First Tier Portfolio Reward

LCNF Tier 1 Projects – Overview and Criterion Assessment

1. Executive Summary

This report gives an overview of UK Power Networks' portfolio of Low Carbon Network Fund (LCNF) Tier 1 projects and provides evidence of exceptional innovation outcomes from these projects in response to the LCNF – First Tier Portfolio Reward (FTPR) call for applications.

This report provides a portfolio level description along with four individual project descriptions. At the portfolio level, the report provides evidence that UK Power Networks has satisfied the criterion outlined in FTPR. UK Power Networks submits a case for exceptional performance of these innovation projects and maximum implementation of project outcomes into business as usual. It highlights the important role that innovation has played and is playing to address challenges such as the transition to a low carbon economy whilst keeping the delivery of benefits to customers at the forefront of our strategy.

Our Tier 1 portfolio projects have delivered innovation and technology development in two key areas:

1. The sustainable integration of renewables into the electricity network; and
2. Network visibility solutions to improve customer supply.

This portfolio includes four out of six LCNF Tier 1 innovation projects as being eligible for the FTPR (two excluded as per Ofgem guidance as projects in progress) they are:

- *Demonstrating the Benefits of Short-term Discharge Energy Storage on an 11kV Distribution Network*
    - Delivered the first DNO integrated storage on the network, which directly informed our Smarter Network Storage project and subsequently the emerging energy storage market as a whole
- *Validation of Photovoltaic (PV) Connection Assessment Tool*
    - Conducted a pioneering study of PV-impacts on network, and produced a tool and formal connections policy used to support the large-scale PV uptake.
- *Distribution Network Visibility*
    - Developed and rolled out the first smart-grid data visualisation tool, enabling greater efficiency and accuracy in network design
- *Low Voltage(LV) Current Sensor Technology Evaluation.*
    - A rigorous comparison of LV monitoring solutions delivered in collaboration with suppliers and other DNOs that drove improvements for the whole industry in these critical assets.

The evidence provided in this report clearly demonstrates how our portfolio has supported the delivery of:

- Multiple aspects of the carbon plan, including reducing business emissions and facilitation of connecting embedded generation to our existing distribution network [Criterion A1]
- Significant network and financial benefits, including releasing network capacity to generators and end-customers, avoiding reinforcement [Criteria A2, A3]
- Innovative solutions deployed on our DNO regions and assisted the implementation elsewhere in GB through learning dissemination [Criterion A4]
- Tangential or unexpected learning to UK Power Networks and wider industry [Criterion A5]
- Valuable learning that has informed internal policies and procedures and assisted, de-risked and even underlined the need for new innovation projects (which have in turn informed GB policies). [Criterion A6]

Our LCNF Tier 1 portfolio has generated and disseminated significant learning which has been instrumental for the continuous improvement of our business and wider industry. The case is also made for how the portfolio has provided exceptional benefits.

UK Power Networks continues to use innovation to prepare and be ready for significant future challenges and deliver value to all our customers and stakeholders. This is achieved by implementing informed changes to business processes, applying outputs of projects to everyday tasks, and above all embedding a culture of innovation across our business.

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2.1. Innovation Portfolio

New technologies such as power electronics, modern sensor and control systems along with data analytics are revolutionising the way that we distribute electricity. We have seen first-hand how our customers, motivated by efficiencies, new technologies, and government policies can drive radical changes on our networks, such as the sudden and widespread connection of renewable generation to our networks. Furthermore, we are of the firm belief that the challenges posed by the low carbon transition require fundamental changes to our role in the energy market.

We continue to deliver a wide-ranging programme of innovation projects, identifying, testing, demonstrating, and transferring to business as usual in order to deliver value to our customers. Specifically, our Low Carbon Networks Fund (LCNF) Tier 1 innovation portfolio has delivered leading innovation in two key areas. The projects focussed on:

1. The sustainable integration of renewables into the electricity network; and
2. Network visibility solutions to improve customer supply.

First, understanding in detail the technical characteristics of new low carbon technologies is a critical focus for innovation and particularly within our Tier 1 portfolio. Second, the smart, low carbon energy system will depend on improved network visibility and data analytics, the second key focus in our Tier 1 portfolio. These projects all focused on timely, fundamental understanding and capabilities and have delivered benefits for our customers and underpinned some of our most successful large scale projects. These key focus areas feed into our business vision and innovation strategy. This portfolio embraces the low carbon transition and demonstrates that UK Power Networks is at forefront of innovation. These focus areas are elaborated upon in table 1.

2.2. Business Vision

UK Power Networks aims to be the most innovative DNO. This will be achieved by:

- Delivering value through innovation and setting the benchmark for best practice;
- Being consistently credited as an active facilitator of, and not an obstacle to, the low carbon transition; and
- Preparing a future-ready distribution business providing new services that meet the needs of tomorrow's customers.

2.3. Portfolio Summary

Four projects are presented in this report and summarised in table 2:

1. Demonstrating the Benefits of Short-term Discharge Energy Storage on an 11kV Distribution Network (Hemsby Storage);
2. Validation of Photovoltaic Connection Assessment Tool (PV Assessment Tool);
3. Distribution Network Visibility (DNV); and
4. Low voltage current sensor technology evaluation (LV Sensor).

These projects represent UK Power Networks' focus on selecting innovation projects that align with our customer's business need. A recent report by Poyry[1] (September 2016) acknowledged that UK Power Networks targets key focus areas; this drives values from the portfolio. The four projects presented in this portfolio de-risked and accelerated the development of larger Tier 2 scale projects. Principles developed within this portfolio are already embedded in, or are on track to becoming business as usual. The portfolio projects fall under two aforementioned focus areas.

[1] P32 "An Independent Evaluation of the LCNF", Pöyry Management Consulting (UK) Ltd. and Ricardo Energy & Environment, October 2016

Table 1 – Project overview and alignment with key focus areas of LCNF Tier 1 projects

Projects	Aim	Alignment with UK Power Networks Innovation Strategy
Demonstrating the Benefits of Short-term Discharge Energy Storage on an 11kV Distribution Network (Hemsby Storage)	The sustainable integration of renewables into the electricity network	Deliver good business value Deliver measurable benefits Facilitate a low carbon system Delivering the right solutions Improving network access Benchmark best practice Quantify and track benefits Thought leader in innovation
Validation of Photovoltaic Connection Assessment Tool (PV Assessment Tool)		
Distribution Network Visibility (DNV)	Network visibility solutions to improve customer supply	
Low voltage current sensor technology evaluation (LV Sensor)		

<u>Hemsby Storage</u>

A genuine first of its kind, this project demonstrated the benefits of grid scale storage. Technical experience from this project, including its autonomous control algorithms, paved the way for the integration of renewables into a smarter grid.

<u>PV Assessment Tool</u>

This project gathered 25,775 days of data spanning 16 months and resulted in 171 million individual observations. The project used the data to develop and validate a tool to assess solar photovoltaic generation connections across the business more efficiently and more accurately. A connections assessment policy formalising these outcomes was drafted, approved and now in use.

<u>Distribution Network Visibility (DNV)</u>

The project has successfully demonstrated the benefits of having greater distribution network visibility. It has also developed the DNV application, a web-based platform that combines data from various sources, converts them into meaningful information and presents them via a suite of visualisations. The DNV application, the first of its kind in the GB DNO community, is currently being used extensively by UK Power Networks planning teams to facilitate the transition to a ‘smarter’ grid: handling large amounts of data and designing smart network solutions such as FUN-LV.

<u>LV Current Sensor Technology Evaluation</u>

The project was a collaborative project in which UK Power Networks and Western Power Distribution worked together to trial and evaluate LV monitoring equipment in both laboratory and operational environments. It has also developed safe working systems to allow live network installations of LV sensors reducing customer interruptions. Learning from the project has been shared with the manufacturers involved in the trials and as a result has driven improvements to their products, further developing the market solutions available to all DNOs.

Our LCNF Tier 1 portfolio has played a crucial role in our facilitation of the low carbon transition and development of the smarter grid. Looking forward, we are confident the low carbon transition will continue – although we cannot be certain exactly how it will unfold; we need to remain agile as our customers' needs and expectations evolve. Disruptive and rapid changes will catch many off guard. Innovating alongside the disruptors will prepare us for the challenges and opportunities that are ahead. Presented in this report is evidence that links our portfolio with the low carbon plan and demonstrates that UK Power Networks is proactive, preparing the network and skillsets for the low carbon transition.

2.4. Project Overview Table

Table 2 - Summary of eligible Tier 1 portfolio

	Tier 1 Project name	Licensee	Project summary (2 sentences)	Tier 1 funding £	Licensee compulsory contribution £	Other contributions £	Link to Close-Down Report
1	Demonstrating the Benefits of Short-term Discharge Energy Storage on an 11kV Distribution Network	Eastern Power Networks plc, London Power Networks plc and South Eastern Power Networks plc	UK Power Networks installed a 200kWh Li-Ion battery at an electricity substation site in Hemsby, near Great Yarmouth. The purpose was to demonstrate that an intelligent energy storage system (ESS) can support the existing distribution network and allow more renewable generation to connect by smoothing their intermittent output, reducing voltage fluctuations and shifting load	£203.6k	1/9th Tier 1 funding, £22.7k from UK Power Networks	From Partner (ABB) £89.4k Additional UK Power Networks £26.8k	UK Power Networks website: Smarter Networks Portal: Ofgem Publications:
2	Validation of Photovoltaic (PV) Connection Assessment Tool	Eastern Power Networks plc and South Eastern Power Networks plc	The project monitored networks with solar PV clusters, site data was collected and analysed to make formal a draft connections assessment policy. In addition a connections assessment tool for solar PV was created and made available internally, as well as to other DNOs.	£400.1k	1/9th Tier 1 funding, £44.5k from UK Power Networks	N/A	UK Power Networks website: Smarter Networks Portal: Ofgem Publications:

	Tier 1 Project name	Licensee	Project summary (2 sentences)	Tier 1 funding £	Licensee compulsory contribution £	Other contributions £	Link to Close-Down Report
3	Distribution Network Visibility	Eastern Power Networks plc, London Power Networks plc and South Eastern Power Networks plc	The project aimed to demonstrate the benefits that come from the smart collection, utilisation and visualisation of distribution network data. It has successfully shown that visibility of network data combined with other data sources can help tackle current and future challenges, such as facilitating new load and generation (including low carbon), increasing asset life and maintaining a secure and reliable supply.	£1,686k	£187.4k	IFI total contribution: £891.3k, of which 20%, £178.3k, was UK Power Networks' compulsory contribution	UK Power Networks website: Smarter Networks Portal: Ofgem Publications:
4	LV current sensor technology evaluation	London Power Networks plc In conjunction with Western Power Distribution (East Midlands) plc	This was a collaborative project between UK Power Networks and Western Power Distribution to compare off-the shelf LV monitoring technologies that can be retrofitted to existing distribution substation equipment. Comparisons were conducted in both laboratory and operational field environments.	UK Power Networks: £102.8k Western Power Distribution: £109.9k [2]	UK Power Networks: £11.4k	N/A	UK Power Networks Website: Smarter Networks Portal: Ofgem Publications:
T				£2,392k[3]	£266k	£1007.5k [4] Total IFI contibution £294.5k [5] 20% UKPN contribution	

[2] Western Power Distribution's Tier 1 funding figure has been taken from the project's close down report. For UK Power Networks' Tier 1 funding and compulsory contributions, the Regulatory Instructions and Guidance (RIGs) tables have been used.

[3] This is the total UK Power Networks Tier 1 funding. It excludes Western Power Distribution's Tier 1 funding for the LV Current Sensor Technology Evaluation.

[4] This total includes both the compulsory 20% contribution from UKPN in addition to other 80% contribution from Tier 1 funding.

[5] This total includes only UKPN's 20% contribution for the DNV project under the preceding IFI project.

3. Project 1 – Hemsby Storage

3.1. Project Description

Project Name	Demonstrating the Benefits of Short-term Discharge Energy Storage on an 11kV Distribution Network
Supplier(s)	ABB
Start Date, End Date	09/2010, 10/2013

UK Power Networks installed a 200kWh Li-Ion Energy Storage System (ESS) at an electricity substation site at Hemsby, near Great Yarmouth, to understand the impact and potential benefits of small-scale electricity storage on a distribution network. The battery was procured in 2007 as part of the AuraNMS (Autonomous Regional Active Network Management System) research project, which was funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Ofgem Innovation Funding Incentive (IFI). The asset was installed by ABB who contributed to the funding of this project.

Two main challenges to the carbon plan are:
1. A rise of intermittent or non-dispatchable low carbon generation; and
2. A more pronounced peak demand caused by distributed low carbon technologies, such as domestic heat pumps and electric vehicles.

These changes will reduce the flexibility of the system, posing challenges for real-time constraint management and local balancing of the system. This project investigated a solution to these challenges and demonstrated network management strategies using an electricity storage asset installed alongside significant renewable generation.

Having commissioned the device in April 2011, UK Power Networks registered the first LCNF Tier 1 project to gain real, practical experience with a storage device and demonstrate its benefits to the network and customers. This installation was the first of its kind.

The trial was a success having met its objectives by demonstrating real network benefits of connecting DNO-owned energy storage directly to an 11kV substation.

3.2. Aims and objectives

The key project objectives listed below were achieved:
- Autonomous voltage control via both reactive and real power control achieved;
- Peak shaving and feeder demand management successfully demonstrated by carrying out short-term imports and exports of real power. A reduction of 200 kW in peak feeder demand was achieved;
- Autonomous charge and discharge operations of the ESS achieved without the direct intervention of the control room;
- Autonomous interaction between the energy storage and local renewable generation demonstrated;
- The efficiency of the device was measured and the relationship with auxiliary power consumption was better understood. The efficiency of the batteries alone varied between 90-95%. Auxiliary power consumption had a significant impact on the round trip efficiency and could be as low as 78%, depending on the amount of power exchanged, as the auxiliary power demand remained constant over time. This is discussed in section 4.6 of the closedown report;
- The accuracy of the manufacturer's datasheet was tested and validated. Deviations were identified between the controller's set-points and the system's behaviour. These were analysed and used to calibrate the controller;
- The lifetime of the energy storage system assessed. The lifetime of the primary equipment and the valves estimated at 25 or more years, 15 years for the control system and 20 years for the batteries, depending on the

mode of operation. Operating the energy storage on a daily cycle that accesses 75% of the battery capacity will reduce the available capacity at a rate of 1.5% per annum. This equates to a 20 year lifetime if end-of-life taken to be 70% of the installed capacity;

- Use cases for energy storage were developed, tested and assessed. The use cases that deliver most benefits to both DNOs and distributed generators are the power-flow management 'peak-shaving' and 'reactive power following' use cases. The use cases which required manual intervention or had local control only were considered to have diminishing returns;
- The impacts of energy storage were monitored on two networks, at Ormesby and Martham. The methods of planning prior to the trial did not consider the time dimension (considering static situations instead of dynamic situations), which is required to simulate charge/discharge behaviour. The knowledge used was captured in the energy storage planning tool developed as part of this project; and
- The operational experience gained shared with DNOs through publications, conferences and the Energy Storage Operators' Forum. These experiences contributed to de-risking recent storage projects such as the Smarter Network Storage second tier project.

3.3. Outcomes

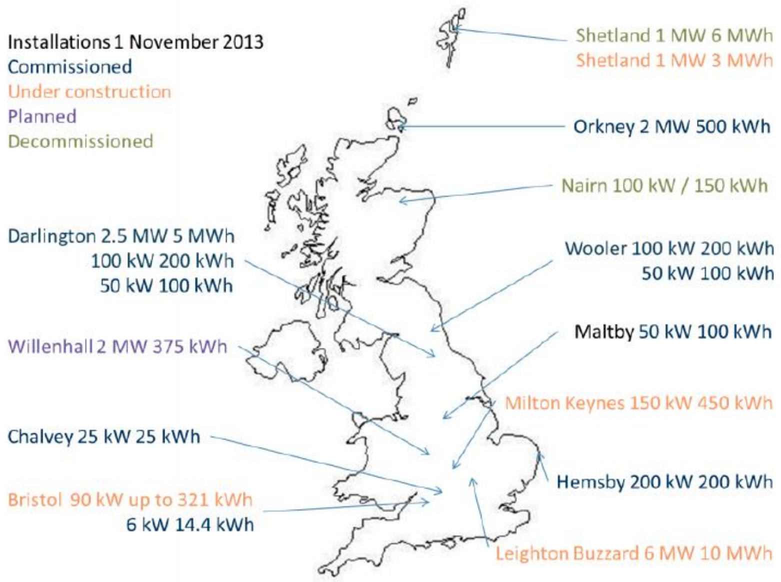
This project met all of the original objectives set out in the original pro-forma.

Table 3 – Hemsby Storage - Evidence of Original Objectives met

Success Criteria	Met?	Details
Perform validation of the storage device's capabilities with respect to data sheet performance, when installed on a real network. Specifically, the efficiency of the device will be measured	✓	The accuracy, efficiency and auxiliary power consumption were tested and assessed. Two key issues covered: • Potential issues with metering and revenue settlement when the accuracy of the system is unknown and the system remains un-calibrated; and • How to define and report efficiency. This information was presented to Energy Storage Operators Forum (ESOF) for the Good Practice Guide on Electrical Energy Storage
Demonstrate load-shifting within the limits of the device capability (200kWh, 1 hour discharge duration)	✓	The load-shifting capability of the device was proven in various degrees of complexity ranging from manual scheduling to more advanced automated algorithms such as wind-following. 200 kW was demonstrated with 200 kWh energy.
Understand the extent to which these interventions could be scaled up to manage larger quantities of demand or generation	✓	Network simulations were carried out to assess the benefits and impact of energy storage on the distribution network. A study considering energy capacity, power rating and location of installation was undertaken. The 'wind following with network switching and automatic voltage control' algorithm demonstrated that by installing an ESS between two feeders with different demand patterns and by operating the ESS using the 'wind following and switching' control, the ESS could manage larger amounts of wind than the capacity of the ESS would normally allow. The outcomes of this project were clearly relevant to the Smarter Network Storage project, which went on to demonstrate the benefits of an energy storage installation with a larger energy capacity.
Validate a number of existing use-cases which have been proposed and simulated, rank their usefulness and understand their relative value to the DNO and to an intermittent generator	✓	The project demonstrated the network impact of the uses cases developed around voltage control and power flow management with various levels of automation. A ranking of their usefulness has been carried out and is presented in section 8.2 of the closedown report.

Success Criteria	Met?	Details
Understand the potential lifetime of the device	✓	The adaptive peak-shaving control algorithm and a voltage control algorithm were used to generate representative operation profiles for the ESS. These profiles were used by Saft, the battery manufacturer, to carry out a lifetime assessment of each operating regime.
Embed the learning into a design tool for network planners, and into dissemination material for the UK DNO community	✓	A planning tool has been developed. It allows UK Power Networks planning engineers to evaluate both the impact of energy storage and additional distribution on the Martham/Ormesby distribution network. This tool is available free of charge to other DNOs.
Propose next steps	✓	Next steps to advance this technology to economic viability have been proposed.

3.4. Learning



The installation used for this trial was relatively small in terms of the amount of energy that can be charged/discharged. A facility of this size fitted the aim of the project very well as the project focussed on demonstrating the proof of concept without making a significant impact on normal network operations. The project provided learning that allowed scalability and ultimately led to the installation of many other units that provide a positive business case. Figure 1 evidences the grid scale installations in the UK close to the time of project closure.

Figure 1 – Storage installations Nov 2013

3.5. Benefits

The project addressed concerns raised by the DNO community in relation to the widespread deployment of storage – a series of trials covered aspects of application, reliability, cost, financial model, market entrance, technical and many more.

The chosen application of storage is believed to be an industry first by UK Power Networks and was well ahead of its time. Large scale energy storage such as battery storage, has been recently flagged by the Smart Grid Forum, the Energy and Climate Change Committee, Ofgem and BEIS (previously DECC) as one of the key smart interventions likely to feature in the future smart grid.

The project, and the subsequent Smarter Networks Storage project, have informed UK Power Networks and fostered a skillset that has allowed informed discussion on future commercial frameworks. The benefits achieved by this project are further described in the criterion evidence section of this report.

3.6. Conclusions

When this project started delivering its first learning, UK Power Networks concluded that the storage technology itself, although not yet mature, was not the main barrier for large-scale deployment of storage. It was the view of UK Power Networks that widespread uptake was hindered by unclear economics due to undeveloped economic models of DNO owned energy storage.

The Technology Readiness Level (TRL) at the start of this project was a seven out of a possible nine. The TRL was seven because many of the elements were commercially available. The project specifically needed to adapt some technology, scaling down equipment designed for higher voltages. A grid scale battery at this scale and voltage had never before been developed. Novel network control methods were demonstrated including:

- Reduction in transformer tapping with voltage control (Criterion A2);
- Manage voltages between feeders (Criterion A3);
- Managing reverse power flows (Criterion A3);
- Regulation of wind farm output (Criterion A1); and
- Switching real power between feeders. (Criterion A3)

Upon closure of this project the technical maturity was higher (Criterion A4). The TRL upon completion of the project was eight, up from seven. The economic models of DNO owned storage however remained unclear. The conclusion of this project was the inception of the much larger Smarter Networks Storage project. Storage is considered important to facilitating the carbon plan. As the costs of storage remain high, UK Power Networks' collective work on storage has demonstrated the business need. Two sizeable battery storage assets (UK Power Networks' SNS and Northern Power Grid's CLNR) have now been technically and commercially integrated in the network (Criterion A6), this accelerated interest in this asset class throughout the DNO community and developed commercial maturity in storage markets.

4. Project 2 – PV Connection Assessment Tool

4.1. Project Description

Project Name	Validation of Photovoltaic (PV) Connection Assessment Tool
Supplier(s)	N/A
Start Date, End Date	01/2012, 11/2014

Domestic solar panels and other small-scale renewable generation are usually connected to UK Power Networks' LV electricity networks without requiring prior consent. A volume of low penetration does not cause any significant impacts to our network; the network does however experience issues when installations are concentrated in a geographic area. This project anticipates and prepares for a future when these forms of renewable energy become mainstream and clustering more common.

Following the introduction of the Feed In Tariff (FIT) in April 2010, clusters of renewable generation were appearing on the LV network. Proposed programmes suggested that large numbers of connections could be concentrated in relatively small geographical areas. This project focussed on the clustering of a more common FIT generation – domestic photo-voltaic solar panels (solar PV); the findings also informed the effect of other renewable micro-generation when installed in close proximity.

These solar PV clusters started to result in more two-way power flows on our cables and substations. Conventional reinforcement is often expensive; the challenge was therefore to find smarter ways to support small-scale renewable generation, without risking an overload of the electricity network infrastructure. Central to managing costly re-enforcement requirements is an accurate knowledge of the effects that solar PV-clustering has on the distribution network.

Small-scale renewables such as solar PV panels are usually connected to the low-voltage network without a DNO's prior consent in accordance with Engineering Recommendation G83 (single-premises). When there is an installation involving multiple units, this G83 states that prior consent is required from the DNO. In response, UK Power Networks developed a draft policy to provide guidelines for planners when studies that are more intensive were required; this policy necessarily had to make some simplifying assumptions. A more accurate user-friendly model was sought informed by measured data to approve or disapprove a solar PV connection, or to advise the need for network re-enforcement costs.

In summary, the project aimed to improve two aspects of assessing clustered PV connections:

Table 4 – PV Assessment Tool Project Deliverable Summary

Process	Issue	Resolve
Draft Policy to Assess Clustered PV Connections	Draft policy only, required measured data and informed reform	Official policy created that more maturely assesses Solar PV connections
Complex Software (Dig silent Power Factory) and Simplified Connection assessment Tool	These were deemed inadequate for the connections team to make an informed judgement. A validated intermediary model was required.	Excel Based PV assessment tool created in accordance with official connections assessment policy.

4.2. Aims and objectives

This project aim was to carry out the following:

- Validate the assumptions within UK Power Networks' draft guidelines and develop an approved policy for assessing G83 PV connection requests for multiple premises
- Gain a detailed understanding of the impact of solar PV on the LV network by:
    - Monitoring several solar PV clusters
    - Considering different types of LV network (suburban and rural)

  - Gathering data by equipping 20 secondary substations and ten solar PV installations with LV network monitoring equipment
- Assess what information is available from installers of PV generation to inform a decision on a connection request
- Investigate what innovative solutions could be applied to address network constraints.
- Analyse data gained and use to validate a new solar PV connection assessment tool.

4.3. Outcomes

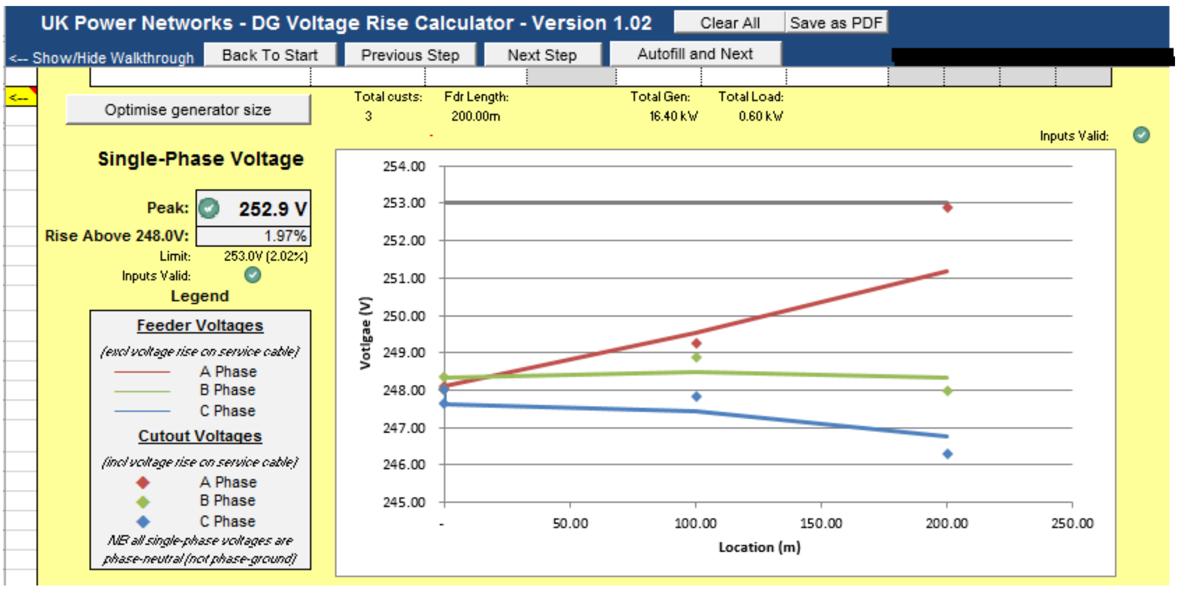
The project delivered the following outcomes:

- A validated connection assessment approach including a formal design procedure. The procedure includes recommended design assumptions, based on acquired data. This data:
  - Improved the PV connection assessment tool, that UK Power Networks adopted into business as usual. It was shared with other GB DNOs. The improved tool calculates voltage rise in three steps: the first step provides a worst-case result using minimal inputs, and if required, subsequent steps provide more-accurate results, using more-detailed inputs; and
  - The project also validated our need to obtain detailed FIT from Ofgem.
- A rich dataset, available for GB DNOs and academic institutions to use including:
  - Measurements from 20 distribution substations and ten customers' PV installations;
  - 25,775 days of valid data, spanning 16 months;
  - Over 171 million individual observations; and
  - Nearly three months of high-resolution (one-minute) measurements over summer 2014.
- A review of voltage control solutions such as
  - Suggestions that could be trialled or adopted in GB; and
  - includes recommendations of which solutions best suit likely voltage constraint scenarios.

4.3.1. Validated and pragmatic connection approach

A voltage rise calculator was developed, informed by the detailed data collection. The tool was validated against 20 feeder models built in PowerFactory and measured data. This model was compared against the PowerFactory results, trial data and the existing model. Once this model was validated, the assumptions in the previous model and draft policy were tested and updated. One screen of the model is presented below.

Figure 2 – Screen Shot of the PV Assessment Tool Analysing Voltage Rise



The validated tool investigated assumptions that fell into several categories:

- Existing documented assumptions written in an approved procedure;
- Existing undocumented assumptions such as unwritten rules of thumb; and
- Proposed assumptions (not previously used).

The assumptions and the methods used to validate them were as follows:

Table 5 – Validation of assumptions in PV Connections Assessment

Assumption	Validation method
Total PV (or DG) capacity on a substation should not exceed 50% of the transformer's nameplate rating (81% for sole-use transformers)	Measured PV's impact on LV networks approaching this level of PV penetration
PV generators do not increase the risk of unacceptable harmonic voltages or currents	Measured PV's impact on harmonic voltages and currents
Substation busbar voltage during peak PV generation: existing assumptions varied from 230V to 250V	Measured substation busbar voltages during peak PV generation
Minimum demand during peak PV generation: existing assumptions ranged from 0 to 200W per customer	Measured minimum demand during daylight hours
Phase imbalance of PV clusters: this was not previously considered	Measured load imbalance on feeders, and inferred that PV generators are similarly imbalanced

In summary, this project validated assumptions in UK Power Networks' existing connection assessment procedure, and recommended several new design assumptions to include in an updated procedure.

After validating the PV assessment tool, the aim was to assess the effect of future PV clustering on the network, in particular:

- How PV generators' output varied with season, weather, and panel orientation;
- How PV generators affected the LV distribution network in terms of voltage rise, reverse power flow, harmonics, and phase imbalance; and
- How these effects varied between different types of networks (e.g. rural vs urban).

4.3.2. Development of rich dataset

The project collected a rich dataset, comprising 25,775 days of data, and over 171 million individual measurements. The trial data was analysed to investigate the behaviour and impacts of PV generation. The data set was reviewed further against the assumptions in the improved model and it was found that:

- The existing tool is likely to underestimate voltage rise if PV generation is sufficiently imbalanced, and is hence not fit for purpose;
- The project developed and validated an improved tool that calculates voltage rise in three steps: the first step provides a worst-case result using minimal inputs, and if required, subsequent steps provide more-accurate results, using more-detailed inputs; and
- The accuracy of any voltage rise calculation is heavily dependent on input data that is often poorly documented (e.g. phase imbalance, substation busbar voltage, and details of existing generators), requiring conservative assumptions or site measurements to assure confidence in the results.

4.3.3. Review voltage control solutions

Many PV installers monitor and collect data from the PV installations that they own, which often comprise G83 multiple-premises schemes. The project obtained and reviewed data from two PV installers to determine whether it (or similar data) could be useful to DNOs, and/or reduce the need for DNOs to deploy their own LV network monitoring schemes.

In addition a desktop review was conducted of alternative (non-reinforcement) solutions to address network constraints that might prevent the connection of new PV generation. Potential solutions were identified from past and present GB innovation projects, and EU conference papers. The solutions were compared to identify their relative strengths and weaknesses. Scenarios were identified where they might each be most useful.

4.4. Benefits

The project delivered additional outcomes:

- There has been several major revisions and improvements to the tool, e.g. improving the process of inputting and tracking generation that already exists on the network when considering a new connection (Criterion A5);
- Improved interaction between the DNO and end customer – the approaches developed within this project informed the wider approach to public relations in addition to de-risking the strategy in the Tier 2 project VCEE (now known as 'energywise') (Criteria A4, A6); and
- The knowledge gained has provided UK Power Networks with a mandate to have greater access to FIT databases. Ultimately, this access will lead to a smoother low carbon transition and will shape future policy in years to come. (Criteria A1,A2,A3)

4.5. Conclusion

The project used the data to develop and validate a tool to assess solar photovoltaic generation connections across the business more efficiently and more accurately. A connections assessment policy formalising these outcomes was drafted and approved. The makeup of customer demand shifted due to aspects of the carbon plan, UK Power Networks proactively adapted internal policy and capability to ensure security of supply in a low carbon future (Criterion A1).

5. Project 3 – Distribution Network Visibility (DNV)

5.1. Project Description

Project Name	Distribution Network Visibility
Supplier(s)	PPA Energy, Capula
Start Date, End Date	03/2011, 02/2014[6]

The transition to a smarter grid and low carbon technologies (LCTs), especially the increase in domestic micro generation and the electrification of transport and heating, has intensified the need to improve visibility of the distribution network at 11kV and below. This improved visibility is expected to enable DNOs to make smarter decisions in the areas of network planning, asset management, new connections and network operations. It will also enable DNOs to better manage the new challenges that this transition will bring. These include:

- Facilitating the connection of low carbon technologies (LCTs) at lower voltage levels;
- Changing load profiles from historic pattern assumptions; and
- A potential increase in voltage and harmonic issues.

Most DNOs have limited monitoring at lower voltage levels. UK Power Networks' London network is different as it has an extensive and widespread monitoring capability, with Remote Terminal Units (RTUs) deployed in approximately 60% of the distribution substations. These RTUs, primarily used to remotely control the high voltage network, had a range of unused features ready to be fully exploited.

The Distribution Network Visibility project successfully harnessed the monitoring capabilities of these RTUs, enabling the collection of large volumes of relevant network data and allowing efficient and effective access to the data for key business users. The project developed a set of algorithms and visualisation tools (the DNV application) to manipulate, update, and where necessary cleanse this data to automatically detect network performance issues and produce useful information such as available capacity.

5.2. Aims and Objectives

The main objective of the project was to demonstrate the business benefits of the smart collection, utilisation and visualisation of existing data (i.e. analogues available from RTUs). The project also aimed to establish optimum levels of distribution network monitoring and frequency of sampling for specific scenarios and applications. It also trialled various optical sensors that can be used to provide detailed monitoring of sites with no RTUs. Areas where this data is potentially of use to the DNO include:

- Identification of localised load growth and changes in load patterns, in order to determine a wide range of options early on;
- Understanding where DG is masking load, which can have an impact on planning, outage calculations and restoration actions after an outage; and
- Understanding whether traditional assumptions about the duty of assets (e.g. tap changers, transformers) are accurate.

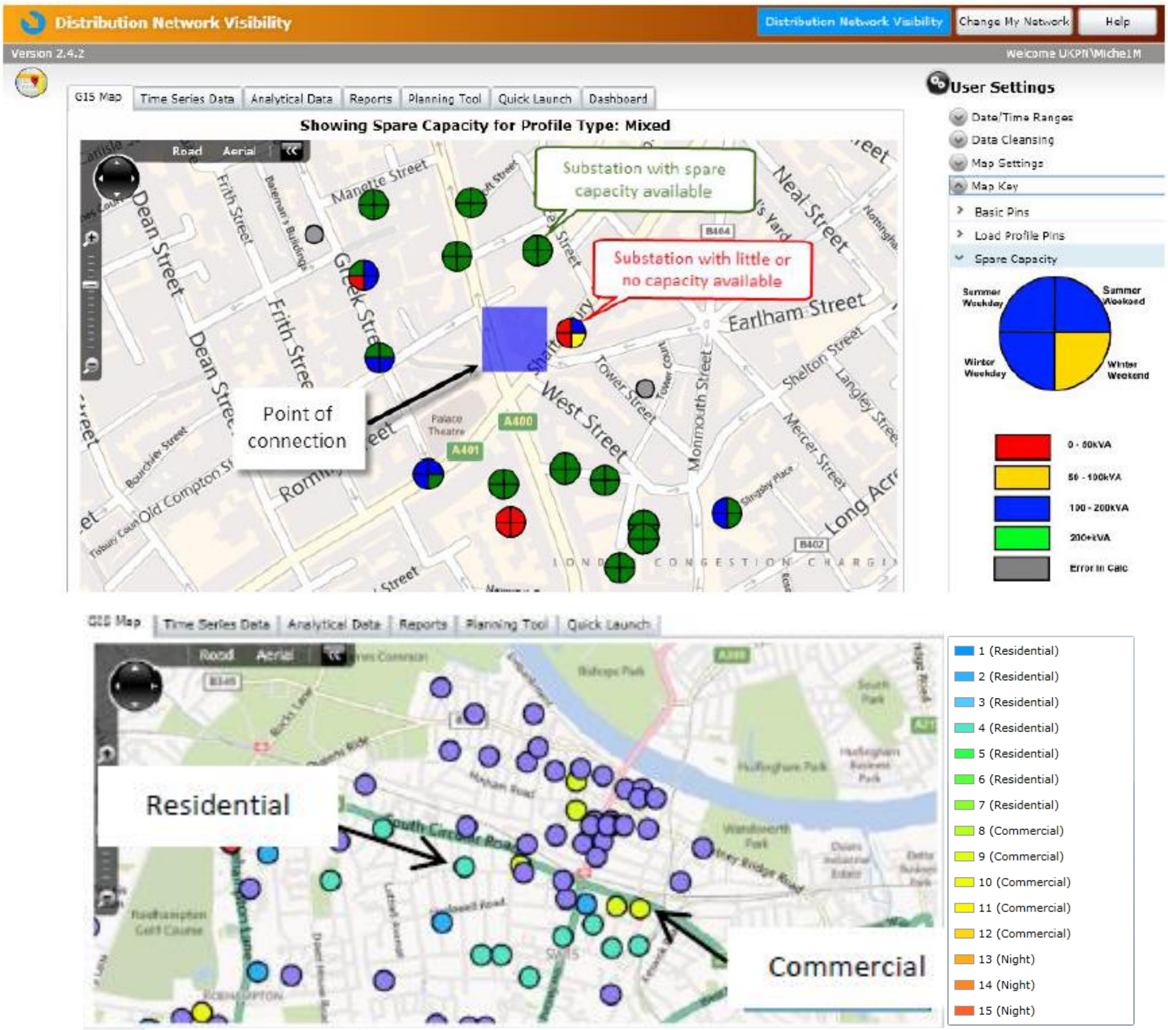
5.3. Outcomes

The project has achieved all its aims and objectives detailed in the previous section. The main outcomes and deliverables of the project can be summarised as follows:

- Definition of business benefits and user requirements: through engagement with various business units within UK Power Networks, a list of benefits that could be enabled by better visualisation of the distribution network was compiled and categorised. As part of this discussion with stakeholders, an initial assessment of what users would require to deliver the benefits was made;

[6] The end date is for the Tier 1 part of the DNV project.

- An assessment of data requirements and data collection: this involved analysing the data that would be needed to support the requirements of the functionalities. To ensure this data was available the following work was undertaken:
    - Exploiting existing network data sources;
    - Installation of advanced monitoring sensors;
    - Integrating asset data; and
    - Upgrading the data historian infrastructure.
- Implementation of visualisation and power flow tools: to combine the data sources described above and process them to fulfil the user requirements, a visualisation, web-based application (the DNV application) was developed (Figure 3). It enables the integration of multiple data sources, and makes it available to users through an easy to use and visual interface. The DNV application has been rolled out into business as usual;
- An IT White Paper was written to assist other DNOs, particularly their IT departments, in replicating the results of the project; (aligns with reward Criteria A4)
- RTU upgrade: 9,885 Secondary RTUs on the London network were upgraded to allow retrieval of a further 11 analogue network measurements in addition to the existing four previously available; (aligns with reward Criteria A4)
- Load flow tools: two commercially available load flow tools (GE DPF and CGI DPlan) were trialled and recommendations made on what further work is required between DNOs and suppliers of these tools to ensure they deliver maximum benefits (aligns with reward Criteria A6); and
- Data integration: data from six separate databases has been integrated into the visualisation application to ensure users are provided with useful information to support business decisions and deliver benefits. (aligns with reward Criteria A1, A2 and A3)



Long Term Primary Assets

Status	Title	No	New	Max	Report
(red)	Primary S/S Capacity	150	0	InfinityMVA/Infinityhrs	Top 20
(green)	Primary Transformer Utilisation	0	0	0.00%	Top 20
					Top 20
(orange)	11kV Feeder Currents	4	2	346.00A	Top 20
					Top 20

Short Term Secondary Assets

Status	Title	No	New	Max	Report
(red)	Secondary S/S Temperature	4	1	59.53degC	Top 20
(green)	High Voltage	2576	320	261.51V	Top 20
(orange)	Low Voltage	6	3	82.22V	Top 20
(green)	Voltage Unbalance	0	0	0.00%	Top 20
(green)	THD	913	43	99.98%	Top 20

Figure 3. DNV application – A selection of the available visualisation tools: (top) Connections and Spare Capacity tool which helps assess new connection requests, (middle) Automated Load Profiling which enables the detection and management of different types of load including low carbon loads, and (bottom) Dashboard which provides a snapshot of the network and highlights any network issues

5.4. Learning

Significant learning has been generated through the project. This can be summarised as follows:

- Advanced monitoring: efficient ways to monitor distribution networks have been explored through trials of a variety of network monitoring sensors (from LV to 33kV) along with analysis of the data requirements of the tools used to enable benefits. It was established that the optical sensors were a suitable solution to monitor sites with no RTUs, although there are limitations in their application with HV steel wire armoured cables;
- Data quality: data quality was identified as a significant issue and a study into data anomalies, their source, and how to correct them has been carried out and the findings implemented. It was found that this is essential due to the fact that tools such as the application developed allow users to access much larger volumes of data than they can practically review manually;
- Load profiling: it has been shown that by applying load profiles to substations and the load profile of new loads, a more efficient use of assets than traditional maximum demand methods can be achieved; and
- Dynamic ratings of assets: the concept of dynamically rating a distribution transformer has been proven. There is an opportunity to finalise this work when more LV monitoring equipment become available on our networks and possibly extend it to other asset categories, in particular underground cables which have a high thermal inertia to take advantage of.

5.5. Benefits

Areas where benefits are expected to be delivered through network data analysis and visibility have been identified, and functionalities required to deliver them developed. Examples include:

- Deferring and avoiding network reinforcement (aligns with reward criterion A2);
- Reducing frequency and duration of customer interruptions (proactive network management by preventing failures in some cases) (aligns with reward criterion A3);
- Avoiding and limiting damage to assets (aligns with reward criterion A3); and
- Improved customer service (better information regarding outages, proactive approaches to voltage issues, more accurate and timely connection proposals) (aligns with reward criterion A6).

The benefits achieved by this project are further described in the criteria evidence section of this report.

5.6. Conclusions

Great Britain’s transition to a low carbon economy is expected to lead to an increase in loads on electricity networks due to transport electrification, heat pumps and cooling demand. This project has shown that visibility of network data and the combination with other data sources can help facilitate this increase. This will be done by ensuring efficient and safe utilisation of assets, avoiding the need for unnecessary expensive network reinforcement.

It has also been shown that this same visibility can help DNOs tackle the challenges they are already facing such as operating an efficient network, reducing customer interruptions, increasing asset lifetimes and improving customer service.

6. Project 4 – Low voltage current sensor evaluation

6.1. Project Description

Project Name	Low Voltage Current Sensor Technology Evaluation
Supplier(s)	N/A
Start Date, End Date	12/2011, 06/2013

In order to make well informed LV network planning and operational decisions, there is an increasing need to improve visibility of distribution substation performance. A growing uptake of LCTs, such as micro generation and electrification of transport, intensifies this need further. Many existing substation sites currently utilise low cost maximum demand indicators with no remote reporting functionality. It is expected that greater visibility of LV network loads and voltage will be required and substation monitoring solutions will play a vital role in future network management.

The scope of the LV Current Sensor Technology Evaluation project was to compare off-the shelf LV monitoring technologies that can be retrofitted to existing distribution substation equipment. It also included the development of safe systems of work to allow equipment to be installed live and to identify monitoring solutions that would provide accurate and detailed information to allow the DNO to assess the performance of the LV network.

6.2. Aims and Objectives

The project aimed to evaluate various current sensor technologies in both controlled laboratory and operational field environments. This project was done as a collaborative project between UK Power Networks and Western Power Distribution allowing a greater range of installation scenarios to be assessed. The project also aimed to generate knowledge of these LV monitoring techniques enabling wider roll-outs to facilitate a low carbon future and minimising disruption to customers. (aligns with reward criterion A1)

6.3. Outcomes

The project involved working with manufacturers of LV monitoring solutions whose equipment had met the project requirements. The monitoring equipment needed to be capable of measuring the current flow in individual LV ways of an LV distribution board or cabinet. In that regard, a joint tender was completed from which seven different monitoring solution manufacturers were selected to participate in the project.

A range of laboratory tests were carried out at National Physical Laboratory (NPL) to assess a range of accuracy scenarios. A test bench was built at NPL using an LV cabinet ensuring that the test facilities would mimic as closely as possible the real life situation encountered in field installations. A side by side comparison of all tested monitoring equipment was then completed using the results.

Another key focus of the project was the safe installation of monitoring equipment. Installation training for each manufacturer’s equipment was carried out at our Sundridge Training Centre. Following the development of installation methodologies, equipment was installed at 14 outdoor substations in Market Harborough by Western Power Distribution and 14 indoor sites in central London by UK Power Networks.

The project has led to the development of installation policies to enable LV monitoring equipment to be installed safely and without the need for an outage on the network . (aligns with reward criteria A3, A5 and A6)

Several methods of making voltage connections were trialled and a hierarchy of preferred methods was developed. These included the use of existing voltage take off points, insulated and fused busbar clamp and modified fuse carriers. The transmission of data via GPRS was also demonstrated but no data integration with the DNO SCADA system was attempted as it was not in of scope for the project.

Basic current and voltage measurements were provided by the equipment from all manufacturers along with the apparent, real and reactive power and power factor. A number of manufacturer’s equipment offered more advanced monitoring functionality which included the measurement of neutral current, power frequency, harmonics, substation air temperature, disturbance recorder functionality and network event alarms.

6.4. Learning

The key learning from this project was firstly around the safe installation of monitoring equipment in a diverse range of substations and the identification and mitigation of installation constraints that each of these equipment present (especially in case of a wide rollout). Secondly, a key learning was how accuracy of various monitoring solutions is impacted under different environmental conditions and installation scenarios. These assessments were carried out in laboratory testing by NPL.

The knowledge generated and disseminated via learning events (e.g. LCNF Conference 2013, National Space Centre knowledge sharing event in 2013) will allow DNOs to make more informed decisions as monitoring of the LV Network increases.

6.5. Benefits

The project has resulted in a number of key benefits to all parties involved. From a DNO perspective, UK Power Networks and Western Power Distribution have developed a detailed knowledge of the challenges faced when deploying substation monitoring across a number of sites. This has led to the development of policies that will allow further installations to be completed in an easier, quicker and safer manner. It has also allowed greater knowledge regarding the required specification of equipment and will support future procurement processes.

The laboratory testing has allowed increased confidence around the level of accuracy available for current measurement. It was demonstrated that all the solutions tested were able to produce a satisfactory level of measurement on site.

A further benefit from the project has been the feedback loop created by the project to the suppliers. The practical learning from the installations has led to all manufacturers making improvements to their systems in response to feedback from the project. This has allowed the market to continue to develop, while increasing competition and choice. (aligns with reward criteria A5, A6, C1, C2 and C3). The benefits achieved by this project are further described in the criterion evidence section of this report.

6.6. Conclusions

The project led to a comprehensive evaluation of seven commercially available LV monitoring solutions and the development of installation policies to allow wider scale deployment on the LV network (aligns with reward criterion A4). The learning from the installations will also benefit any further LCNF projects involving LV monitoring. (aligns with reward criterion A6)

The project demonstrated that the current generation of monitoring solutions are mature enough to allow sufficient data to be collected by DNOs to assess the performance of LV networks. Monitoring solutions can provide network load measurement with accuracies of around 2.5% for Rogowski coils, and 1% or better for solid state sensors, such as split core current transformers.

As a result of the field and laboratory trials feedback was provided to manufacturers, leading to improvements in their products. (aligns with reward criteria A6, C3)

The table below outlines the overall conclusions from the assessments carried out of the products from the seven participating manufacturers. It should be pointed out here that these conclusions reflect the performance and functionality of systems tested in this trial and not necessarily of the current iteration of products.

Table 6 - Overall project conclusions for all seven manufacturers' current sensors

Manufacturer	Overall Rating	NPL Test	Ease of Installation	Installation time per site (mins)	Relative Cost	Positive	Negative	Monitoring type
GMC i-Prosys	Excellent	Average	Easy	35-45	£	Plug and Play	Bulky metrology unit	Advanced
Sentec/Selex (Gridkey)	Excellent	Good	Easy	40-50	£	Plug and Play	Hard to access internal electronics	Advanced
Current	Good	Good	Easy	45-60	£££	Plug and Play	Case not fully weather proof	Advanced
PowerSense	Good	Average	Medium	60-90	££	Back up battery, robust case	Time consuming sensor connection	Advanced
Ambient	Good	Good	Easy	45-60	£££	Plug and Play	No commissioning indicators. One unit per feeder	Advanced
Haysys	Satisfactory	Average	Hard	90-100	£	Large sensor aperture	Time consuming sensor connection	Basic
Locamation	Satisfactory	Good	Easy	45-60	££	Plug and Play	Electronics prone to failure	Advanced

7. Portfolio Criterion Assessment

7.1. Criterion A

A1. Aspects of the Carbon Plan that have been facilitated

Our portfolio successfully delivered solutions that helped overcome distribution network challenges associated with the carbon transition. The portfolio has facilitated aspects of the Carbon Plan as follows:

- The facilitation of connection of low carbon technologies including renewables on our networks
- The facilitation of secure, sustainable low carbon energy
- The reduction of emissions from business, industry and waste.

Project 1 – Benefits of Short-term Storage

Large scale energy storage such as battery storage, has been recently flagged by the Smart Grid Forum, the Energy and Climate Change Committee, Ofgem and BEIS (previously DECC) as one of the key smart interventions likely to feature in the future smart grid. Both low carbon demand and generation cause intermittent power flows. This intermittency causes short-term thermal spikes and breaches to statutory voltage limits.

The site at Hemsby was identified as having local wind generation that would allow data to be collected about real power exchange. The 200kWh Hemsby storage asset managed demand on a network connected to significant renewable generation (ten windfarms sized at 200kW each). **It provided the possibility to accommodate additional demand or generation from low carbon technology deferring reinforcement costs**. Real power was shifted between networks and the reliability of such a shifting of real power was demonstrated.

This project demonstrated, for the first time, the ability to stack benefits of a storage asset. This project had a prime focus on demonstrating the business case for using storage to manage the distribution network; a later project, Smarter Networks Storage, advanced upon these ideas and created cross industry commercial frameworks. These cross industry frameworks informed the ongoing debate into the need to treat storage as a separate asset class. Key to a low carbon, climate resilient economy is with informed, regulatory support of storage to support the low carbon transition and provide stability to both transmission and distribution networks.

Storage helps maintain a reliable, secure network whilst moving into a low carbon future. It allows adherence to technical and safety limits of electrical circuits connected to low carbon technologies. Renewable generation fluctuates and a network operator must consider worst-case scenarios. A short-term discharge of real and reactive power avoids breach of voltage limits or needing to curtail (shut down) renewable generation. Voltage issues arising from variable renewable generation were resolved by using the STATCOM function of the battery. The voltages were kept within statutory limits (10.96kV ±0.11kV) and adhered to tighter standards (10.96kV ±0.08kV). The project shaped future strategies for managing networks with a storage asset by demonstrating benefits beyond balancing real power.

Project 2 – PV Connection Assessment Tool

The volumes of PV connection notifications and applications in 2011 and 2012 were unprecedented; solar generation enquiries increased 1400% between 2010 and 2015. In order to efficiently and accurately complete connection designs for our customers, UK Power Networks had to develop new tools, procedures, and design assumptions. The project improved the accuracy with which UK Power Networks is able to assess reinforcement requirements **facilitating the connection of renewables**. After the project Solar PV generation could connect without risking security of supply.

This project enabled system readiness for the drive in the uptake of renewables. It delivered a validated and pragmatic connection assessment approach, comprising a formal design procedure and an improved tool. This tool is business as usual within UK Power Networks and was actively shared with other GB DNOs in 2015. A draft connections policy was improved and became official UK Power Networks policy as a result of this project. This has avoided localised loss of power, voltage complaints and ensured trust in micro-renewable generation. The FIT scheme, implemented by Ofgem as the most effective way to decarbonise generation at the time (key aspect of the carbon plan), led to more renewable generation connection requests. This project facilitated the connection of this renewable generation.

Project 3 – Distribution Network Visibility

One of the challenges of connecting distributed generation onto the distribution network is that it can cause voltage rises (particularly at times of light load). Therefore, **creating voltage headroom can allow more generation to be connected on existing networks without the need for reinforcement**. The DNV application has enabled us to efficiently monitor our assets and identify opportunities for improving voltage headroom at primary and secondary substations.

Example: The Dashboard report (figure 3) produced by the DNV application picked up a number of secondary substations (s/s) supplied by Kimberley Rd primary for having high voltage values. Further analysis on DNV showed that 71 s/s fed by Kimberley Rd primary presented voltage issues and a voltage step change at the primary substation in July 2013. An onsite investigation at Kimberley Rd showed that the tap changer motor protection relays on transformers T2 and T4 had tripped. Motor protection relays were reset and voltage headroom was created at the LV level (on average approximately 4V at each the secondary substations supplied by T2 and T4 transformers at Kimberley Rd). A similar case was picked up at Osborn Street primary substation using DNV. DNV has helped create a voltage headroom of approximately 4V at each secondary substation supplied by Osborn Street T1 and T4 primary transformers.

Reinforcing the distribution network can be a very carbon intensive exercise. It involves the collection and disposal of the old, replaced assets (e.g. transformers, oil, switchgear), although raw materials are recycled where possible, and the delivery and installation of new assets. **The greater network visibility offered by the DNV application is informing business decisions on planning reinforcement and preventing it**.

Example: The London Distribution Planning team were requested to look into replacing a 500kVA transformer at the Bromley High Street Warren House s/s. The transformer, based on maximum demand indicators taken in 2009 and 2011, was reported as overloaded. However, further analysis using the DNV application (load duration curves, utilisation report, analytical and time series data on transformer's loading) (figure 4) revealed that the percentage of time the transformer has been >100% utilised from 2008-2013 is very small and the transformer has never been 120% or more utilised. The DNV analysis was followed up and confirmed by onsite investigation. The replacement of the transformer was successfully avoided which led to significant carbon savings included in table 7.

DNV has also help reduce greenhouse gas emissions by reducing or avoiding operational vehicle miles. The 71 substations supplied by Kimberley Rd and 48 supplied by Osborn Street would have been attended by operational staff after customer complaints. This would have led to 60 individual investigations (assuming each investigation would cover 2 separate site investigations). Assuming an average of 4 miles travelled/investigation, a total of 240 miles (=386km) have been saved. For our lighter diesel vans (up to 3.5 tonnes), the equivalent of carbon dioxide emissions saved was 0.110toCO_2e (please note that in some cases heavier duty vans attend sites).[7] If at least one similar case is picked up in LPN using the DNV application from 2020 onwards, the anticipated avoided equivalent carbon emissions for individually visiting secondary substations (assuming average number of 40 substation per LPN primary) would be roughly 0.0684 toCO_2e/year (assuming lighter diesel vans are used for the visits).

By 2050 DNV will have saved over 2 tonnes of CO2(equivalent) summarised below.

Table 7 **–** *Realised and Forecasted Carbon Benefits in toCO_2e (cumulative basis)*

Project	10/11	11/12	12/13	13/14	15/16	2020	2030	2040	2050
DNV	-	-	-	0.066	0.110	0.178	0.862	1.546	2.230

DNV helps maintain a resilient network that facilitates the connection of low carbon technologies (load and generation), reduce load related faults and asset damage and even prevent customer interruptions, leading to clear carbon benefits and better customer service. It does so through the wide range of information and analysis tools available through the DNV application that allow the quick identification of highly loaded sections on the network, more detailed assessment of connection requests (assessment of transformer utilisation and spare capacity) and the analysis of fault conditions.

[7] "Greenhouse gas reporting – Conversion factors 2016", https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016, 07 February 2016.

Project 4 – LV Current Sensor Technology Evaluation

The aim of the LV Current Sensor Technology Evaluation project was to evaluate a number of commercially available LV current sensor systems. This was carried out in both controlled laboratory and operational environments; this work informed other DNOs about the technical issues associated with a wider rollout of these technologies in the low carbon future. This supports a more efficient and targeted rollout of these technologies across GB and will contribute to increasing visibility of the LV network. As our Tier 1 Distribution Network Visibility project has demonstrated, **greater visibility of the network can enable more load and embedded generation connections onto the existing network without the need to reinforce**.[8] Moving forward, the learning outcomes, and the improvements in the monitoring solutions available on the market, that have resulted from the LV Current Sensor Technology Project will be available to support many of the LV-connected LCT devices that we have forecast for connection in our networks over the RIIO-ED1 period.

A2. Releasing network capacity

Project 1 – Benefits of Short-term Storage

This project raised the technology readiness level (TRL) for grid-scale storage devices from seven to an eight and allowed the deployment of a much larger asset in our Smarter Network Storage Project with additional capabilities such as dynamic frequency response that aided the business case for deferred reinforcement. Whilst the storage device trialled in this project, and the associated network, did not receive any new connection applications that breached the ratings of the line, the project did successfully demonstrate management of network voltage which can be a barrier to releasing network capacity. Voltage issues arising from variable renewable generation were resolved by using the STATCOM function of the battery. The voltages were kept within statutory limits (10.96kV ±0.11kV) and adhered to tighter standards (10.96kV ±0.08kV) without the need for a tap change on the transformer. This technique will inform future approaches to voltage constraints.

In addition, this demonstration allowed the Smarter Network Storage, to install a larger asset in Leighton Buzzard, based upon the learning outcomes from the trial. The Smarter Network Storage asset deferred re-enforcement, a 35MVA overhead line installation, by peak lopping with a 6MW capacity storage device. This technique would not have been realised without the learnings from this Tier 1 project.

Project 2 – PV Connection Assessment Tool

The project delivered key learning about PV generators' behaviour and impacts on the LV network in terms of diversity, voltage rise, reverse power flow, harmonics, and voltage imbalance; based on 25,775 days of data gathered from 20 secondary substations and 10 PV connection points. This data has informed internal policy about concerns for PV uptake and provided assurance. Based upon the data analysed from this project, an informal connections assessment policy was altered and became formal. The formalised procedure guidelines, along with the created PV connection assessment tool, more accurately allows planners to accept/reject reinforcement requirements. Both are products from the project and inform reinforcement decisions for connections. There have been 96 connection requests (of type G83) guided by the reviewed policy guidelines and developed tool; these requests were more accurately assessed, minimising network issues. These requests amounted to more than 368 kW generation capacity.

Project 3 – Distribution Network Visibility

The DNV application (apparent power data, utilisation visualisations, and load profiling) concluded that a 53kVA residential load (for a small block of flats) could be connected without the need for reinforcement. The traditional method using PI Historian (database of time series analogue values) showed that the substation closest to the referred connection was heavily loaded. The DNV application detailed analysis showed that the peak of the incoming residential load did not add to the peak of the overloaded substation, which enabled us to connect the customer without additional reinforcement;. This technique is currently being applied for any connection application with sufficient DNV on-site monitoring data.

[8] "An Independent Evaluation of the LCNF", Pöyry Management Consulting (UK) Ltd. and Ricardo Energy & Environment, October 2016

In addition to thermal capacity, the DNV project has helped identify opportunities to increase voltage headroom at the LV level, which also supports the releasing of network capacity, particularly for LCTs This is demonstrated in the case studies of Kimberley Rd and Osborn Street primary substations presented in criterion A1. The voltage headroom increase in those cases was approximately 450V at the LV level (cumulatively).

<u>Project 4 – LV Current Sensor Technology Evaluation</u>
Not applicable. Releasing network capacity did not form part of the aims and objectives of the project. However, the knowledge generated from it is expected to promote and facilitate the use of LV monitoring devices on the distribution network which will then lead to greater visibility of it. Proven case studies from our DNV project have successfully demonstrated how this greater network visibility can lead to the release of network capacity.

A3. Delivering financial benefits

A summary of financial benefits is presented below followed by evidenced statements. Financial benefits are presented on a cumulative basis since the start of the relevant project.

Table 8 - DPCR5 savings that accrue to the electricity network

Project	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016
Project 1 – Storage Discharge	£160,4k	£313.4k	£461.9k	£2,673.6k	£2,889.9k
Project 2 – PV Tool	-	-	£0.5k	£1.0k	£1.6k
Project 3 – DNV	-	£6.1k	£94k	£119.5k	£135.9k
Project 4 – LV Current Sensor	-	-	-	-	£98.9k
Total	£160k	£320k	£556k	£2,794k	£3,126k

Table 9 – Forecasted savings that accrue to the electricity network

Project	2020	2030	2040	2050
Project 1 – Storage Discharge	£3,889.9k	£4,866k	£4,866k	£4,866k
Project 2 – PV Tool	£5.7k	£13.0k	£13.6k	£13.6k
Project 3 – DNV	£433.5k	£2,244.2k	£3,527.8k	£4,493.4k
Total	£4,329k	£7,123k	£8,407k	£9,373k

Table 9 clearly shows that our portfolio has delivered enough financial benefits within DPCR5 to cover its costs.

<u>Project 1 – Benefits of Short-term Storage</u>

- **Labour cost savings from automation**

Advanced control algorithms enabled the energy storage device to operate autonomously, without centralised control room intervention. This is major achievement as decentralised intelligence and open architecture are the key principles of a smart grid and essential for all storage sites due to small scales and commercial drivers. This development produced a saving upon the staffing needed to control this storage asset by 3.5k man hours a year from the stage of automation – £[redacted] pa (an equivalent saving was also achieved from this learning for the SNS project). This demonstration also allowed energy suppliers to be confident in future builds and inform the policy and risk assessments of an unmanned site.

- **Site operational cost savings**

The auxiliary power consumption and the operating regime of the ESS had a significant impact on total round trip efficiency. Optimisation of auxiliary support systems reduced power consumption in future installations. Data collected informed a power consumption saving of £8k per annum in the installation of the smarter networks storage asset (SNS) – the cooling activated only when the power electronics were in use. In addition the Hemsby ESS contained many exposed live components – the site needed to be shut down before anyone could enter. UK Power Networks learnt from these experiences and in the later build of the SNS ESS insulated all components and saved £6k a year on the need to shut down.

- **Cost savings from commercial maturity**

Suppliers typically were not prepared to offer even standard energy tariffs for Hemsby. The import price of the seasonal tariff used at Hemsby varies between [redacted]. From learning under the Hemsby project the SNS project has achieved close to system sell and buy prices ([redacted]) through an agreement with an energy supplier. This resulted in £60k pa cost saving over the first year for SNS as the data from the Hemsby project guided the future agreements.

- **Lowered cost of future installations**

After the completion of the Hemsby trial, ABB estimated that savings of up to 15% could be expected on a similar project. This was based on having deployed a real asset, the technology then available and lessons learned. The SNS project was directly informed by these learning outcomes and increased supply market maturity when installing a much larger installation and achieving much greater functionality. Considering this, savings on the original investment achieved through the reduced SNS build cost are estimated to be up to £2m.

<u>Project 2 – PV Connection Assessment Tool</u>

The tool developed under this project, in addition to improving design accuracy, reduces the processing time required for PV connection applications. The tool allows a customer's application to be more accurately assessed and costed with a faster turnaround. An improved user interface allows two minutes saved, conservatively, per relevant application. In the two regions deployed, EPN and SPN, UK Power Networks receive 2,000 applications per year; the tool has saved [redacted] man-hours a year on relevant applications; this saving will continue through its lifetime.

<u>Project 3 – Distribution Network Visibility</u>

- **Labour cost savings**

DNV saves on average 8hrs/week on new connection referrals. Using the current hourly rate for planning engineers DNV saves £[redacted]/ working day. DNV has been used by the LPN planners since December 2012, so savings from December 2012 to March 2016 (working days only) are: £[redacted] (in 2016/17 prices)

Assuming that i) the number of connection referrals remains the same in the coming years in LPN, ii) there is full rollout of the DNV application to EPN and SPN by 2020:
LPN: £[redacted]/year, SPN: £[redacted]/year and EPN: £[redacted]/year (in 2016/17 prices)

- **Avoidance of network reinforcement**

This project deferred the replacement of two secondary transformers at Anerley Road Bettswood and Bromley High Street Warren House saving £[redacted]. This is the total cost including collection and disposal of replaced assets and delivery, installation and commissioning of new assets.

If we assume similar success rates in all three areas, we would be able to potentially defer up to eight transformer replacements per year. This could lead to savings of £[redacted] per year.

- **Proactive investigation of over-voltage issues at secondary substations**

Assuming the problem at the primary level was not identified and UK Power Networks only acted following customer complaints:

- Kimberley Rd Case Study: 71 substations affected that could have been individually investigated at different times. If tap changing required at 50% of sites (36 sites), the cost could have been £[redacted]. This is based on 2 people (1 fitter and 1 engineer) spending half a day per site manually changing the tap position of a transformer. It excludes any transport costs to and from the sites.
- Osborn Street Case Study: Similarly, for 48 secondary transformers normally supplied by transformers T1 and T4 at Osborn Street primary, the cost for manually tap changing 50% of sites (24) could have been £[redacted]. This again excludes any transport costs to and from the sites.

If at least one similar case is picked up in LPN using the DNV application, the anticipated avoided costs for individually visiting, investigating and tapping individual transformers would be roughly £[redacted] per year (assuming a number of secondary substations per primary similar to the Osborn Street case).

- **Extend life of assets by limiting exposure to damaging conditions**

The project reduced assets' exposure to damaging temperatures at Piccadilly Ritz Hotel Leicester SQ 11kV S/S, Oxford Street Debenhams A and B S/S and Old Marylebone Rd Regina House S/S which could have led to early failure of transformers and switchgear at these sites (high operating temperatures can decrease asset life[9]). These assets were identified by the DNV application to have temperatures above specific thresholds and were referred to our operational staff for onsite investigations. Corrective actions have been taken and temperature at the substations are now within acceptable levels. The corrective actions taken have deferred replacement of the assets.

Project 4 – LV Current Sensor Technology Evaluation

The project developed safe systems of work to allow installations of LV monitoring equipment on live network with no impact to CIs and CMLs (no outages required for installations). Our Tier 2 project "Flexible Urban Networks – Low Voltage (FUN-LV)" has used the results of the project to select an LV monitoring solution which would be safe, efficient, and quick to install and would not require an outage for its installation. The fact that all installations were made on the live network negated the need for planned interruptions, in this case equivalent to Customer Interruptions (CIs) of: 0.003 for LPN, 0.0015 for SPN. In addition it saved the following Customer Minutes Lost (CMLs), 0.122 for LPN, 0.061 for SPN. Drawn from costs per CI and CML, the total combined avoided costs = £98,820.5 in 2015/16 prices.

It should also be noted here that selecting easy to install sensors minimises time on site. For confined spaces this means cost savings from contractors carrying out works and/or supplying specialist equipment.

Maximising the value of background and foreground intellectual property

Project 1 – Benefits of Short-term Storage

The project built a smart network integrating the energy storage system, remote monitoring of distributed generators and the wider network. This was achieved through the development of a series of advanced algorithms for the ESS controller, written by a third party. This work also fed the development of the software FOSS, Forecasting, Optimisation and Scheduling System, used in a later battery system at UK Power Networks.

Project 2 – PV Connection Assessment Tool

Along with the full publishing of project outcomes and learning reports, the PV assessment tool was shared in its entirety with the Innovation Teams within every DNO in Great Britain. In addition the Design and Planning team at Scottish Power Energy Networks (SPEN) requested and was subsequently sent the tool.

Project 3 – Distribution Network Visibility

There is foreground intellectual property (including certain software components) generated within the project and owned by the project's partners, and for which UK Power Networks worked to provide for a royalty-free license for all GB DNOs to be supplied on request. This can maximise dissemination which will then, provided the intellectual property is used for improvement of network management, lead to more value to customers.

Project 4 – LV Current Sensor Technology Evaluation

The collaborative nature of the project in particular enabled learning from the project to be shared with the manufacturers of the tested monitoring solutions. Improving their understanding of DNO requirements (i.e. solution requirement, safe retrofit installation, operation and communication of LV monitoring equipment), confidence in the demand for the products, and ultimately supporting product improvement efforts that will deliver – when deployed on distribution networks – more benefits to customers. This has also allowed the relevant market to continue to develop, while increasing competition and choice which results in more options, better performance, lower prices.

[9] "IEC 60076-7:2005: Part 7: Loading guide for oil-immersed power transformers", International Electrotechnical Commission, December 2015

A4. Rollout across the DNO's system and across GB

Project 1 – Benefits of Short-term Storage

This project contributed to a prominent forum and informed future grid-scale battery installations. To facilitate knowledge sharing between DNOs and the energy storage industry, the Energy Storage Operators' Forum (ESOF) was established in May 2012. They provided an indication of growing momentum in their White Paper 'State of Charge GB' which states that in November 2013, 5.1 MW and 6.4 MWh of distribution network connected energy storage was commissioned with an additional 7.2 MW and 13.8 MWh either under construction or being planned.

Ofgem recently commissioned an independent evaluation of the LCNF. This report, by Poyry, was published in September 2016 and supported the fact that this project enabled UK Power Networks and other DNOs to proceed with larger scale storage projects[10]. Poyry, in the report, linked this project to the deployment of both Smarter Network Storage (UK Power Networks) and Rise Carr (Northern Power Grid). The large scale project smarter network storage would have been hard to approve without the demonstration of grid scale storage in this Hemsby project.

The Technology Readiness Level (TRL) is a heavily weighted factor that affects the decision of another DNO to install innovation into business as usual. Before the project, the TRL was a seven out of a range of one to nine. After the project the TRL was higher, raised to eight and was an important step in the development of the technology and enabling further connections of grid scale storage.

Project 2 – PV Connection Assessment Tool

The project delivered a validated and pragmatic connection assessment approach, comprising a formal design procedure and an improved tool that UK Power Networks adopted into business as usual and shared with other GB DNOs. This tool was shared with the Innovation Teams within each DNO in Great Britain at the time of the closedown report. On 8 December 2016, the Head of design planning at SPEN requested the tool; it was shared and an offer of support given. The aforementioned Poyry report states that the project's extensive data set has been shared with industry. The tool is being used by two DNO regions within UK Power Networks, with staff in the final region being trained.

Project 3 – Distribution Network Visibility

DNV has been rolled out across our LPN network, where all Remote Terminal Units (RTUs) have been upgraded to allow greater visibility through the retrieval of more network data. The project has not yet been fully rolled out in EPN and SPN due to lack of secondary substation RTUs. The transition though from DNO to DSO will require greater network visibility and the population of more primary and secondary substations with advanced RTUs. This will drive the full expansion of the DNV application in our EPN and SPN regions. It should be noted that all other data sources and functionalities (e.g. RTUs at primary substations) are already available in these areas.

Significant effort was put into ensuring that the outcomes and products of the DNV project are adopted by the business. The project team: i) tailored interactive training sessions with each of the UK Power Network teams that would be using the application including relevant case studies and examples; ii) asked users to complete feedback forms check that the required support was provided for adoption of the application; iii) developed (in consultation with business early adopters) the updated business process documents and application handouts to support the wider business as usual integration; and iv) shared user guide, how-to guides and videos produced with the application users.

Dissemination events took place before and after the project had finished including demonstrations and conferences (e.g. UK Power Networks has presented the progress and findings of the project in LCNF conference in 2012 and 2013 and the use of the DNV application in business as usual processes at the 2015 LCNI conference after the project had finished). In order to facilitate the replication of the DNV application by other DNOs and maximise the technology rollout, an IT White Paper was produced, as well as a number of reports on network monitoring, real time power flow and RTU advanced features.

[10] P48 "An Independent Evaluation of the LCNF", Pöyry Management Consulting (UK) Ltd. and Ricardo Energy & Environment, October 2016

To our knowledge, there are no other innovations that could be used as widely within the business as the Distribution Network Visibility project. The DNV application developed as a one of the project's products is unique and the first of its kind; it brings together data from six different business sources/databases (over 6,000,000 data points/day), converts them into useful information through advanced algorithms and presents them in various visual ways to assist business processes and support business decisions. It also allows engineers to access real-time and historic information for the distribution network that were previously either not available or difficult to retrieve.

Project 4 – Low voltage current sensor evaluation
64 GMC i-Prosys sensors were deployed in LPN and SPN in 2015 as part of the FUN-LV Tier 2 project. A further £70k was invested in LV sensors evaluated from this project to monitor our network.

Since this project, UK Power Networks has specified in an Engineering Design Standard (EDS 08-5040: "Guidelines for the provision of system monitoring) the need to equip LV boards with LV monitoring devices to enable a 'smarter' electricity network. Learning from this project will be used to either select or develop these solutions (UK Power Network is currently developing LV Remote Terminal Unit (RTU) and LV monitoring Input/Output (I/O) module specifications based on this learning) or to install them safely on the live network (use of installation guides and procedures developed or informed by the project[11]).

In regards to future deployment of LV monitoring devices across GB, we expect other DNOs to have similar strategies and plans in place as described in our EDS 08-5040 engineering standard as the industry continue to develop smart distribution networks and the transformation to a Distribution System Operator.

The learning from this project has also informed other innovation projects relating to LV network visibility and management. Based on the evaluation results of this project, our Tier 2 project FUN-LV selected LV sensors to be used in its trials. WPD, a project partner, has used learning from the project in their LV Network Templates project.[12]

This project has influenced the LV monitoring market in the UK and internationally (as some of the manufacturers whose products were tested and evaluated have international interests) in a unique way. UK Power Networks and WPD along with National Physical Laboratory (leading the laboratory trials) held meetings with multiple manufacturers before the end of the project to disseminate the learning from the project to help them improve their products and understand DNO requirements better. This has allowed the market to continue to develop, while increasing competition and choice.

A5. Other benefits

Project 1 – Benefits of Short-term Storage
To provide network visibility, the trial included the installation of remote monitoring across the network to enable the control algorithms to respond not only to local (at ESS) network events, but also to wider network issues such as under-voltage at remote feeder locations, generators or reverse power flows. This was a precursor to the control systems required to deliver frequency response capability, a service that now dominates the storage market and also requires local control and network monitoring. This market maturity kept the cost of the EFR tender low; we demonstrated and shared information about the technological maturity of such a complex control algorithm. Hemsby, along with SNS, de-risked investment cases for autonomous grid-scale storage in the UK.

An additional point of learning was that the installation footprint does not necessarily increase significantly for installations with a higher rating and/or energy capacity for Li-Ion. The batteries at Hemsby occupied less than 3% of the site. The ancillaries (heating, cooling, water pumps, lighting, CO2 fire suppressant, etc.) and the AC components in the outdoor compound occupied significant space. There was insight that a higher capacity battery build could be achieved without proportionally larger associated land costs.

[11] "Engineering Operating Standard 01-0053 v2.0: Installation and Operation of Monitoring Equipment on LV Distribution Equipment", UK Power Networks (Ross Thomson and Omer Khan), 28 April 2014
[12] "An Independent Evaluation of the LCNF", Pöyry Management Consulting (UK) Ltd. and Ricardo Energy & Environment, October 2016

The project, and later Smarter Networks Storage project, have informed UK Power Networks and fostered a skillset that has allowed UK Power Networks to take a leading role in discussion on future commercial frameworks through government consultations, such as the 'A smart, flexible energy system: Call for evidence'[13].

Project 2 – PV Connection Assessment Tool

It was found upon rollout of the tool that there was not a great deal of knowledge about existing PV installations. The rollout of the tool has provided a heightened sense of the issue and provided capability to assess the impacts of incomplete PV data on network design assumptions. This other benefit has provided UK Power Networks with the mandate to secure geographical information about solar PV installations. The argument for secure sustainable energy supply allowed the information to be shared – it would not have been made available without a cogent business case, supported by the PV assessment tool. The informed conclusion proved that G83 notifications are not accurate, and DNOs need access to better information, through the FIT register about the existing PV generation connected to their networks.

Project 3 – Distribution Network Visibility

The DNV project has produced significant additional learning captured in a number of reports:

- The DNV application has successfully demonstrated the need for efficiently managing large amounts of data gathered from distribution networks and the delivery of benefits that derive from it. When moving to a 'smarter' network where LV monitoring is more widely deployed, having one application that collects all data, converts them into useful information and presents them in different ways through various visualisation tools depending on business needs, will become increasingly important if not a necessity.
- The project has also highlighted the importance of data quality. For an informed and thorough assessment of the networks' condition, it is not enough to have the right systems in place (databases, analysis tools etc.). One needs correct and trusted data that to make decisions upon. The DNV application is producing a daily network wide report which looks at the health of our fleet of RTUs pointing out any issues of abnormal measurements or communication problems, this anticipates issues saving cost.
- Further development of the Sequence Component Transform method which allows monitoring of HV current and voltage at a substation using only HV current sensors LV voltage measurements, avoiding the need to measure HV voltage and hence reducing monitoring costs. Details of the method are available to other DNOs.
- A model has been developed to investigate the dynamic rating of transformers using the substation temperature, the ambient temperature and the transformer loading. The concept has been proven and allows future integration with the DNV application when more sensors become available at substations.

Project 4 – Low voltage current sensor evaluation

Additional learning has been generated within this project not only for DNOs but also for manufacturers of LV monitoring solutions:

- A feedback loop created by the project with the seven project suppliers has informed the LV monitoring industry of DNO requirements for network visibility and the challenges associated with wide rollout of such technologies. This practical learning has led to all of the involved manufacturers making improvements to their systems. For example, the Sentec have made a number of improvements to their GridKey Metrology and Communications Unit including adding Ethernet functionality to communicate data and upgrading it to include Total Harmonic Distortion in the data to transmit (more examples can be found in the project's close down report). This has positively influenced the market and therefore delivered benefits to both DNOs and customers.

A6. Portfolio Management

Project 1 – Benefits of Short-term Storage

This Tier 1 LCNF project was a key, early stage of grid-scale storage development; it directly links to our subsequent Smarter Network Storage (SNS) project. The project bid and delivery were de-risked by several areas of learning including:

[13] Department for Business, Energy & Industrial Strategy, 10 November 2016,https://www.gov.uk/government/consultations/call-for-evidence-a-smart-flexible-energy-system

- Development of a tool by Newcastle University to enable the planning teams at UK Power Networks to give an accurate model representation of energy storage on the distribution network;
- Demonstration of the method of capacity release [Criteria A2];
- Financial benefits from lower cost of installation and maintenance [Criteria A3];
- Algorithms for scheduling and automation of battery control, this accelerated the development of the platform for the Smarter Network Storage projects; and
- Knowledge about installation, operation and maintenance of a battery storage device.

Project 2 – PV Connection Assessment Tool

This project informed and de-risked the £5m VCEE bid, (the LCNF Tier 2 project now known 'energywise'). The success of energywise relied on installing equipment to monitor energy use and gained the trust of residents in a housing estate. The PV assessment tool commanded similar skills, the learning from recruiting and earning trust significantly de-risked the larger energywise project –lack of experience with customer engagement would have added to the risk. The PV Assessment Tool project also generated valuable information about the success rate of monitoring customer power flow and other methods of customer interaction. These learning experiences ensured the successful outcome of the energywise bid.

Project 3 – Distribution Network Visibility

The LCNF Tier 2 FUN-LV project used the DNV application to select heavily loaded substations that also had a lightly loaded substation neighbouring them. These substations were then reviewed for use in the capacity sharing trials. Load profiles were also extracted and compared to estimate the levels of capacity transfer a Soft Open Point (SOP) could deliver. The DNV application was also regularly used for our Tier 1 Smart Urban Low Voltage Network (SULVN) project to obtain information on primary and secondary substation assets, such as nameplate ratings, maximum demand indicators and the asset hierarchy (i.e. which feeders and secondary substations are fed from each primary substation), enabling greater visibility of how assets are performing and facilitating project decisions.

Learning from the project was used to build the successful business case for upgrading over 9,000 RTUs in LPN to enable all 15 possible analogue measurements (only 500 RTUs were originally upgraded for proof-of-concept purposes). The greater visibility of the LV network facilitated through the availability of more network data offers more benefits to the customer as some of the case studies presented above clearly demonstrate. Other examples of benefits to customers include:

- The DNV application highlights areas of maximum and minimum voltage for attention by operational teams. Engineers use the application to gain an overview of the historical voltage/load profiles/generation, and either send someone to site to take spot measurements, install measuring equipment over a period of time, reconfigure the system or pass the issue to the planning team;
- Identification of LV out of balance and harmonics: Using the DNV application a voltage unbalance was identified as above 3% at a substation. A site investigation identified that the substation was unlocked, and the earth bar had been stolen. A replacement earth bar rectified the voltage unbalance. The benefit of being able to identify this type of situations is clearly significant as it could have resulted in a life threatening situation; and
- Network-wide reporting of voltages outside of limits which improves customer service by proactively solving voltage issue and avoids the need for fitting voltage measuring equipment in response to inquiries.

Project 4 – Low voltage current sensor evaluation

- The results of the project were used as pre-qualification criteria for the LV monitoring required in our Tier 2 FUN-LV project. Criteria for selection were ease of installation, safety and time to install; and
- Even the amount of data produced by the trials within this project was too much to analyse manually. It was therefore made clear that for any wider deployment, suitable analytical tools should be developed and utilised to summarise every-day running arrangements into meaningful metrics, and allow the automated identification of abnormal situations. This has de-risked the development of the DNV application through the Tier 1 Distribution Network Visibility project.

7.2. Criterion B

Only two of our four eligible Tier 1 projects made use of additional DNO funding (above the 10% compulsory contribution) or external funding to ensure successful delivery of learning and project outcomes. The two projects that required additional funding are the Benefits of Short-term Storage and the Distribution Network Visibility projects. Accordingly only those projects have been included below.

B1. Details and significance of DNOs additional contribution

- **Details of any additional DNO funding above the 10 per cent compulsory contribution**

Project 1 – Benefits of Short-term Storage

A change request was agreed with Ofgem to extend the project end date from October 2012 to the 31 October 2013. As part of this change request, UK Power Networks offered to cover all costs incurred beyond the 3-year anniversary (June 2013) of the project. This was testament to the importance of this project to us.

Table 10 – Summary of planned Tier 1 project funding and outturn

LCNF Tier 1 project funding details	
Planned funding for trial period	**Project budget: £340k** LCN Funding budget: £250k (inc 10% comp.) Partner (ABB) Contribution: £90k
Actual Cost of trial	**Total project cost: £385.1k** LCNF eligible cost: £226.3k (inc 10% comp.) Partner (ABB) Contribution: £89.4k Funded by UK Power Networks: £69.6k

The final project expenditure came out at £385.1k[14]. This included the costs beyond the third year project anniversary which were borne in full by UK Power Networks as agreed with Ofgem in the change requests presented in Chapter 6 of the closedown report. An outline of these costs are also listed below and detailed further in section B2.

The additional contribution above the 10% compulsory contribution (£22.7k) by UK Power Networks amounts to £69.6k

As listed in table 10, ABB also contributed £89.4k to the project. ABB were contributors to the project. The ESS was controlled by ABB's Mach2 control system. In addition ABB designed and specified an SVC light power conversion system, step up transformer with AC filters, thermal management system and a prefabricated building with integrated protection and control.

Project 3 – Distribution Network Visibility

The second and third out of the three phases of the project were funded partly by the Innovation Funding Incentive (IFI) mechanism and partly by the LCNF Tier 1 mechanism. This funding split was carried out by assessing the use cases for the project outcomes and identifying the proportion of them that strongly contribute to the transition to a low carbon future (this proportion was funded through the LCNF Tier 1 scheme).

The total spend for the IFI phases of the project was: £891.3k, out of which 20%, £178.3k, were funded by UK Power Networks (compulsory DNO contribution for IFI projects). It should be noted here that the IFI compulsory contribution is mentioned here as the first tier reward criteria ask for any funding used above the 10% compulsory contribution for Tier 1 projects.

[14] This figure differs from Table 2 - these costs are beyond the three year anniversary of the project.

- **Details of any additional external funding (from sources such as UK/Scottish Government or the EU)**

Project 1 – Benefits of Short-term Storage
UK Power Networks acquired a second hand battery for this project. Much of the cost of installation was covered by AuraNMS, a preceding innovation project funded by EPSRC. This amounted to £2,061,194 and consisted of the purchase and installation costs which were not included in the First Tier project budget. This demonstrates that UK Power Networks sought value for customers by sourcing the most cost effective battery for project.

Project 3 – Distribution Network Visibility
As mentioned above, two of the project's phases were partly funded through the IFI scheme. The total spend for the IFI phases of the project was £891.3, out of which £713k (80%) were the eligible IFI funds and £178.3k (20%) the compulsory DNO contribution for IFI projects.

B2. Issues that justified the additional contribution

Project 1 – Benefits of Short-term Storage
The original project close date was October 2012. The project was formally extended after commissioning delays. Change requests, approved by Ofgem, extended the deadline. The change requests are detailed comprehensively in chapter 6 of the closedown report, collectively they caused an extension of the project to the 31 January 2014. Additional expenditure after June 2013 was covered, in full, by UK Power Networks.

This delay was caused by several issues associated with the first of a kind nature of the project, such as intermittent tripping of the circuit breaker connecting the battery to the voltage source converter, spurious alarms from the control system and protracted development of the maintenance and energy contracts. Many lessons were learnt from the operation of the storage asset and the benefits of this experience shared with UK Power Network's subsequent Smarter Network Storage project and with the industry.

B3. Demonstrable benefits to customers

Project 1 – Benefits of Short-term Storage
The trials needed to be completed to demonstrate the benefits of short-term storage to the DNO network. The shared service structure that later developed is one that has significantly informed the future commercial strategy of storage installations; it was important to complete the trials described fully in the four page project overview. The benefits described in criterion A1 - A6 could not have been achieved without the completion of the trials.

Project 3 – Distribution Network Visibility
Phases 2 and 3, which are the phases that were partially funded through IFI, included the upgrade of RTUs and the collection of additional data into our databases, as well as the development of the DNV application. These deliverables have offered greater network visibility enabling us to deliver better customer service. The section on Criteria A has more details on how network visibility has changed the way we operate to deliver more customer benefits.

7.3. Criterion C

C1. Delivered more learning than was expected

Project 1 – Benefits of Short-term Storage
In the original proforma it outlines an objective: “Embed the learning…into dissemination material for the UK DNO community”. The project met and exceeded this original outcome.

UK Power Networks has been an active, founding member of the Energy Storage Operators Forum (ESOF). ESOF was established as the forum for UK DNO/TSO owner/operators of electrical energy storage systems to meet and to share knowledge and learning. Learning was shared in relation to implementation, safety case development and operation of grid scale storage on UK power distribution and/or transmission networks.

UK Power Networks was an active contributor to this forum. The first recorded involvement was in May 2012 with active participation and contribution to the group well before and continuing well after the project closing date (31 January 2014).

Through this group, UK Power Networks was one of the key drafting contributors to the Good Practice Guide on Electrical Energy Storage that is a publicly available document, accessible by a global audience. This participation was not an initial objective however an extension of the dissemination responsibilities.

The information provided through ESOF has helped inform the need for grid scale storage and reduced operational costs from providing information about the Hembsy ESS and future installations.

Project 2 – PV Connection Assessment Tool
This tool has been later used to inform an approach for electric heat pumps. Based on the learning from the trial the method to collect information about existing installations was improved.

Within the closedown report seven unique voltage issues were discussed that are expected to become prevalent in the future. In the report, ten solutions were proposed to these commonly experienced voltage issues. Many are now innovation projects; for example a proposed solution, control of residential storage devices, is being studied in our Domestic Energy Storage and Control (DESC) project. Other solutions proposed in the project have been pursued for BAU implementation. Pole-mounted voltage regulators are planned to be installed to address voltage complaints, this method was informed by the project. Finally, one tier-2 project Flexible Urban Networks-Low Voltage (FUN-LV), run by UK Power Networks, is now completed; the network management strategy was proposed in this project. The most effective deployment strategy was informed by the data and learning.

Project 3 – Distribution Network Visibility
The main objective of the project was to demonstrate the DNO business benefits deriving from the smart collection, utilisation and visualisation of existing data (e.g. analogues available from RTUs and asset information stored in databases).

The project managed to exceed expectations by not only delivering business benefits (i.e. financial benefits, improved business processes), but also delivering benefits to customers and environmental benefits. Benefits to customers include more timely assessment of connection requests, more cost-efficient connections of load and generation (creating voltage headroom and avoiding reinforcement) and better customer service due to less customer interruptions. The realised environmental benefits include fewer carbon emissions from avoiding asset replacement and reinforcement and fewer vehicle miles of operational staff from proactive investigation of network issues. These have been demonstrated through case studies detailed in section 7.1 on Criterion A.

Project 4 – Low voltage current sensor evaluation
The project aimed to generate knowledge on LV monitoring techniques and enable wide rollout of these in order to facilitate a low carbon future while keeping any customer supply disruptions to the minimum. The project has managed to

inform the industry about available LV monitoring solutions that can be installed without outages (no disruption to customers) and the potential challenges that can arise from a wide rollout of LV monitoring.

In addition to the originally anticipated benefits, the learning generated through the project has also delivered the following:

- It has influenced the LV monitoring market. Manufacturers that took part in the trials gained a good understanding of the type of requirements DNO have around monitoring of the LV network and have improved their products accordingly. The market for LV monitoring solutions has grown offering a wider range of choices at lower prices and of better quality; and
- It has not only informed internal policies but it is currently being used for UK Power Network's recent updates to RTU specification policies that will be used for any future RTU purchases.

The project has also delivered unexpected learning that was not directly relevant to the solution:

- Communications: The communication method adopted for this project was GPRS. Due to the diverse landscape of the GB DNOs, it was concluded that the reach of GPRS/3G/4G would be limited in certain situations and this would mean using other communication technologies to bring back the data. For example, in cases where the substations are located indoors in basements the mobile signal strength would be weak and would require a BT line or Power Line Communications to be used. This point of learning will be key for the implementation of smart meters and increased LV monitoring.
- Even the amount of data produced by the trials within this project was too much to analyse manually. It was therefore made clear that for any wider deployment, suitable analytical tools should be developed and utilised to summarise every-day running arrangements into meaningful metrics and allow the automated identification of abnormal situations. This has de-risked the development of the DNV application through our tier 1 DNV project.
- For this trial a range of standard and company specific protocols were used by the manufacturers. It was concluded that to allow the DNO to easily integrate the equipment into their SCADA system, the manufacturers should adopt communications protocols that would allow interoperability across different hardware (e.g. IEC 61850). The need for communication protocols that allow interoperability highlighted through the project has informed DNO procurement processes around network monitoring, as well as encouraged the market and relevant industry to adopt to DNO needs and use such protocols more widely.
- The aim of the project was to assess a number of existing LV monitoring solutions and develop knowledge about challenges associated with their wider rollout. Understanding the challenges for a large scale deployment and having produced policies and procedures that facilitate this, a greater visibility of the LV network is expected in the near future. FUN-LV is another example where visibility of the LV network informs decisions for releasing network capacity and avoiding reinforcement, both leading to financial and network reliability benefits.

C2. Additional learning from exceptional effort

Whilst we commit significant and dedicated effort to all of our innovation portfolio, we consider that the effort required to successfully deliver our Benefits of Short-term Storage and PV Connection Assessment Tool projects was in line with expectation and thus are not presented here as exceptional. The two projects for which we believe exceptional effort was committed are Distribution Network Visibility and LV Current Sensor Technology Evaluation. Accordingly only those projects have been included below.

<u>Project 3 – Distribution Network Visibility</u>

Dynamic Rating of Transformers through temperature measurements

It was identified in the progress of the project that the data available was sufficient to assess the possibility of dynamically rating assets based on recent historic loading and environmental conditions. A model was developed to investigate the dynamic rating of transformers based on 10 sample sites using the substation temperature, the ambient temperature and the transformer loading, as well as the transformer temperature taken from additional sensors installed for the purposes of this exercise. Additional effort on the DNV project proved this concept, and the functionality will be able to be built into the application in the future where the additional sensors are installed at substation sites. The method has been well documented to allow a future integration onto the DNV application when more sensors become available at substations.

Further development of the Sequence Component Transform method
In areas of the secondary LPN network not covered by RTUs and in the majority of the SPN and EPN secondary networks, there is very little visibility of power flow. The project undertook trial installations of optical current sensors with the aim of developing and validating a toolbox of applications. As part of this work, a technique known as the 'Sequence Component Transform' method was further developed. It allows monitoring of HV current and voltage at a substation using only HV current sensors LV voltage measurements, avoiding the need to measure HV voltage and hence reducing monitoring costs. Details of the method are available to other DNOs on request. This further development was an addition to the original scope of the project.

<u>Project 4 – LV Current Sensor Technology Evaluation</u>
Exceptional effort has been made for manufacturers involved in the project trials to gain a better understanding of DNO requirements when it comes to network monitoring and the challenges associated with the wide rollout of such technologies. The need for things such as flexibility around remote communication of data, interoperability of hardware to facilitate SCADA integration and greater range of measurements from the network has been highlighted by the project and has been fed back to the manufacturers. For example, Current Grid responded to early feedback from the installation training held at UK Power Networks before the start of the field trials and made changes to some elements of their hardware in order to facilitate trials although this was beyond the scope of their contract. This feedback loop has given the opportunity to manufacturers to improve their products to make them more suited for a wider DNO adoption.

C3. Exceptional capture and dissemination of learning

<u>Project 1 – Benefits of Short-term Storage</u>
UK Power Networks was a key contributor to the good practice guide on electrical energy storage; salient information about this first of a kind installation was included. This guide contains information about energy storage relating to the current 'state of the art', description of various ESS technologies, codes standards and legislation, procurement and implementation. This guide and approach of ESOF have contributed to the high interest in the recent National Grid EFR tender. The value of the four-year contracts produced by the tender are estimated to be £[redacted] less than the expected clearing price. This was driven largely by the number of prospective market participants that felt in a place to build a grid scale storage unit. ESOF aimed to enable the widespread purchase and deployment of grid scale batteries.

ESOF's Objectives are:

- Review of members' activities in relation to the sourcing, implementation, commissioning and operation of EES systems;
- Presentation and discussion of specific member case study material, in relation to the development of operational safety cases;
- Review of the prevalent safety, regulatory, codes, standards and licensing landscape, relative to the technologies and systems involved;
- Exchange of knowledge and experience in relation to the operation and in-service performance of EES systems, on members' networks;
- Receipt of invited presentations from key third party stakeholders (e.g. Health and Safety Executive, overseas owners/operators etc);
- Identification of specific issues to be addressed, either as supplementary activities, within the club, or via other means; and
- Provision of collective DNO/TSO owner/operator "platform", with which to address/progress issues of common interest.

These objectives were met with a substantial and sustained contribution from UK Power Networks that has maximised value to the end consumer. UK Power Networks went above and beyond the original objectives laid out in the project proforma.

<u>Project 2 – PV Connection Assessment Tool</u>
Learning from the project produced a tool which is being used in the business, the wider industry also remains aware of this innovation and requested it after the project closedown. The created PV assessment connection tool was shared

directly with the Innovation Teams of every DNO region in the UK. On 8 December 2015, the Head of Design Planning at SPEN also requested the tool; it was shared with support. The aforementioned Poyry report states that the project's extensive data set has been shared with industry. The tool is being used by two DNO regions within UK Power Networks, with staff in the final region being trained.

Project 3 – Distribution Network Visibility

Tailored training sessions rather than a generic one were designed and delivered to all relevant business users. The sessions were designed to cover all features of the DNV application that could be of use for each department and how these could influence their current business processes following direct feedback from the different business units. This has also been captured in post-DNV updated business process documents. This facilitated maximum business adoption of the DNV application which leads to better customer service from business improvements such as quicker assessment of connection referrals, proactive management of the distribution network. The training and dissemination of the DNV tool within the business is most clearly evidenced by its successful take up as an everyday tool for our planning team.

A separate exercise was completed to collect and collate suggestions for future developments (DNV application enhancements) through speaking to the business at all stages of the project. This additional effort was committed in order to ensure that the best improvements in efficiency of processes and practices within the business were achieved and offer greater value to customers. They are being prioritised and programmed for implementation.

Project 4 – Low voltage current sensor evaluation

The project partners have shared the learning from both the laboratory and field trials with the manufacturers of the trialled LV monitoring systems. Better understanding of the challenges associated with a large scale rollout of such systems has been captured in reports (communications, data handling, interoperability of systems and protocols) and disseminated to DNOs across GB (through conferences and knowledge sharing events). As a result, not only some of the manufacturers have improved their products but also the relevant market has since been growing and is now offering a wider choice of better performing products at more competitive prices.

The value to the customers will come from the wide rollout of LV monitoring equipment which will help DNOs gain greater visibility of their LV network and realise associated benefits (faster and cheaper connections of embedded generation and low carbon loads, greater network reliability etc.).

These benefits, now available to all DNOs through the products available from the market, are inherent to the collaborative approach taken with multiple DNOs and manufacturers involved in the project, yielding exceptional dissemination and outcomes from the project.