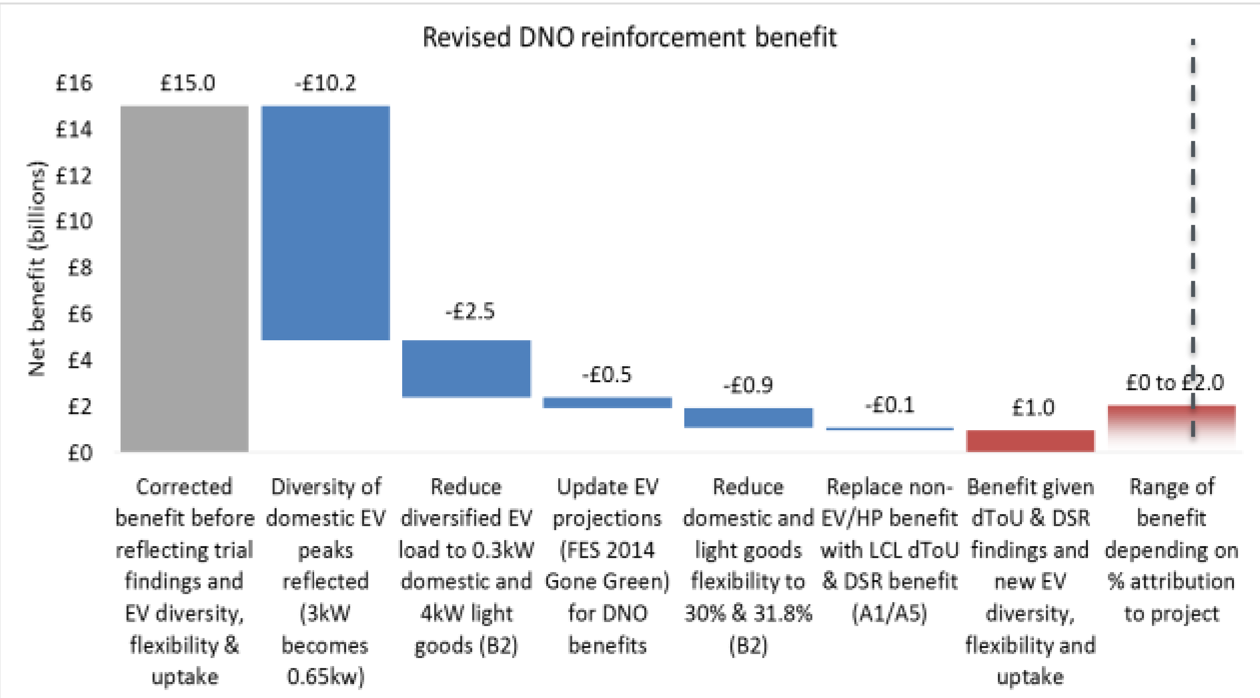


Updated overall DNO benefit from flexible demand

The combined change in direct DNO benefits is summarised in figure 22 and is driven by the following assumptions:

- The impact of EVs on substation reinforcement is likely to be lower than assumed at the bid stage for two reasons:
    - Diversity between different EV charging peaks, and between EV and domestic peak loads, means that the contribution of EVs to the network peak is significantly reduced
    - There is uncertainty in the number of EVs that will be connected to the grid, but current projections are lower than was assumed at the bid stage
- Demand flexibility has been estimated to be lower than anticipated based on extrapolation from the residential dToU tariff trials, reflecting both the willingness of consumers to respond, and the magnitude and duration of peak reduction required to have a material effect on peak load.

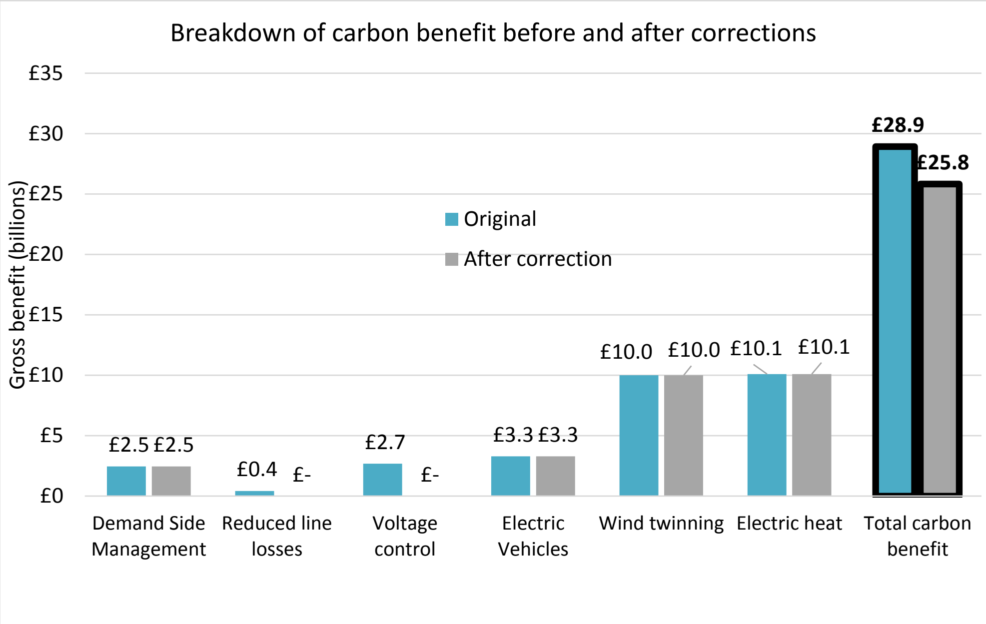
Figure 22 Overall change in DNO gross benefit



Gross carbon benefits from demand flexibility

This section considers the gross benefit of reduced carbon emissions arising from use of the "smart grid". Having carried out the update detailed above, the originally quoted carbon benefit is reduced from £28.9bn to £25.8bn, as shown in figure 23 below.

Figure 23 Corrections to gross carbon benefits in the original LCL bid



This initial correction only removed the estimated benefit arising from reduced line losses and voltage control on the basis that these were not investigated as part of LCL. It made no changes to the approach taken to calculating the carbon benefits arising from exploiting flexible demand. Nor did it update the LCT uptake projections used.

It is worth reiterating that the estimated £25.8bn carbon benefit is for the energy system as a whole, not just the DNOs. It also does not limit itself to DNO-led actions, and therefore implicitly includes "smart" actions that might be taken by suppliers, National Grid or other market participants with interests other than deferring distribution substation reinforcement. This should therefore be treated as a separate analysis from that above, which considered only the benefits of DNO-led actions.

Updating the grid assumptions for a revised carbon benefit

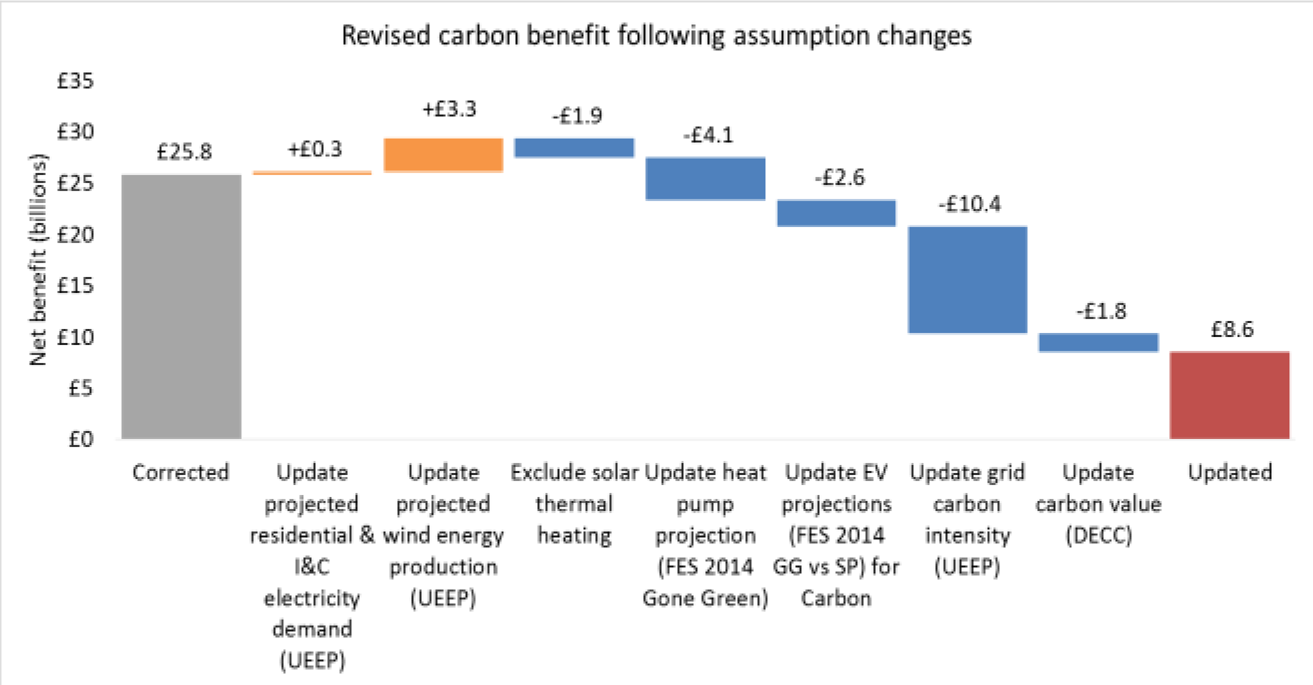
This section takes the approach used to calculate the carbon benefits in the original bid submission and updates the grid assumptions used to perform the calculations.

- Where possible, the Reference scenario from DECC's latest (September 2014) Updated Energy and Emissions Projections (UEEP) have been used[20]. These do not include HP or EV projections, so in this case National Grid's FES "Gone Green" scenario is used.
- In the specific case of EVs the approach taken required the use of a "high" and a "central" uptake case. In this instance the "Gone Green" is compared with the NG "Slow Progression" scenario.

On this basis, the incremental changes to the estimated carbon benefits are summarised in Figure 24. Note that the LCL trials did not investigate the system carbon benefits, so none of the assumption changes in Figure 24 are the result of LCL findings.

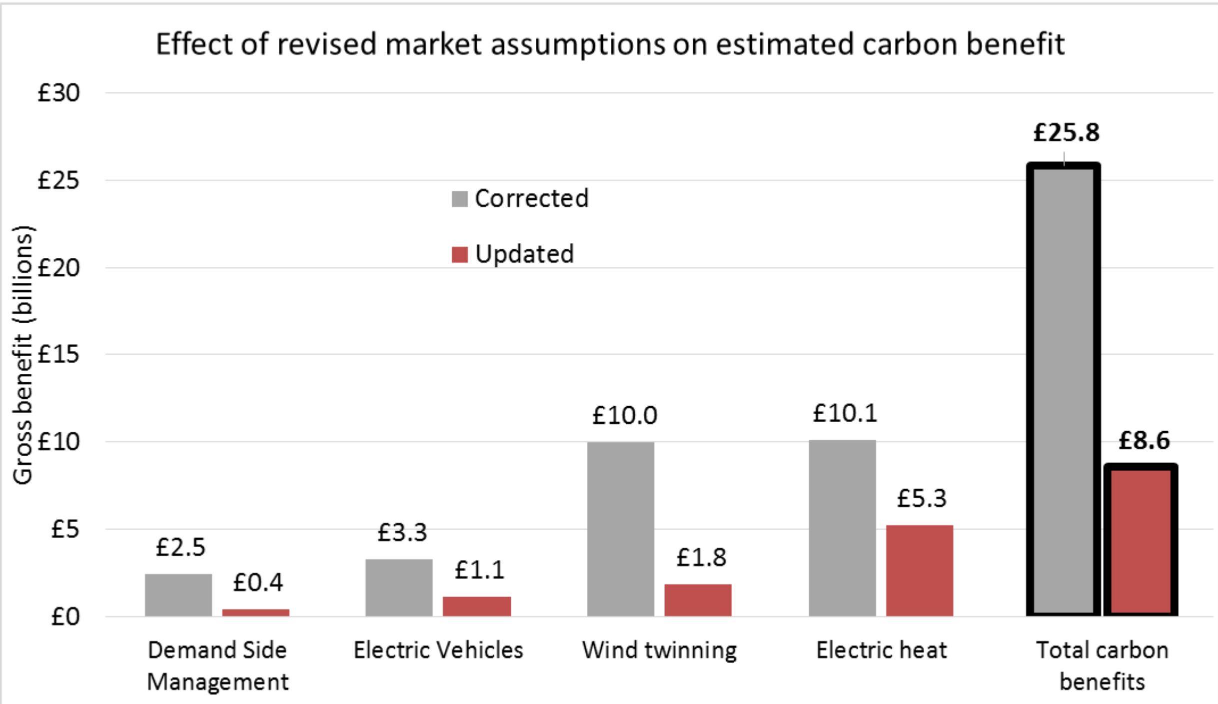
[20] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2014

Figure 24 Revised gross carbon benefits following assumption updates



Some of these assumptions affect multiple benefits (e.g. grid carbon intensity and the value of carbon). The overall impact on each of these benefit areas is summarised in Figure 25, and the reasons for the changes are detailed in the sections below.

Figure 25 Breakdown of gross carbon benefits following assumption updates



Demand Side Management (DSM)

The Residential and I&C DSM estimate was based on a static 2009 DUKES figure for electricity demand. This has been changed to a variable demand based on the UEEP reference case. This has made little difference to the resulting estimate. The majority of the change arises as a result a reduction in both the carbon emission of the electricity grid (meaning that reducing the demand has less impact) and the value of carbon.

The original approach assumed that electricity demand can be reduced by 5-10% (depending on customer type and the year of implementation) as a result of consumers having "greater visibility of energy use". This implies that this is a benefit of smart meters themselves, rather than using such technologies to make demand more flexible, and perhaps should be excluded. There would be some carbon benefit from shifting demand away from peak times and using flexible demand to provide balancing services. There is a risk, however, of double counting with the "wind twinning" benefit. Since the relative size of this benefit is small, it has been left unchanged, but the point should be noted.

Electric vehicles

Electric vehicle projections were based on a number of different sources, but primarily the 2008 BERR Electric vehicle report[21]. The carbon benefit was explicitly separated into two categories:

- Benefits from displacing fossil fuel cars (analogous with the approach taken for HPs)
- A much smaller benefit from using existing EVs as flexible demand to store energy and smooth peaks

Because the former represents a much larger proportion of the benefit, reducing the carbon intensity increases the benefit of enabling EVs to displace conventional vehicles (for which between 0% and 35% is attributed to the "smart grid"). As was seen in the case of DNO benefits, however, the projection of EV numbers in the original bid is higher than most of the more recent projections. Using instead the FES "Gone Green" scenario, this benefit is reduced.

Wind twinning

The renewables forecast providing the basis for the wind twinning benefit has been made consistent with UEEP (having been based on a 2008 book by David MacKay[22]). The UEEP projection is higher than that used in the bid, with a corresponding increase in estimated carbon benefit. As with the DSM example, the reduction in grid benefit and carbon intensity causes the biggest reduction in the estimated benefit.

The contribution made from "smart" actions was estimated by taking the forecast renewables uptake, then apportioning between 0% and 35% of that renewables growth to the smart grid. However, the LCL project did not investigate this question as part of the trials (except in Imperial's report 14-2 discussed in the next section).

Electric heating

The electric heating estimate has been reduced for two reasons:

- Uptake for solar thermal was contributing to the original smart benefit estimate. There seems to be little justification for including this since although it displaces some other heating demand, it cannot be controlled in a "smart" way, and therefore falls outside the scope of LCL
- The revised HP uptake assumption is based on the FES "Gone Green" scenario, which is lower than in the original bid.

In the case of HPs, the reduced grid carbon intensity has a positive effect since it is assumed that HPs displace gas boilers. As such, the lower the carbon intensity of the electricity, the more beneficial this displacement is. However this point does highlight the fact that this benefit is based on the notion that some of the uptake of HPs is attributable to "smart grids", rather than using existing HPs in a smart way to reduce grid carbon emissions.

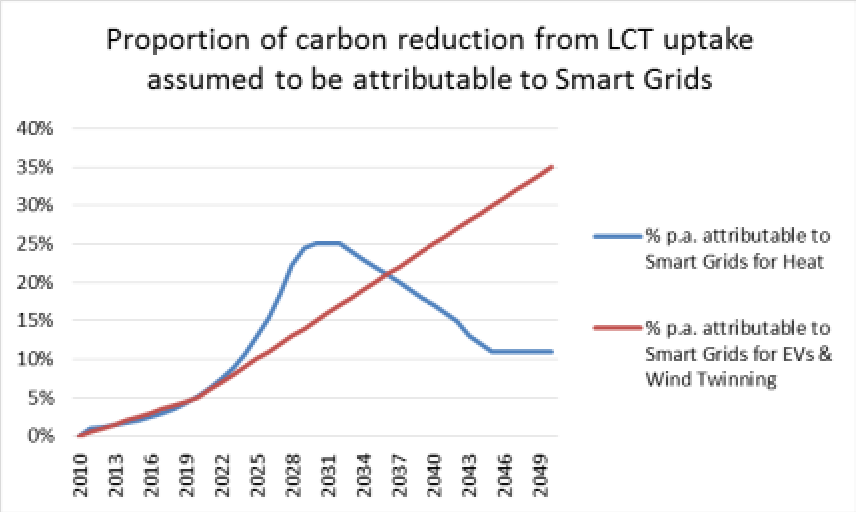
As with the "wind twinning" benefit, an assumption was made regarding the carbon reduction from HP uptake that can be attributed to smart actions. In this case it is between 0% and 11%.

For these last three assumptions (wind twinning, electric heating and EVs), the approach taken in the original bid was to forecast the uptake of these wind generation, HPs and EVs, calculate the effect they have on reducing the

[21] ARUP (2008) *Investigation into the Scope for the Transport Sector to Switch to Electric Vehicles and Plugin Hybrid Vehicles*, BERR/DfT, http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file48653.pdf
[22] MacKay (2008) *Sustainable Energy: Without the Hot Air*, UIT

carbon intensity of the grid, and then attributing some proportion of this carbon reduction to the existence of smart grids. The annual scaling assumption for each of these LCTs is shown in Figure 26.

Figure 26 Scaling factor applied to overall carbon reduction to estimate "smart grid" contribution



For EVs and wind generation, the assumption was that for the installed load/capacity reached at a given time, a gradually increasing proportion of the associated carbon reduction could be attributed to smart grids. A number of plausible mechanisms exist for this, including:

- For a given installed wind capacity, smart grids increase the volume of electricity produced (e.g. avoiding curtailment). The role of smart grids becomes increasingly important as wind penetration increases.
- A certain level of flexible demand may be required to allow EVs onto the system (e.g. avoiding network constraints).
- Some renewable generation projects might not be viable without assurances that they will not suffer excessive curtailment. Smart grids might make viable projects that would otherwise not have gone ahead.

For Heat Pumps, the attributable benefit increases to 25% before declining from that point onwards.

The LCL trials did not directly look at understanding how LCT uptake might be affected by the use of smart grids, so there is no robust means of updating these assumptions. It should be noted, however, that this is a key parameter for calculating the overall carbon benefits using the approach taken in the bid submission.

However, Imperial College London has produced a report that does consider the carbon reduction benefits of using flexible demand to avoid curtailment and balance the grid. The approach taken is fundamentally different from that taken in the bid. Nevertheless, it may provide a point of reference to test the plausibility of the "attribution" figures above.

Comparison with ICL Report 14-2

Imperial College London (ICL) has conducted analysis as part of Report 14-2 looking at the carbon benefit that can be associated with using smart appliances on a distribution network. The report considered two scenarios in 2030 and one in 2050 to estimate the additional carbon reduction that arises from allowing EVs, HPs, residential and commercial demand to be used flexibly to avoid wind curtailment and provide balancing services.

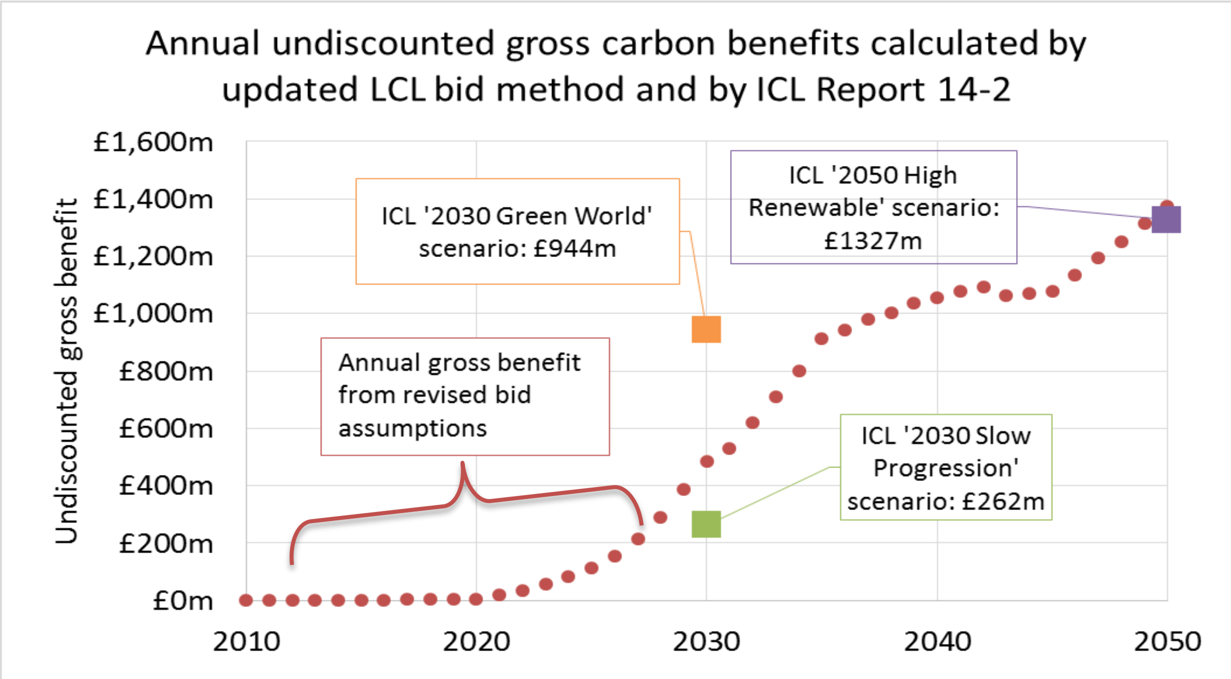
A number of differences exist between the ICL approach and that used in the sections above. These are summarised as follows:

- The ICL report assumed a fixed generation and demand mix for each scenario (two for 2030 and one for 2050). The carbon benefit was based on exploiting the flexibility of EVs, HPs, residential and I&C demand. By contrast, for some of the carbon benefits estimated in the LCL bid (EVs, HPs & wind twinning) it was implied that smart grids facilitate the connection of additional LCTs. The ICL estimate would therefore be below the bid estimate, all else being equal.

- The residential and I&C flexibility in the ICL report were taken to be 20% and 10%, respectively. The bid submission used between 5% and 10%. The LCL trials did not consider using smart grids to use the grid more efficiently, so this assumption has not been revised in this estimate. Nevertheless, the ICL report tends to consider the upper range of response. This is true also for EVs, where 80% flexibility is taken, based on the demand shifting that could in principle occur. There is no comparable figure for carbon reduction in the bid approach, but the LCL dToU trial (used to infer EV flexibility) gave a more conservative figure of 30%.
- The revised bid figures use scenarios differently from the ICL report meaning they cannot be fully reconciled. Although ICL bases its model on scenarios from FES and the DECC carbon plan, the amount of consumption and production by each asset type is determined by the model's internal dispatch rules. Carbon intensity is therefore an output of the model. By contrast, the approach taken in the bid submission necessitates that the demand and production of market participants and grid intensity be specified up front.

Given the inherent differences between the bid submission and the ICL approach, it is not proposed to attempt to reconcile these. However, it is worth noting that the snapshot benefits calculated by ICL are not inconsistent with the annual carbon benefits generated by the LCL bid approach with revised assumptions, as shown in Figure 27.

Figure 27 Comparing estimated gross carbon benefit with ICL report 14-2

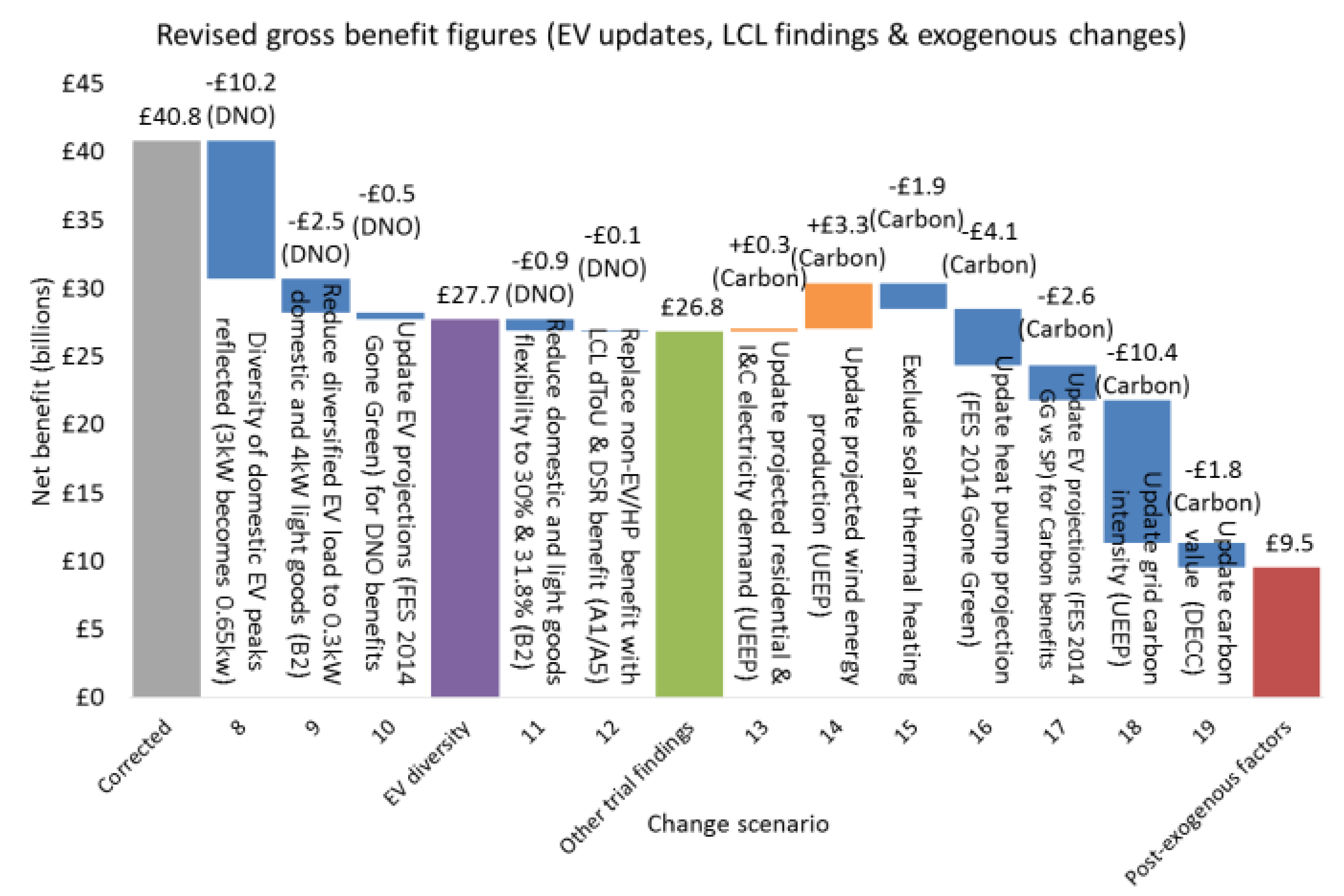


Revised benefit case & conclusions

The net effect of incorporating the LCL findings and updating the exogenous factors to reflect the latest scenarios is shown in Figure 28.[23]

[23] Note that the absolute change in benefit for each element may depend on the order in which it is applied.

Figure 28 Updated LCL bid gross benefits



EV revisions and other DNO benefits

There were three key variables that affected the benefit of LCL methods when applied to Electric Vehicles:

1. The flexibility of EVs was originally thought to allow for a 60% reduction in their contribution to the network peak. The results of the trials suggested that this should be reduced to 30%.
2. The forecast uptake of EVs was higher than is shown in more recent scenarios. This would translate into a reduction in burden for DNOs, but also means that the absolute benefit of smart solutions is reduced.
3. Similarly, the impact of any one EV is lower when diversification is considered. This was reduced in two stages (pre-bid and post-trial). In both cases, the underlying cost of EVs to the DNOs is reduced, with the corresponding benefit of adjusting those loads in a “smart” way reducing accordingly.

The absolute benefit of residential dToU and I&C DSR is expected to be lower in absolute terms. Having been estimated to have a benefit of **£220m** at the bid stage, the results of the trials and subsequent Cost Benefit Analysis give a figure of **£123m**.

Carbon benefits

The carbon benefits are less affected by the corrections made to the LCL bid. However, with the exception of the wind generation, the uptake assumptions tended to be above levels given in more recent projections. The final carbon benefit was particularly sensitive to the overall carbon intensity of the grid, which is lower in the latest DECC UEEP projections that the Ofgem assumption originally used.

One major source of uncertainty in the original analysis was how to estimate the contribution that “smart grid” behaviours contributed to the overall decarbonisation of the electricity system. This question was not addressed as part of the LCL trials, which was focused on using flexible demand to achieve benefits for the distribution network.

However, the ICL report provides a point of comparison, and suggests that the updated estimates in the revised bid calculations are broadly consistent with their modelling approach.

Costs

The focus of this report has been on gross benefits. Other than an RPI correction, the costs associated with operating a smart grid have not been updated. Cost estimates do exist for specific “smart” applications, and can be found in the CBAs carried out as part of the LCL learning reports. However, there is insufficient evidence to make a general statement about how much it would cost to achieve the gross benefits specified above. It should also be noted that the cost of implementing these measures will depend on the way in which they are implemented:

- Whether schemes are voluntary or mandated will affect the overall cost and the distribution of those costs amongst electricity market actors
- The upfront costs associated with putting in place the technology, systems and process required for the smart grid could be substantial. It may, however, be possible to share those costs between the market actors that might benefit (DNOs, suppliers, National Grid, etc.)
- The way in which smart measures are used is important. For example, using DSR on a post-fault basis incurs minimal utilisation costs, but has little carbon reduction effect. The sustained DSR actions required to have a material effect on overall energy use is likely to be much more costly to implement.

The original bid submission estimated that a nationwide roll-out of the measures investigated under LCL would cost **£0.7bn** (**£0.6bn** after the RPI correction). This appears to be a substantial upfront cost when compared with the **£1.2-2.5bn** benefit that DNOs might see over 40 years. However, some of this cost would need to be incurred to achieve the wider system carbon benefits, so it is probably not appropriate to account for it as solely a DNO cost.

The other cost component included was for I&C DSR availability and utilisation payments. This came to **£2.9bn** (**£1.7bn** after RPI corrections). As discussed above, these costs are very sensitive to the manner and frequency in which DSR is used. Given that the overall estimated benefit of dToU and DSR was only **£0.12bn**, the DNO-specific cost of well-targeted DSR would be lower than this. However, in order to achieve the wider carbon reductions that smart grids might deliver, the costs associated with this would be considerably higher.

Appendix 11 Project learning artefacts

Output	Title	Comments
Paper	CIRED'14	March 2014
Paper	CIRED Workshop 11th June Rome	June 2014
Paper	Network Benefits of Energy Efficient Lighting - *22nd International Conference on Electricity Distribution Stockholm*,	June 2013
Paper	Application of demand Side Response and Energy Storage to Enhance the Utilisation of the Existing Distribution Network Capacity - *22nd International Conference on Electricity Distribution Stockholm*,	June 2013
Report	Distribution Network Impact of Electric Vehicles	December 2012
Report	200028-ANM3-06A HMI Specification	November 2013
Report	200028-ANM3-07A Demand Response Notification Interface Specification	April 2014
Report	ANMDR Winter Trials - Bankside C and Lithos Road Analysis	November 2013
Report	200028-LIC-05B Security of Supply Trials Local Interface Controller Specification	November 2013
Report	200028-ANM1-07B ANM Drop 1 Bankside C Demand Response	August 2013
Report	200028-ANM1-08A ANM Drop 1 Moreton St Demand Response Analysis Report	January 2013
Report	200028-ANM1-09A ANM Drop 1 Bankside C Threshold Analysis Report	November 2013
Report	200028-ANM1-04B Drop 1 FDS as built	January 2014
Report	200028-ANM1-05B Drop 1 Site Acceptance Test Specification SCAN	January 2014
Report	200028-ANM2-02A ANM Drop 2 Moreton Street Demand Response	January 2014
Report	200028-ANM2-04B Drop 2 FDS as built	January 2014
Report	200028-ANM2-05B Drop 2 Site Acceptance Test Specification SCAN	January 2014
Report	200028-ANM2-06A Drop2 Lithos Road Demand Response Analysis Report	November 2013
Report	200028-ANM4-04B Drop 4 FDS as built	October 2013
Report	200028-ANM4-05B SAT Issue	October 2013
Report	200028-ANM4-06A Drop 4 Carbon Sync Integration Specification	July 2013
Report	200028-ANM4-06B Drop 4 Carbon Sync Integration Specification	August 2013
Report	200028-ANM4-07A Test Evidence	October 2013
Report	Data requirements briefing for power quality report	October 2013
Presentation	Learning Lab objectives and infrastructure	September 2011
Presentation	Understanding Consumer Behaviour, presentation for Low Carbon London Learning Laboratory Launch	October 2011
Presentation	Bottom-up modelling for application to Low Carbon London (Ofgem visit)	March 2012
Presentation	Learning Lab progress update	March 2012
Presentation	Low Carbon London - Project Update, Presentation for Ofgem	March 2012
Presentation	Understanding the Consumer - Residential ToU Trial	June 2012
Presentation	Learning Lab infrastructure and analysis	July 2012
Presentation	Network benefits of energy efficient lighting	February 2013
Presentation	Low Carbon London Dynamic time-of-use Tariff Trial	April 2013
Presentation	Dynamic Time-of-Use tariff trial (ToU learning event)	May 2013
Presentation	Learning lab workflow and tool requirements	July 2013
Presentation	Low Carbon London / Preparing Smart Grids – Arup event, London	October 2013
Presentation	Consumer engagement & the LCL Residential Dynamic Pricing Trial	November 2013
Presentation	Consumer acceptance, engagement and responsiveness on the UK's first trial of a dynamic time-of-use tariff for residential electricity - Norwegian University of Science and Technology, Trondheim, Norway	April 2014
Presentation	Eurelectric 2nd June London	June 2014
Presentation	6th Smart Grids & Cleanpower Conference 3rd June Cambridge	June 2014

Output	Title	Comments
Presentation	Base London 26th June London	June 2014
Presentation	LCL Roadshows: WPD 1st September Dudley	September 2014
Presentation	LCL Roadshows: ENW 15th September Preston	September 2014
Presentation	LCL Roadshows: SPEN 25th September Glasgow	September 2014
Presentation	LCL Roadshows: SSE 29th September Reading	September 2014
Presentation	HubNet Smart Grids Symposium 9th September Glasgow	September 2014
Presentation	DG Forum 15th September London	September 2014
Presentation	IET Power in Unity 2nd Oct Birmingham	October 2014
Presentation	Ofgem presentation: Optimising the future distribution network: strategies and options 8th Oct London	October 2014
Presentation	Ordnance Survey Energy & Infrastructure Seminar 8th Oct Daventry	October 2014
Presentation	LCNF workshops for Ofgem: Consumers 13th Oct London	October 2014
Presentation	LCNF workshops for Ofgem: DG & Storage 16th October London	October 2014
Presentation	2nd annual Utility Week Congress 14th October Birmingham	October 2014
Presentation	Low Carbon Networks and Innovation conference 20th – 22nd October Aberdeen Examining the impact of electric vehicle charging on the distribution network and investigating ways to mitigate and manage demand profiles through new technical and commercial mechanisms	October 2014
Presentation	Low Carbon Networks and Innovation conference 20th – 22nd October Aberdeen How successful innovation projects are being introduced into the 'business as usual' practices of distribution network operators	October 2014
Presentation	Low Carbon Networks and Innovation conference 20th – 22nd October Aberdeen Improving and introducing technology to improve the effective operation of the distribution network ensuring faster responses to faults and increasing the return on assets	October 2014
Presentation	Low Carbon Networks and Innovation conference 20th – 22nd October Aberdeen Analysing the results from extensive network monitoring and delivering new ways to manage the LV network including mitigating the effects of voltage fluctuation	October 2014
Presentation	Low Carbon Networks and Innovation conference 20th – 22nd October Aberdeen Exploring the new relationships and contractual arrangements between customers and the distribution network operators and the introduction of these into standard business operations	October 2014
Presentation	European Utility Week 4th – 6th November Amsterdam	November 2014
Presentation	The smart electricity consumer : developing domestic DSR 5th November London	November 2014
Presentation	Westminster Energy, Environment & Transport Forum 26th November London	November 2014
Presentation	IET Future Intelligent Cities 4th December London	December 2014
Document	Research Aims by Report	October 2011
Document	Briefing document on issues for SM/ToU trial design and recruitment	December 2011
Document	Control Group and Pre-treatment measure	January 2012
Document	Metadata requirements	May 2012
Document	Monthly dToU feedback design	July 2012
Document	*d*ToU notification strategy	August 2012
Document	Ofgem change request appendices one and two	October 2012
Document	Briefing document for Smart Meter trial design	December 2012
Document	ToU interview Discussion Guide	February 2013
Document	*d*ToU Control Group Exclusions	July 2013
Document	Planning Analyses of DSR and Savings	July 2013
Survey	Smart meter / dToU Household appliance survey	April 2013
Survey	dToU closing survey	November 2013

Appendix 12 Northern Powergrid peer review letter