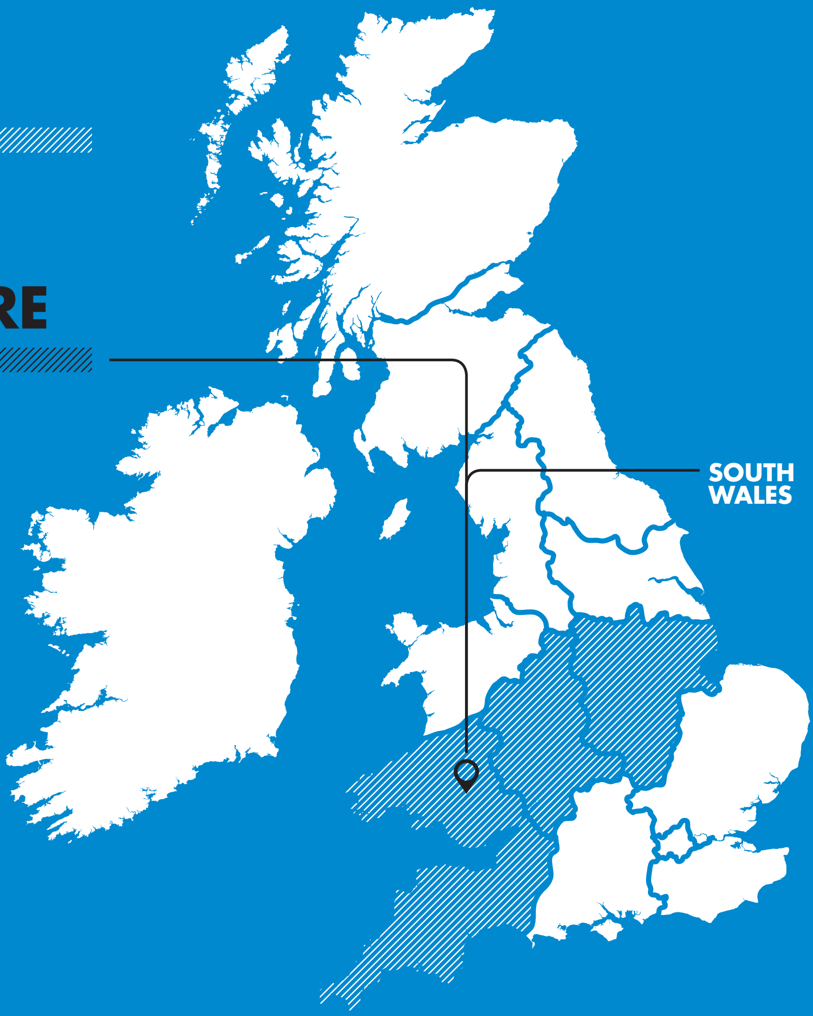
WESTERN POWER DISTRIBUTION

NETWORK TEMPLATES

LV NETWORK TEMPLATES FOR A LOW-CARBON FUTURE

CLOSE DOWN REPORT



LCN Fund Low Carbon Networks | Llywodraeth Cymru Welsh Government | npower | University of Bath | GE imagination at work | PassivSystems | accenture

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ACKNOWLEDGEMENTS

Western Power Distribution would like to thank all of the Project Partners (University of Bath, GE, NPower, Passiv Systems, Welsh Assembly Government and Accenture,) for their hard-work. The findings and additional work that has been delivered on-top of what we initially planned to do, is a direct result of the commitment and efforts that have been invested into delivering LV Network Templates.

Additionally WPD would like to thank all of the DNOs for sharing both fixed and variable data from their respective networks, as it has enabled the Project to validate the templates and classification tool even further. This information has been invaluable and has reinforced that the benefits and confidence we have in this Projects outputs can also be applied on a GB-wide scale. We hope to continue working with interested parties, in order to help the wider industry embed the outputs from this Project as business as usual.

Finally, special thanks to Ofgem and our customers for providing us with the opportunity of trialling this innovative and cost effective solution.

Roger Hey, Future Network Manager WPD

CONTENTS

PROJECT BACKGROUND

The UK Government is committed to reducing greenhouse gas emissions by at least 80% by 2050 relative to the 1990 emission levels. Supporting this commitment is the UK Renewable Energy Roadmap that applies targets for 30% of electricity, 12% of heat and 10% of transport to come from renewable sources [1]. In its December 2012 update, DECC confirmed that by 2020, 15% of UK energy demand will be supplied by renewable generation. Both Scotland and Wales have more ambitious targets of 42% and 40% [2] by 2020.

As the UK transitions to a low carbon economy electricity networks face a series of challenges. The increased connection of low carbon technologies (LCT) and generation to the distribution network will put pressure on existing assets. Responding to this is effectively is hindered by uncertainty. LCT rates of adoption will be driven by policy, technological development and customer behaviour all of which are difficult to predict. DNOs do not know when and where new challenges will emerge on their network.

These changes will impact the low voltage network, where there is currently limited visibility of asset utilisation and grid state, which makes it hard for DNOs to optimise network planning and operation. The System Operator also faces challenges. They do not currently have full visibility of the output and voltage impact of generation connected to the distribution network. This restricts the System Operators ability to efficiently balance the systems

DNOs currently design the network to a) operate within statutory limits and to b) remain resilient under a worst case scenario e.g. evening peak during the coldest part of winter. LV planners also size network assets on the assumption that load growth for existing customers will be relatively small, widespread and predictable. Large scale LCT adoption could change the worst case scenario and undermine current load growth assumptions. Without LV visibility it will be difficult to identify when these changes have occurred and hence alter the manner in which the distribution network is planned and operated.

All these challenges pose a key question, “is there a simple method, outside of costly widespread monitoring that can assist in providing the visibility needed in order to effectively design, plan and operate the LV distribution network; as more low carbon technologies and distributed generation is connected”?

This Project seeks to address this question through the development of a new planning tool: LV Network Templates. This Project has developed LV Network Templates that will allow network planners to accurately estimate the load and voltage at any given substation without the need for costly monitoring. This will allow planners to more accurately estimate the capacity and voltage headroom available and be able to more confidently conclude whether the installation of a low carbon technology will lead to voltage or thermal limits being breached.

[1] Ofgem “The Carbon Plan: Delivering a low carbon future” Dec 2011 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf
[2] Scottish Power RIIO-ED1 Business Plan

The key findings of this Project and derived templates will help DNOs make more informed cost-effective investment and operational decisions for the management of the low voltage distribution network; as the UK transitions to a low carbon economy.

This report shows how WPD have delivered what was promised, whilst highlighting the lessons learned along the way and the anticipated and unforeseen outcomes of the research. All of the key activities undertaken in developing the LV network templates are discussed in order to facilitate replication of the Project's approach, analysis and template tools across the wider industry.

SCOPE AND OBJECTIVES

In developing credible and representative templates, a clear scope of work and objectives was identified pre-submission. This ensured that both the scope, objectives sought to address the challenges mentioned above and to clearly define the resulting role of the involved Partners (including vendors) from the start. Both of these two types of scope and objectives will be discussed below in-turn.

PROJECT SCOPE AND OBJECTIVES

The **primary objective** of the LV Network Template Project is to establish a set of novel "templates" that would accurately estimate different cluster types of load and associated voltage profiles at a given substation without the need for costly monitoring. In developing such templates, four important **secondary objectives** were also derived due to the value and insight they would bring to the industry:

1. **The ability to identify low carbon stresses through templates and the associated voltage profiles** [3]. With greater visibility of temporal variations, UK LV network planners would be able to more effectively identify headroom constraints and opportunities against each template for the absorption of future low carbon stresses.
2. **A greater understanding of the actual difference between stressed and non-stressed parts of the network, due to either the connection or not, of low carbon technologies to the network (e.g. Heat Pumps, PV, Electric Vehicles)** [4]. Having such an understanding would allow network planners identify parts of the network better suited to be able accommodate certain types of low carbon technologies, at particular point in time be it at weekdays/weekends and or seasons.
3. **The statistical case for using a limited number of PV feed-in-tariff meters (meter readings to reflect the aggregate output of others** [5]. If proven, it would provide a lower cost solution in understanding network demand and generation at a local level. This insight would be both of value to the distribution network operators and to National Grid in their short/long term forecasting and management of the wider GB network (e.g. spinning reserve capacity). Therefore this Project will confirm the viability of providing National Grid with a real time view

[3] Stresses on the LV Network caused by Low Carbon Technologies Report (01.05.2013)
[4] Stresses on the LV Network caused by Low Carbon Technologies Report (01.05.2013)
[5] Report on the use of proxy PV FiT meters to reflect local area Generation (01.05.2013)
[6] Stresses on the LV Network caused by Low Carbon Technologies Report (01.05.2013) & Discussion paper on adoption of EU low voltage tolerances (PWest)

of actual PV generation down to the LV network for the first time, showing “backed off / hidden” demand at the Grid Supply Point level via a tier 1 ICCP link trial.

4. **The degree of headroom and actual voltage levels measured across wide parts of the LV system (topology and customer mixes)** [7] The Expert Panel were advised at the time of the original submission that, valuable insight could be gained into the headroom that might, or might not exist, within the existing 230v+10%/-6% limits set out in the UK legislation. Furthermore, if it were to be demonstrated that there was a valid case that compliance was maintained throughout daily and seasonal voltage changes, then there could be a strong case to argue for a change in legislation to move to the EU 230v +10/-10% voltage range. White goods have, for many years, been manufactured to be compliant with the wider EU voltage limits). If the Project highlighted that a large number of feeder-end points operated at the upper limits of statutory voltage limits. Then a business case would present itself, in which the network voltage for that given feeder-point could be dropped by 2.5% via a ‘tap down’ of the primary substation transformer. This would result in a number of benefits, with one being, the ability to allow for additional DG to be accommodated.

Further **additional** activities have since the original submission been added to the scope and objectives of this Project, as can be seen in the figure below. This additional work has taken two forms: **DNO Template Validation** and the development of a business as usual **Classification Tool**.

Figure 1, Core, Secondary and Additional Work

[7] Statement made in the Original Submission “Low Carbon Networks Fund Full Submission Pro-forma”

- **DNO Template Validation:** To provide the industry with confidence that the Project's findings are valid outside the South Wales area, further validation work was undertaken by analysing both fixed and variable data from all the other DNOs. This work considered the effectiveness of the classification process to confirm that this would be valid for other DNOs. It also compared estimates to actual values as recorded by the other DNO's monitoring equipment to check that the templates themselves were not limited to local use. This work would be a necessary for other DNOs to adopt the Network Templates and was carried out at no additional cost to the Project. This value-adding activity was not initially planned for, as the necessary monitoring by other DNOs was not in place at the time of the original submission. Nonetheless this further validation was regarded as a unique opportunity to further share and validates the templates suitability in its application to "at least 50% of the GB wider network [8]". Much of this validation using data from other DNOs was undertaken after the original templates report was complete, so this report contains the first record of the work and its findings
- **Classification Tool:** Alongside the development of the templates, a classification tool was developed at no additional cost to the Project, within which the templates and models would sit. This tool alongside traditional planning tools would allow the templates to be immediately embedded into business as usual.

The South of Wales was selected to be the trial area of this Project (refer to diagram below) as this was considered best able to fulfil the Project's primary, secondary and additional objectives. The Project area selected identified LV networks that represented the wider GB network due to the variations in network topology, the number and type of low carbon technologies/generation connected to the network. Additionally the Project trial area was chosen because it would be able to take advantage from the Welsh Assembly Governments (WAG) ARBED initiative that would provide fixed data on 40368 retrofitted homes with low carbon technologies and energy efficiency solutions (e.g. 912 PVs, 616 Solar Water Heaters, 62 Air Source Heat Pumps and much more).

[8] Note, that at the time of the analysis undertaken 4036 homes were retrofitted with low carbon technologies and energy efficiency solutions.

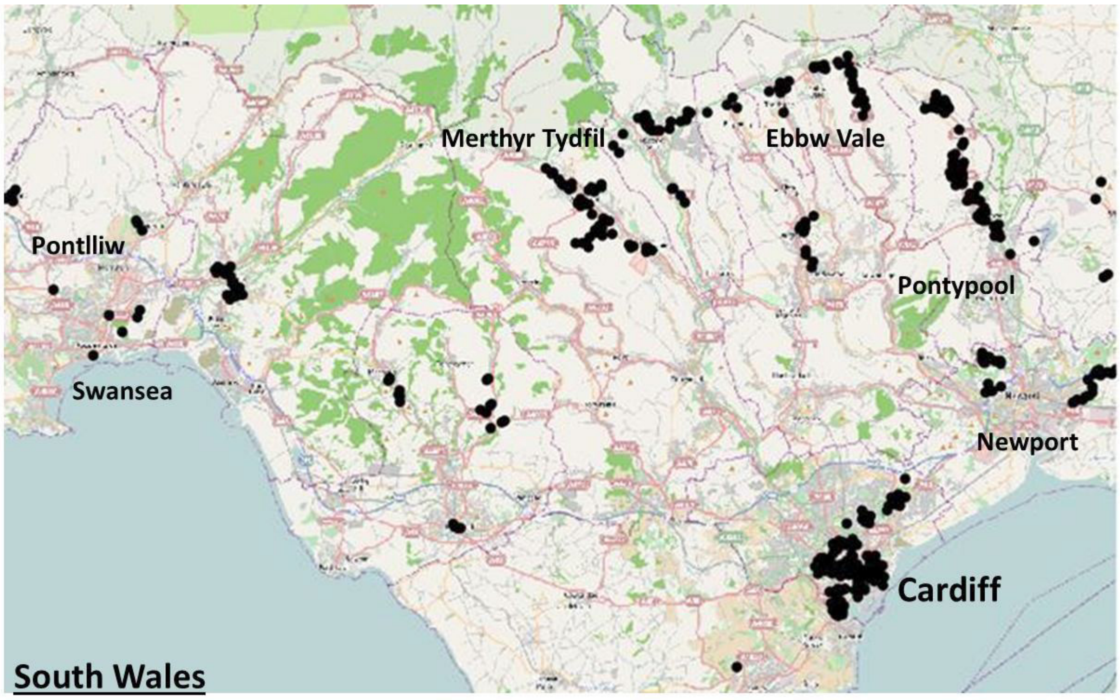


Figure 2, Map of locations of monitored substations within the South Wales Study Area

As a result the scope of the trial area would include both stressed and non-stressed parts of the network, from rural to urban locations and residential to commercial customers. The South Wales trial area therefore provides the ideal test bed for development of the templates as it reflects the extensive spectrum of challenges that another DNO will face with similar network topologies, customer mixes and incurred stresses to the system from low carbon technologies. As a result of these factors, the resulting templates and Project findings would also be credible, representative and suitable for another DNOs network to adopt.

Behind the templates development, is both fixed and a full years' worth of half hourly monitored data. The monitored data would be collected from over 824 substations, 3600 feeder-ends and 525 domestic PV installations. It should be noted that the fixed Arbed data was associated with 115 substations of which ca. 100 were within the trial area of the Project.

PARTNERS SCOPE AND OBJECTIVES

Selecting the right partners to deliver LV Network Templates was central to ensuring success. Partners were shortlisted and selected in a competitive manner leveraging their core strengths and leading expertise to successfully deliver this Project. The partner eco-system can be seen in the figure and described in further detail in the table below:

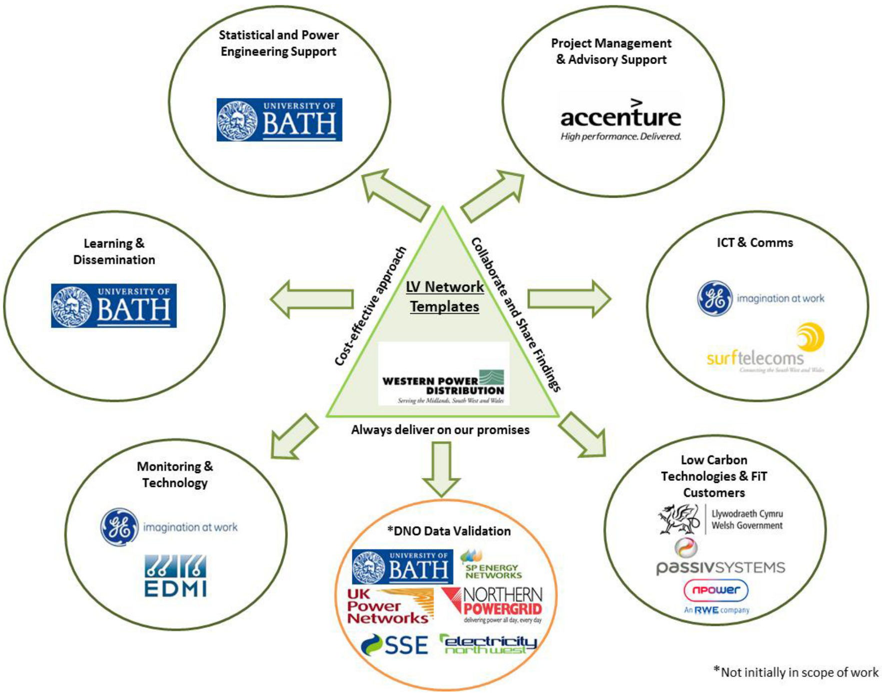


Figure 3, Partners and Vendors Eco-System

LV Network Template Partners		
Organisation	**Description**	**Role**
Welsh Assembly Government	The Welsh Assembly Government (WAG) is the devolved government of Wales. In 2009, WAG established the Arbed programme in Wales. This programme supports the UKs carbon agenda and seeks to also eradicate fuel poverty, whilst boosting economic development and regenerations.	WAGs role was to share fixed Arbed data in order to help identify stressed and non-stressed networks in South Wales.
University of Bath	The University of Bath was established in 1966 by Royal Charter, and is recognised by the British Government for the award of degrees. The university is a leading institute for statistical and power engineering.	The University of Bath was responsible for: 1. Data management 2. The statistical and power engineering analysis of data 3. Learning and dissemination
Accenture	Accenture is a global management consulting, technology services and outsourcing company, with approximately 275,000 people serving clients in more than 120 countries. Accenture Smart Grid Services provides the experience and skills, global resources, proven methodologies and industry-leading technology assets utilities need to realize the vision of a more intelligent grid.	Project management and advisory support across all workstreams of the Project

npower	RWE npower is a leading integrated UK energy company. Supplying gas, electricity and related services to residential and business customers. Npower is part of the RWE Group.	Support Project in FiT customer engagement for PV monitoring
GE	General Electric Company (GE) is a diversified technology and financial services company. The products and services of the Company range from aircraft engines, power generation, water processing, and household appliances to medical imaging, business and consumer financing and industrial products. It serves customers in more than 100 countries.	Provide communication and substation monitoring equipment
Passiv Systems	PassivSystems automates the management of home energy loads, providing optimised comfort while delivering significant savings.	Provide fixed and variable PV FiT data. This data will support network stress and proxy metering activities.
EDMI Meters	EDMI is a global Smart Energy Solutions provider. Who are dedicated to the design, development and manufacturing of innovative/ technologically advanced energy meters/systems for the global utility industry.	Provide the Project with metering equipment
All UK Distribution Network Operators	All the UK electricity distribution network operators, each who own, manage and maintain their networks (Scottish Power, UK Power Networks, Electricity North West, Northern PowerGrid, Scottish Southern Electricity Distribution)	Provide fixed and variable data of monitored parts of their LV network for the purposes of further DNO validation activities.

Table 1, Partner Responsibility Table

SUCCESS CRITERIA

The LV Network Templates Project has managed to achieve all of the below successful delivery criteria. As stated in the direction issued by Ofgem on the 5th of April 2011 [9].

Successful delivery reward criterion	Proposed Evidence	Actual Evidence	
All data concentrators successfully deployed by 31.03.2012.	Evidenced by communications being established between data concentrators and Enmac with voltage data consistently being received.	Evidenced by communications being established between data concentrators and Enmac with voltage data consistently being received. As reported in the Jun 2012 6 monthly report. See www.westernpowerinnovation.co.uk	☑
Back office systems upgraded and communications path to sensors proven by 13.09.2011 ready for data collection on 14.09.2011.	All ENMAC and other back office IT integration has been completed and WPD has visibility of monitoring equipment outputs	A proof of concept demonstration with GE proved the communications path throughout the system. As reported in the December 2011 6 monthly report. See www.westernpowerinnovation.co.uk	☑
All sensors deployed by 07.04.2012 and operational.	All monitoring data processed successfully and visible to WPD in database.	Completion in line change request CCR 001.	☑
Data from 13.09.2011 onward sent securely in required format to Bath for analysis and modelling, through to the last set of data on 07.04.2013. Evidence of successful transfer evidenced by 25.10.2011.	Data sets received by Bath University in a manner that is applicable to statistical study confirmation of receipt received by Bath.	Data sets were received from 13.09.2011 and increased as more monitors were installed. Data is continuing to be captured and securely sent to the University of Bath for the foreseeable future.	☑
Effects of stresses on the network from local low-carbon installations identified and significantly relevant, findings identified by 01.05.2013	The output of the analysis from Bath University will demonstrate these stresses and statistically prove that the findings are significant and relevant to prove the hypothesis correct.	Refer to the published "Stresses on the LV Network caused by low carbon technologies" www.westernpowerinnovation.co.uk.	☑
Bath University undertake a statistical comparison of data flows against templates and report findings by 01.07.2013	Report produced by Bath University demonstrating the templates, which are statistically proven to be relevant and reusable by other DNOs.	Refer to the published "Demonstration of LV Network Templates through statistical analysis" report www.westernpowerinnovation.co.uk	☑

[9] https://www.ofgem.gov.uk/ofgem-publications/45930/lcn-fund-direction-amend-Project-direction-wpd.pdf

Ability to use proxy FIT meters to reflect local area generation output, draft report by 01.05.2013	Bath's statistical analysis report will demonstrate the ability to understand network headroom to absorb low-carbon stresses through using the templates	Refer to the published "report on the use of proxy PV FiT meters to reflect local area generation" www.westernpowerinnovation.co.uk	☑
Provide Ofgem with a 6 monthly Project review report starting from 6 months post installation start date 17.06.2011. The report will include updates such as: • Project status compared to plan • Learning's to date • Next steps and actions	Acceptance by Ofgem of a Project review report	Ofgem has provided WPD with acceptance of all the 6 monthly reports: 17.06.2011 6 monthly Report 16.12.2011 6 monthly Report 15.06.2012 6 monthly Report 17.12.2012 6 monthly Report 16.06.2013 6 monthly Report All above reports can be found at www.westernpowerinnovation.co.uk	☑
Demonstrate provision of actual live data of distributed generation to National Grid to assist them with improved forecasting and generation scheduling in the future, by 19.12.2011.	Data on embedded generation load on network areas sent to, and received by, National Grid, on a near-real time basis.	On the 19.12.2011, National Grid was provided with live sample, distributed generation data. This work was completed under Project WPDT1001. The close down report was sent to Ofgem on 30th April 2013	☑
Share learning's with all partners and other interested parties including Ofgem (1-2) throughout the Project from 19.12.11 to 01.07.2013; (3-4) by 31.07.2013	1. Raw data received from sensing network and embedded generation load will be provided to other parties to utilise in their network scenario models; 2. Participation in annual conference 3. Output analysis from Bath University publicly disseminated 4. DNOs provided with analysis and WPD commentary on application of output to network management in response to low carbon stresses and benefits	1. Raw data has been requested from CSE, Loughborough University and Reading University. A data sharing agreement is in place and WPD have been and will continue to provide data as and when requested. 2. All annual conferences were participated 3. All outputs and findings have been publically disseminated, refer to table 7 Refer to the following reports in www.westernpowerinnovation.co.uk: a "Stresses on the LV Network caused by low carbon technologies" report b "Demonstration of LV Network Templates through statistical analysis" report c "Report on the use of proxy PV FiT meters to reflect local area generation"	☑

EXECUTIVE SUMMARY

The UK Governments' plans to decarbonise the heat and transport sectors, will impose new stresses on DNO electricity networks. These stresses will have the greatest impact on HV/LV transformers and on LV distribution networks. These are the parts of the network about which DNOs have the least visibility, as most monitoring is at 11KV and above. The ability of a given distribution substation to absorb these new low carbon stresses will depend upon the amount of demand and voltage headroom available at different times of the day and season.

WPD believed that it would be possible to identify a number of templates for demand and associated voltage that would be common to at least half of GB HV/LV substations, and shows which were most suited to accommodating new low carbon stresses. The ability to test this required extensive monitoring of hundreds of HV/LV substations and LV feeder-ends followed by extensive statistical and power engineering analysis. This was the subject of LV Network Templates, a Tier 2 Project proposed under Ofgem's Low Carbon network Fund, which won approval in December 2010.

The Project resulted in the installation of over 800 substations monitors and 3600 voltage monitors together with associated communication and data handling infrastructure. The University of Bath undertook the statistical analysis of over 500,000,000 [10] measurements, leading to a wide range of valuable findings that have been shared with industrial, academic and regulatory stakeholders throughout the Project:-

- Ten distinct LV Templates were successfully identified. These were then assessed for their suitability to incorporate various low carbon technologies
- Analysis of actual LV connected PV installations identified an additional 20% headroom on the existing network, for future connections. The PV analysis also proved the ability to use a single proxy LV PV FiT meter to accurately reflect the aggregate outputs of all other LV connected PV installations in the local, high level postcode area; giving the ability to provide real time LV PV data to national Grid to aid generation scheduling, forecasting and the effective management of spinning reserves. A meeting with National Grid forecasting team was held in September 2013, to disseminate these findings, with positive results. The aim is to progress this further, with the adoption of an ICCP link as Business as usual
- Voltage tolerance was shown to be within current limits, with greater number above the nominal level than below, thus affording the ability to reduce target voltages at HV, providing demand and CO2 reduction, savings in customer bills, and additional voltage headroom for LV Distributed Generation. As a result of these findings WPD are planning to reduce the voltage levels in South Wales. This will result in savings of approximately 15.7MW in maximum demand, £9,421,000 and 41,000 tonnes of C02. This saving alone is representative of the total LCNF funding for the Project , however, if rolled out nationally, in conjunction with the adoption of EU network voltage tolerances (+/- 10%) the savings could be 618MW, £315,000,000 and 1.98 million tonnes of CO2. More detail on this can be found in the Project Output section of this report

[10] Measurements at time of 01.07.2013 report "Demonstration of LV Network Templates through statistical analysis"

In addition to all of these outcomes and originally scoped objectives, the Project has been able to deliver further benefits than was initially anticipated. These will be of benefit to the other DNOs and the wider industry as a whole:

- Further validation work was undertaken by analysing an additional +200 substations from other DNOs, which has demonstrated that the templates were applicable to substantially more than the 50% of GB networks originally anticipated
- A ready-to-use classification tool which was developed to help replicate the Project without the need to undertake the work that was carried out again
- To identify the scale of benefits that could derive from UK adoption of the wider +/- 10% EU LV voltage tolerances
- All findings and Project outcomes have been published and shared with key stakeholders at dissemination events. Those which necessitate national debate to take forward have been presented to DECC and key national forums. Finally, all of the work and findings delivered have been done so on time and within budget

DETAILS OF THE WORK CARRIED OUT

Details of what Methods the DNO trialled. The DNO should also describe the trialling methodology that it used.

This section will look at the end-to-end methods that were applied from Project governance, installation of monitoring to the methods that were trialled in developing the templates and resulting findings. It should be noted that a number of lessons were learnt and applied along the way. All of which will discussed in greater detail in the lessons learnt /planned implementation chapters, and the knowledge management report (Appendix A).

The high level Project plan below identifies when key activities were undertaken in the Project. The figure below is not an exhaustive list of activities but highlights the key areas that will be discussed, from which the granular detail can be drawn from.

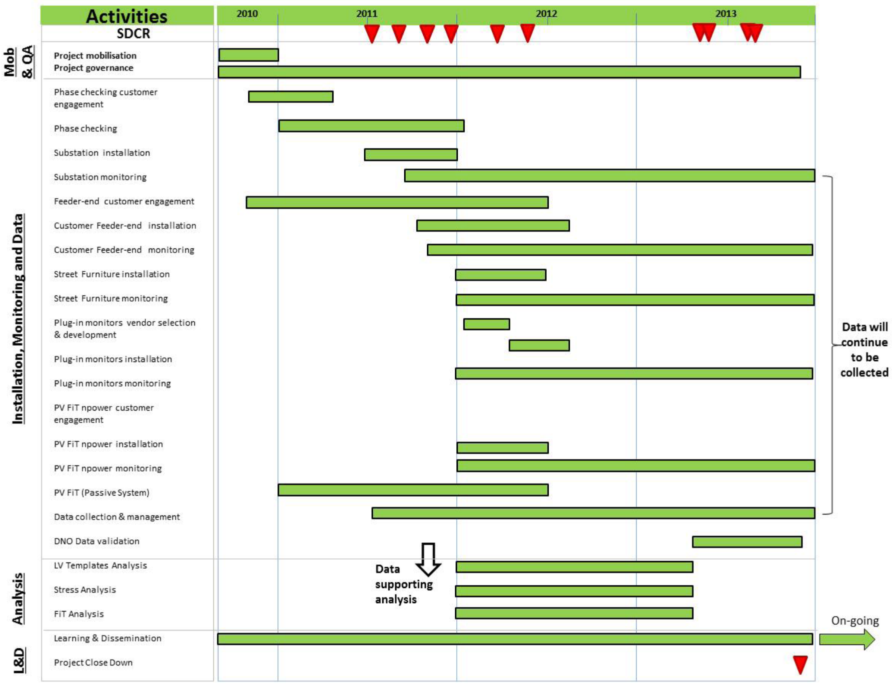


Figure 4, High level Project-Plan

PROJECT MANAGEMENT AND PROJECT GOVERNANCE

On the 29th of November 2010, Western Power Distribution was awarded the funding to deliver the LV Network Templates Project as part of the LCN Fund. From the 29th of November to the end of December, WPD established the Project management office and put in place a strong Project governance arrangement in accordance with the "LCN fund Project direction" [11]. Both of which will be discussed in detail below:

[11] https://www.ofgem.gov.uk/ofgem-publications/45931/lcn-fund-Project-direction-wpd.pdf

PROJECT MANAGEMENT METHOD

As part of the Projects overall Project management approach, WPD applied its internal standards and methodologies such as Prince2, MSP, CIM as well leveraging Accenture's delivery methodology (ADM, refer to the diagram below). ADM maps to all of WPDs methodologies and where appropriate provides the Project with the flexibility of considering other alternatives should it be required.

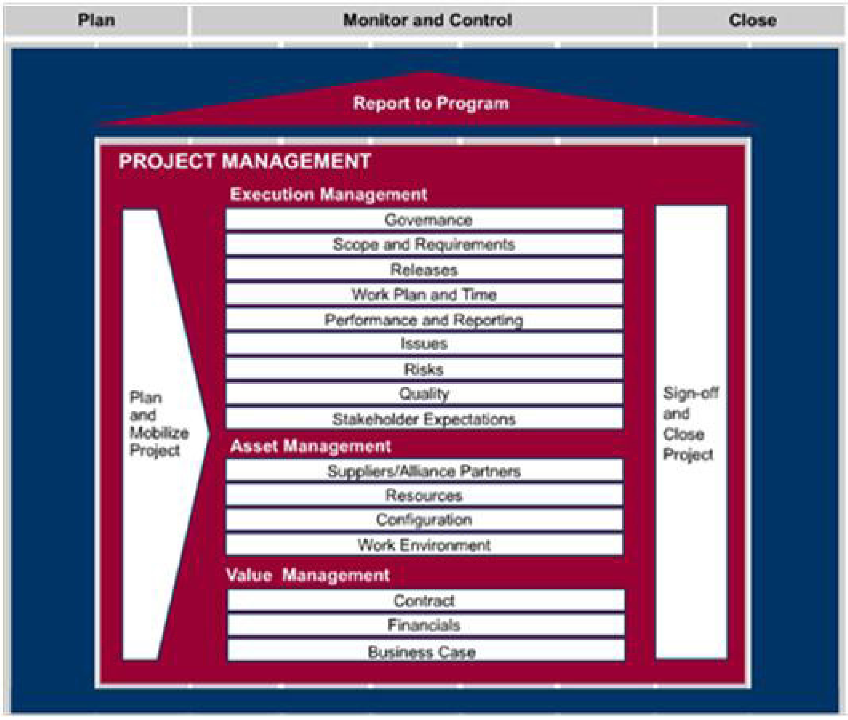


Figure 5, Accenture Delivery Methodology

Some of the key aspects of Project Management that were applied to monitor and control this Project are as follows:

Planning: Core to the Project Management Methodology applied as part of LV Network Templates was the planning and the development of a Project plan with well-defined milestones and deliverables that provided the baseline against which Project progress can be measured. This work began as part of the proposal and was carried forward throughout the Project from the development of a Project initiation document (PID) to its close down.

Scope Control Management: As part of the Project Initiation Document a detailed scope management plan was developed to make sure that the Project is managed, controlled and verified throughout its lifecycle and that scope creep is avoided.

Risk, Assumption, Issue and Dependency (RAID) Management: A RAID log was created, managed and updated centrally by the Project Manager. This log allowed for risks, issues, assumptions and dependencies to be effectively tracked and addressed.

Stakeholder and Communications Management: A core element of LCN funded Projects is focused on the sharing of the learning's both internally and externally to all interested parties. WPD developed the concept of all Partners being 'Learning and Dissemination Ambassadors' to the Project, ensuring that every Partner had scoped and committed to the delivery and sharing of findings to interested parties prior to the Project starting. This approach was furthermore driven by the WPD Project Manager and University of Bath who identified all the stakeholders involved, impacted or potentially interested; by the Project execution, findings and proposed changes. This approach contributed to the Stakeholder and Communications Management strategy, identifying when and how best to engage with internal or external stakeholders.

Quality Assurance: LV Network Templates appointed Accenture for quality assurance, Project management and advisory support services. Having this external advice to the Project allowed for potential risks and opportunities to be identified early on.

Status Reporting: A structured reporting arrangement was put in place at the start of the Project in the form of 6 monthly reports to Ofgem and the wider industry, as well as internal monthly Project presentations to interested stakeholders.

Collaboration: This was core to the Project management approach especially given the various partners involved in the Project. As such both WPD and the Partners were committed to working as 'One Team' in delivering such a complex Project.

LV NETWORK TEMPLATES APPROACH FOR STRONG PROJECT GOVERNANCE

A LV Networks Templates governance model was established around realising the business case through timely and effective decision making, resolution of issues and mitigation of risk. Given the nature and complexity of this Project, effective governance becomes even more important because of the multiple stakeholders (e.g. GE, npower, DNOs, Customers, and third parties) involved in the programme, interdependences (customer consent --> good data --> analysis) and the tight delivery deadlines. Therefore for this Project we had both a **Project delivery team** (refer Figure 6, red boxes = external Partners) and **Project Board** (refer Figure 7), responsible for overseeing the workings of the Project. These two teams were developed so as to have a clearly defined structure for decision-making and risk mitigation, with representation across all key Project stakeholder groups.

The role of the Project Delivery Team was as follows:

- Support the successful delivery of the LCNF Network Templates Project
- Understand both internal and external Project stakeholders' background and expectations of the Project. Confirm or modify targeted expectations with the stakeholders and align expectations with formal agreements
- Manage the involvement of the work package teams in Project tasks. This includes

reviewing and signing off of key Project tasks and deliverables, monitoring Project progress and critical dependencies, and identifying and resolving issues and risk

- Conduct periodic status and milestone review meetings to engage stakeholders and increase their level of ownership and commitment to the Project
- Monitor changes in stakeholder landscape by identifying new key stakeholders, their expectations, and the impact on the existing expectations of the Project
- Use stakeholder goals and expectations as a guide to process improvement
- Periodically assess and report stakeholder satisfaction

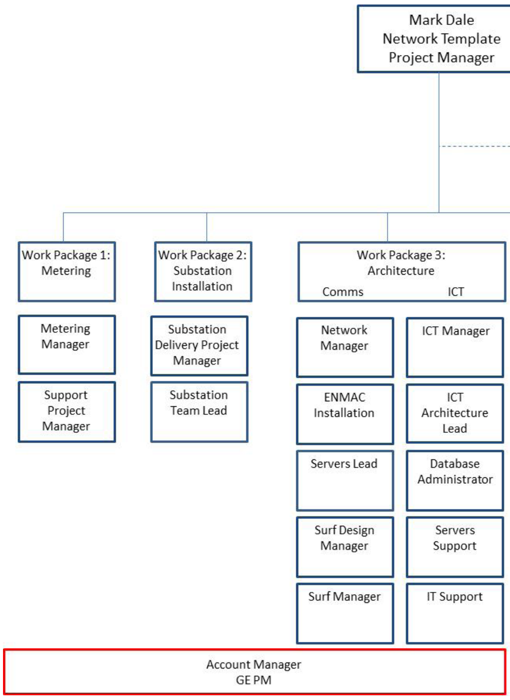


Figure 6 Project Delivery Team

Whilst the role of the Project Board is to undertake the following:

- Coordinate and monitor the successful delivery of the LCNF Network Templates Project
- Understand Project stakeholders' background and expectations of the Project. Confirm or modify targeted expectations with the stakeholders. Align expectations with formal agreements and resolve discrepancies
- Manage the involvement of Project stakeholders in Project tasks. This includes reviewing and signing off key Project tasks and deliverables, monitoring Project progress and critical dependencies, and identifying and resolving issues and risks
- Conduct periodic status and milestone review meetings to engage stakeholders and increase their level of ownership and commitment to the Project
- Monitor changes in internal and external stakeholder landscape. Identify new key stakeholders, their expectations, and the impact on the existing expectations of the Project
- Periodically review/assess and report stakeholder satisfaction
- Provide solutions to potential resourcing conflicts

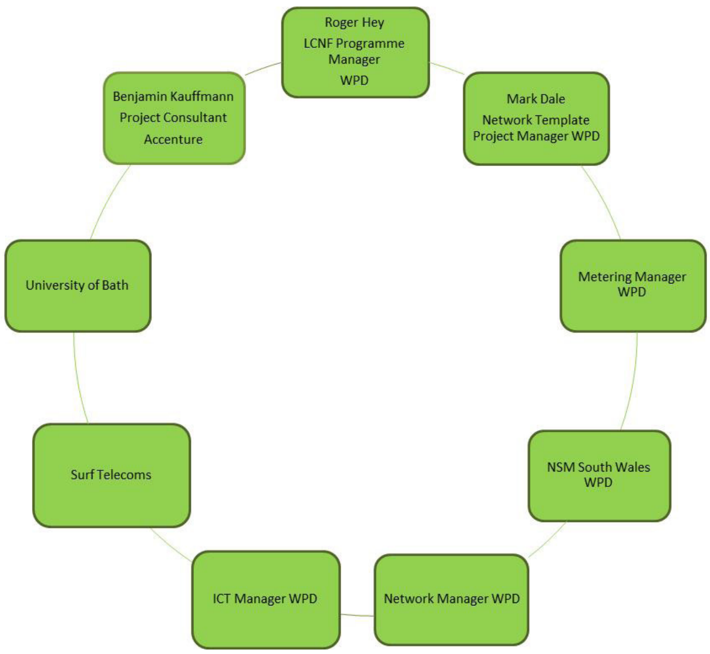


Figure 7, LV Network Template Board

INSTALLATION, MONITORING AND DATA

SUBSTATION MONITORING

In preparation of the LV Network Template submission, WPD installed a trial current transformer (CT) within a LV 11kV substation in Pontypool. This trial confirmed the feasibility of installing monitoring in substations to measure demand levels – albeit at a far smaller scale.

At time of Project award, Ofgem included a requirement for WPD to undertake a 2 week consultation of the other DNOs on the availability of sensors that might be employed to measure current without the need for shutdowns. This consultation, together with follow up contacts to potential suppliers, revealed that there were at that time no viable alternatives to use within the volume and timelines required by the Project.

This confirmed WPD's choice of technologies and the monitoring methodology to be deployed for the LV Network Templates Project. The lessons learnt from early CT installations were used to shape and refine the methodology further in order to have a robust and timely approach that would minimise customer interruptions and minutes lost.

As a result by January 2012 a total of 951 substations had CTs, monitors and communication links installed. From these installations data was successfully retrieved from 824 substations consisting of 705 ground mounted and 246 pole mounted substations. It was anticipated that the retrofitting of current transformers and communication equipment at substations would cause some customer interruptions and minutes lost. This was recognised by Ofgem in a letter to the WPD

Company Secretary dated 5 April 2011. This letter, and the amendment to the Project Direction (also dated 5 April 2011) set out by Ofgem, provided additional protection [WJA13]against customer interruptions (CIs) and customer minutes lost (CMLs) up to the level of 115,173 CIs and 15,834,60 CMLs. A combination of robust substation installation methodology ,effective Project governance and stakeholder engagement, enabled WPD to minimise customer interruptions and minutes lost to values well within Ofgem's allowances by achieving:

- Customer Interruptions – 72,568 (**63%** of allowance)
- Customer Minutes Lost – 12,590,195 (**79.5%** of allowance)

Furthermore measures were also taken to ensure that any interruptions or minutes lost occurred at times that caused the least disruption to customers including evenings, weekends and early hours of the morning. A high level overview of the final methodology and steps taken is discussed in detail further below (refer to figure 8):

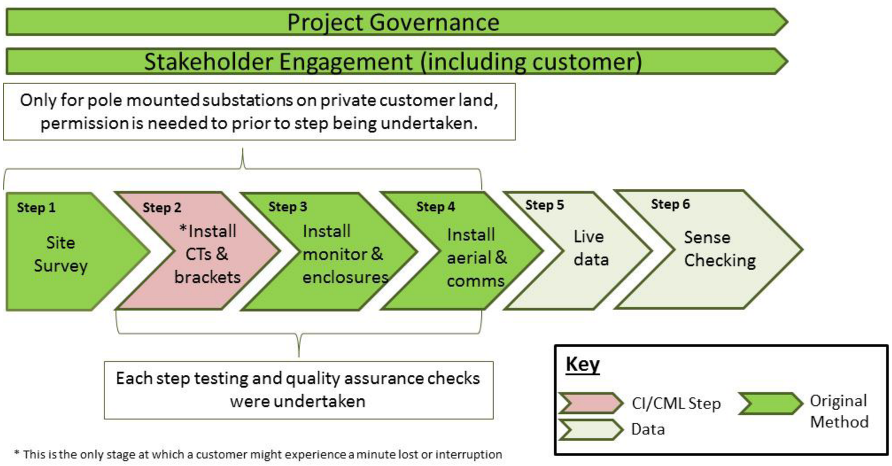


Figure 8, Ground and pole mounted substation monitoring methodology

Project Governance and Stakeholder Engagement

As previously mentioned, due to the installation of CTs it was recognised that some customers may experience supply interruptions. In order to effectively inform, and reassure the potentially impacted customers, a customer and stakeholder engagement approach was developed. This approach formed part of the "Customer Communication Plan" and "Data Privacy Strategy (Appendix B)" which was approved by Ofgem at the end of March 2011. [12]

As a result of this approval, the first shutdown letters were sent out on the 4th of April 2011 well in advance of any work having taken place. Additional assistance was given from the WPD Contact Centre in Cardiff to ensure the right people were informed regarding the up-coming shutdowns (including the local councils and the police being contacted). And finally, customers with any questions were able to also use a dedicated telephone number, and email address to get into contact with the local Project team.
A just-in-time deployment method was taken, for the installation (including testing) of

[12] Ofgem "The Carbon Plan: Delivering a low carbon future" Dec 2011 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf

monitoring equipment. This method resulted in multiple substation visits, due to different skill sets and safety authorisation levels needed in order to undertake the work (e.g. i) Survey; ii) install the CTs and brackets; (iii) install the monitor enclosure, (iv) install and test the aerial and communications). The criteria that helped identify the need of adopting this method, was to fundamentally ensure that a timely and cost effective deployment was delivered. Additionally specialised skills were needed at each step of the installation process and it was quickly identified that equipment would be arriving in batches from GEs manufacturing plants: furthermore reinforcing the suitability of this method. This method therefore meant that as one activity was completed at a particular substation the next one would take place. All of these activities of work were effectively managed and clearly communicated by the Project deliver team. So as to ensure that the Project milestones could be met and to ensure business as usual work continued, whilst making best use of the resources and funding available.

Site Survey
It was initially planned to monitor 1000 substations, however through initial site survey activities carried out by WPD it became clear that some substations were unsuitable; resulting in the final 951 substations being monitored.

The unsuitable substations faced difficulties either due to not having enough available space to house the monitor enclosures, or because some substations required planned/unplanned reinforcement work to be undertaken within the lifetime of the Project. It should be noted that this initial site survey work could not be carried out prior to the submission due to the cost and time it would have taken to cover the full 1000 substations. Nonetheless this initial work proved invaluable as it helped identify substations early on that were or were not suitable to be part of the Project. The information that was gained by these visits was passed onto both the installers and planners to identify prior to the visit what the most appropriate, safe and cost effective approach to installation would be.

Installation of Current Transformer's (CT) and Brackets
With the installation of the CTs causing a potential interruption to a customer's supply, proactive measures were taken to arrange for installations to occur at times, convenient to the customer. This was also a large factor as to why the fitting of the CTs was separated from the fitting of the monitors, enclosures and aerials, so as to reduce the overall length of shutdown time (CI and CML)

The installation of CTs and the brackets was a complex task especially for the ground mounted substations. This was due to differences in substation configurations and layouts, potentially requiring the removal of parts of the LV cabinet, routing the cabling inside and outside the cabinet, installing a terminal block and a mounting bracket.

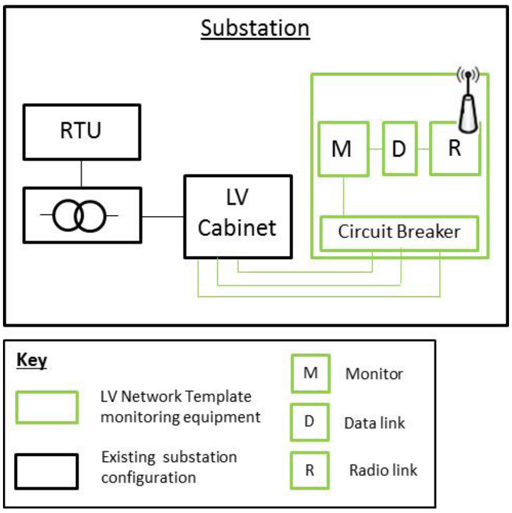
For pole mounted substations, other key challenges played a role such as the gaining of customer consent for those substations located on private land. Nonetheless the installation of all 951 current transformers (CTs) and the brackets were completed in January 2012.

Installation of monitoring & enclosures

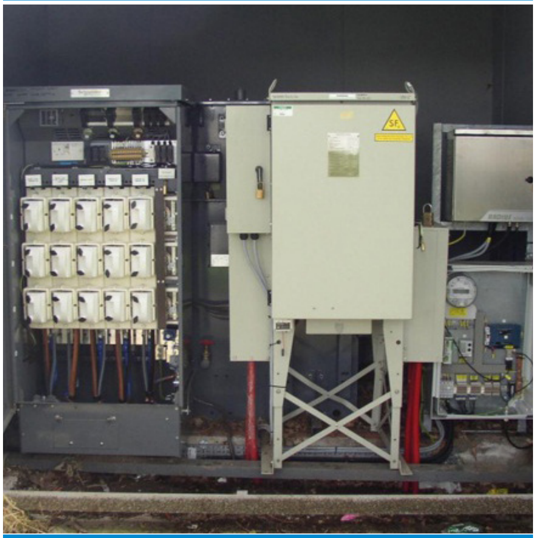
As a result of the trial area being representative of the wider GB network (urban to rural), prior to any aerials and communication units being installed, radio site surveys needed to be undertaken to understand what meshed radio type of technology could be applied to capture the data. From the radio surveys and using Surf Telecoms insight into telecoms and WPDs network topology, UHF Radio was regarded as the best solution. As a result Surf Telecoms acquired an additional 6 Ultra High Frequencies from the JRC, to extend their network to cover the whole Project area. Enabling the distribution substations to communicate to the associated access point (normally a primary substation) and for the access points to communicate to the gateway sites, which in turn connect into WPD's WAN (refer to Data, ICT, and Comms Figure 21 for more information).

Based on this GE meters were configured; housed in the enclosures; tested and CE marked by certified WPD engineers within WPDs Plant Centre near Cwmbran, Wales. Whilst it was initially planned that GE would send pre-programmed, housed and tested substation monitors to WPD; due to some logistical issues that GE faced at their Bilbao manufacturing site the decision was made by both WPD and GE to separately send the initial enclosures and meters in batches. Later batches were pre-programmed and housed and the enclosures CE marked by GE. These housed monitors were then installed by contractors in batches without the aerials and communication links. Both how electrically and visually monitoring equipment was connected to the ground and pole mounted substations is shown in the figure below.

GE ground and pole mounted substation enclosure



GE substation monitoring electrical configuration (Pole and Ground)



Ground Mounted Substation Monitoring

Pole Mounted Substation Monitoring

Figure 9, Ground and Pole Mounted Substation Monitoring

For ground mounted substations the fitting of the enclosed monitors (705 Sites), was very quick as the enclosures fitted onto the mounting brackets already installed on the LV cabinets as part of the CT installation works, and connected into the small wiring brought out from the cabinet.

Whereas the pole mounted substations (246 Sites) required separate cabinets to be constructed for the CTs, which was manufactured in WPD’s Plant Centre and then housed. All enclosed monitors for both ground and pole mounted substations were installed by January 2012 as planned.

Installation of aerials and communication

Following the installation of the enclosure and pre-programmed monitors, aerials could be installed that suited the communication requirements needed in order to successfully transmit data back to the central data server. This work and the testing of the communication links were carried out by Surf Telecoms as and when substations had an enclosed monitor installed. All communications enclosures and antennas were installed by March 2012.

Live data and sense-checking

Initial substation test data was transmitted to the University of Bath from 13.09.2011; with data volumes increasing as more substation came online. A continual sense checking approach was undertaken by both WPDs data administrators and the University of Baths statistical/power engineers. The data sense checking and quality assurance activities undertaken by the University of Bath is discussed in further detail within the data analysis section.

PHASE CHECKING

During the detailed design and mobilisation stage of the Project, it was identified that to ensure all three phases were monitored at remote ends of the LV networks, the phase details of the customers would need to be checked prior to the potential installation of a voltage monitor. This activity was not planned for as part of the original submission but was necessary to ensure adequate phase coverage was achieved at a reasonable cost.

Whilst the recording of each customer's service phase connection is now a business as usual activity for WPD and other DNO mains records diagrams, it has not always been the case and mains service connections may well be unchanged since the house was built,; possibly up to 100 years ago. Connectivity data of a customer connection to a given mains cable and thus to a local HV/LV transformer, is recorded and necessary to respond or notify Customers in the event of a fault or planned shutdown. In seeking to deploy voltage monitors across phases of monitored LV feeders, WPD sought non-invasive instruments that could reliably detect phase connectivity without the need to enter a property, but was unable to locate any via global searches.

In ensuring that customers were properly informed around the need for phase checking, customer engagement and communication material (phase checking letter in Appendix B) were developed by WPDs internal communication team. This engagement material echoed WPDs business as usual approach to phase checking, in that customers will not face an interruption to their supply, but that it did involve entering customer premises to connect monitoring equipment to a standard electrical outlet for a short period of time. Letters sent out were followed up by telephone calls (where contact information was available) and visits by the Project team to gain customer consent to carry out this work.

The phase checking approach was coordinated by WPDs smart metering team, who worked very closely with the internal mapping centres to capture all the phase checked customers. WPD deployed their existing contractors NewCon to undertake this work, who also took the opportunity of checking and addressing if required the general quality and health of the assets such as the cut-outs and meter housing boards. This approach enabled between January and November/December 2011, WPD to be able to get 14000 phases checked having sent out communication material to over 12000 customers.

FEEDER-END MONITORING (VOLTAGE MONITORING AT THE CUSTOMER PREMISE)

Following the phase checking activities, the monitoring of feeder-ends could be started. In the initial submission it was proposed that approximately 7,000 voltage monitors would be installed using two different communication technologies: GPRS and Power Line Carrier (PLC). The installation of 7000 voltage monitors was unfortunately not attainable, due to customer uptake being lower than expected and reflects factors outside of the control of WPD, and some lessons that WPD learnt along the way.

In the end 3600 feeder-end monitors were installed, that are still providing voltage data. This will continue d for the foreseeable future. It should be noted that statistical analysis undertaken by the University of Bath confirmed that the final number of 3600 voltage monitors installed across the network was representative of the wider GB network, and would allow for credible templates to be developed (refer to Appendix B for further information)

The feeder–end monitoring was ultimately achieved through both traditional and novel, non-intrusive monitoring methods (see figure 9). The significance of these additional methods was that they provided another means of capturing the data cost effectively, without which the final number could not have been achieved. Furthermore, the additional methods did not require interruptions to customer supplies. Both the original and additional monitoring methods formed the final feeder-end monitoring methodology (see figure 9 over page).

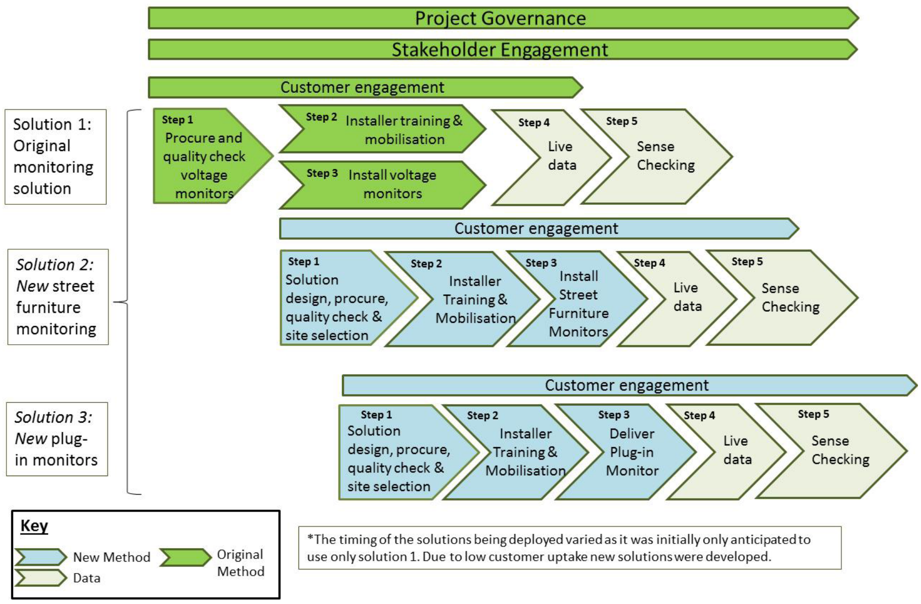


Figure 9, Feeder-end monitoring methodology

As a result, the majority of voltage monitors were installed in customer's premises including 249 plug-in monitors with the remaining feeder ends being installed through either pole or ground mounted street furniture (single or three phase). A high level timeline versus install numbers is provided in the figure below (Figure 10).

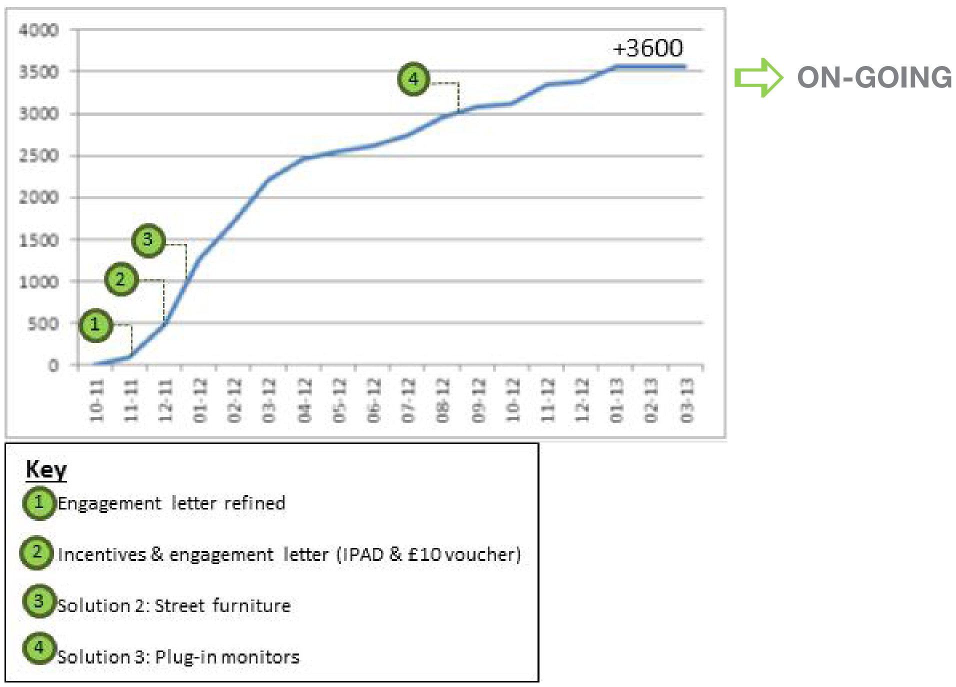


Figure 10, High-level feeder-end installation overview

As figure 10 illustrates the installation and monitoring of feeder-ends took place between November 2011 – December 2012.

Overall Project Governance and Stakeholder Engagement
The end-to-end deployment and installation of voltage monitors was managed by WPD's Smart Metering Team, covering all methods trialled: GPRS meters, PowerLine Carrier meters, plug-in, and street furniture monitoring solutions). As with every activity undertaken within the Project, the importance of strong governance and stakeholder engagement was essential; this was even more so the case for feeder-end installation activities. It was through this governance and continual engagement way of working with our stakeholders, that unforeseen risks were quickly identified and addressed. Additionally it also allowed us to listen to our customers in order to then take on board their feedback, and to then dynamically adapt our way of working around their needs. As a result, this led to the monitoring method being refined as and when needed, by embedding the lessons learnt along the way, and developing solutions that were designed by starting with the customer first [13]; and working our way backwards to the solutions design.

The importance of clear and concise messaging was recognised at the start of the Project as being fundamental to the Project's success. This was in part due to the need, for voluntary consent being given, prior to the installation or fitting of any EDMI or Plug-in monitor within a customer's home. Delivering this message across in an attractive and convenient manner, leading to a timely customer response and consent being given is even more difficult than normal, due to the inherently complex nature of the Project. Bearing this in mind, the following factors were also considered during the development of all engagement materials, and when speaking with customers around feeder-end monitoring;

- Every customer has different drivers, it's important to recognise and satisfy one or a number of these [14] (Typical examples are cost, carbon savings, security & quality of supply, and the low carbon agenda)
- Make Project content available to customers via a number of channels that are convenient for them (e.g. websites (Ofgem, WPD Innovation, Low carbon UK), WPD (email, telephone))

The customer engagement approach deployed for all the monitoring solutions occurred via four direct [15] or indirect [16] methods:

- Participation Letters including appointment cards and stamped envelopes (Direct)
- Door knocking and post-cards(Direct)
- Cold calling (Direct)
- Word-of-mouth (Indirect)

[13] This approach follows WPDs core believe of designing the network from the first mile onwards, rather than the commonly stated last mile.
[14] Ideally you would like to satisfy all of the drivers that a customer has, and if this is not possible satisfy the ones they hold to be the most important
[15] Direct method of engagement, are those that we have direct control over as to how the message comes across to the customer'
[16] In-direct method of engagement, are those that are a knock-on effect from another activity (e.g. Customer discusses installer visit and reasons with neighbours, leading to potentially more or less interest depending on the overall customer experience)

It's important to highlight word-of-mouth as a key indirect engagement method due to the fact that it's driven by the perceptions and experiences gained by the customers in the trial area via the cold calls, letter, incentives and/or installer experiences received. As such, it's a customer-driven method and its success is the most difficult to control as its sensitive to the delivery of the other engagement methods: resulting in either 'good,' 'neutral' or 'bad' experiences being reinforced within community. Whilst there may have been more indirect methods that inadvertently either led to more or less installations; "word-of-mouth" was recognised at the start of the Project as being a crucial form of engagement.

Additionally prior to any form of customer engagement, key community representatives such as the local councils and the police were informed about the Project, so as to assist them with any potential questions from the public around the work taking place. These community representatives were also made aware that should customers wish to 'find out more' then further information would be available via websites (Ofgem LCNF, westernpowerinnovations.co.uk and lowcarbonuk.com) or directly via WPD (email or a dedicated Project telephone number).

It's important to note that this approach was the basis from which all customer engagement began regardless of the solution being deployed and whether or not customer consent was needed e.g. not required for street furniture installs. Finally it's important to note that from this basis as each solution did differ slightly in the way they impacted the customers, some more tailored messaging and engagement methods were provided. These methods and the work undertaken for each solution will be discussed in further detail below.

Feeder-end monitoring method 1: EDMI (GRPS) and GE (PLC) Meter Installation
The installation of fixed meters within a customer's premise was what was originally stated as the chosen method for monitoring feeder-end voltage flows. These monitors would transmit data back via two different GPRS and PLC communication technologies. Whilst the two types of technologies applied did not change the content of the customer engagement materials, it did impact the methods of procurement, installer training, installation and sense checking.

Customer Engagement
As previously discussed, four different engagement methods were applied (letters, cold calling, door knocking (including post-card drops) and word of mouth). As a result of this methodology within a 17 month period from the list of 12,000 phase-checked customers; approximately 11,580 letters were sent, followed-up by 7,900 telephone calls to 5,500 different properties; and post-cards being left at customer premises. These letters, cold calls and post-cards translated into 1,381 feeder-end monitors being installed and 1,754 responses declining such a request. As the high level feeder-end installation overview figure 10 illustrates, lessons were learnt along the way and incorporated into the four engagement methods, as can be seen below

Letters & Incentives

One of the first steps taken in obtaining permission from customers was through a mail shot method in which bi-lingual letters and engagement materials (English and Welsh) were sent to selected customers within the trial area (See Appendix B). The materials sent to the customer explained the Project, and also provided a consent and appointment booking form for them to complete. In addition to which a pre-stamped and addressed envelope was also enclosed [17]. It should be noted that the original consumer engagement letters/materials were drafted and developed at the LV Network Template proposal stage, alongside npower's customer services team. From the initial batch of letters sent, a number of further refinements and improvements were made, these are discussed below:

1. Modifying the language and simplifying the message of the engagement materials: It was recognised during the Project that letters sent to homeowners needed to use an appropriate level and style of language. Therefore, the content of the letters were simplified and incorporated more emphasis on the benefits of the Project. Improvements and feedback were captured from continually engaging with both customers and other interested stakeholders, for example:

   - The door-to-door experiences of the installers
   - Call centre staff and customer feedback
   - Dissemination event held in Cardiff University [18]

2. Focusing further on customer drivers and incorporating incentives (£10 discount vouchers and Chance of winning IPAD prize draw): The first 4347 letters sent out didn't receive a high initial response rate, which was in part due to the letters being sent out in the winter rather than the planned for summer months (due to delay caused by phase-checking). But also because the initial feedback received from the customers resulted in the installers and the Project call centre constantly facing the question of "whats in it for me"? Whilst key messaging such as the need to "better understand what stresses the current and future network faces from connecting distributed generation" proved effective with customers; the customer install numbers showed that more work was needed in order to convert an informed customer into a monitored customer.

   As a result, two incentives were given to customers from January 2012 and sent out with the re-worded letter to over 7236 premises. Prior to this, extensive work was done in understanding what and how incentives can best be applied. With the key criteria being to do it as cost-effectively as possible resulting in a significant change in the number of customers providing consent to having a monitor installed. This work led to WPD engaging with the University of Bath's Psychology Department in order to better understand, what incentives have worked in the past and in other industries that could prove relevant to this Project.

[17] Should the customer prior to giving consent wish to understand a little bit more, the engagement materials highlighted a dedicated Project email address and telephone for them to call at their convenience

[18] A Cardiff University Professor who was aware of the Project and received the engagement materials provided valuable insight and feedback into further ways of refining the messaging into an even simpler format. This feedback was incorporated into a redrafted version.

Based on this work, the University of Bath recommended that the best incentives would be in the form of a large prize competition and IPAD. Especially as a large prize competition could also enable customers driven by "community spirit" to select a chosen charity for the prize fund to go towards, should they wish to do so. And by having an IPAD on offer as well that could be won through being second place on the prize draw, customers who were driven by technology and the need in having the latest 'gizmo', would also be captured.

It was however eventually decided by the Smart Metering team to offer a £10 voucher incentive for each successful monitor install instead, and to hold a prize competition at the end of the Project for the IPAD. The rationale for having chosen these two methods was due to cost, and also the wish to guarantee customers with an installed monitor with some sort of compensation. As seen in the table below (Table 2), following the period in which the modified letter and incentives were introduced in a statistically significant increase in consents resulted, from 12% to 18%.

Letter Type	Sent	Further Contact, including subsequent consents	Letter Consent	Letter Decline
Original wording, no incentive	4347	42%	12%	20%
Modified wording with incentive	7236	52%	18%	20%

Table 2, Customer Consent Overview

Smart Metering Call Centre & Customer Services

As letters and engagement materials were being sent out, the specialist customer services team consisting of five members were then tasked with cold calling customers. The objective of these calls were to follow up the material already sent, in order to firstly) inform and answer any questions that customers may have about the Project; secondly) gain consent and finally) to schedule the installation of a monitor on a date and time that is convenient for them. The specialist customer services team operated under flexi-time, as the best and most convenient times to contact the customers were quickly identified as being between 18:00 – 1930 [19] for domestic customers, and between 10:00-14:00 [20] for commercial customers. As appointments were made, the customer services team coordinated the work of the installers on a weekly and at times daily basis to ensure that appointments scheduled in the same area were clustered together. This way of working formed part of the installation approach and safe-guarded customers from being approached on multiple occasions from different installers.

[19] Customers were not contacted after 1930 as this would be considered by the Project as being a late and intrusive time to call the customer
[20] Contacting a business before 10am and the staff are often preoccupied checking emails and setting up for the day, whilst after 3pm staff are less keen to discuss the Project as people are closing off items before heading home.

Door to Door & Post-cards

Another customer engagement method applied was to leave postcards behind letting the householder know that 'WPD had visited'. This method of customer engagement was originally only intended in instances where a customer had missed a pre-booked installation appointment, and provided the customer with a convenient opportunity to rearrange such a visit (another day or later on that same day). However this method was also used by the installers to proactively reach out to customers in the areas in which they were already undertaking work; so as to engage and inform customers via a door-to-door approach. The rationale for approach was to be both cost effective and timely with installations, especially in the eventuality of their only being a small number of pre-booked appointments available for the installer for a given day. It provided the installers with the opportunity of booking and installing unscheduled appointments, whilst allowing customers to be further informed about the Project and how it will benefit them.

Procure & Quality Check Voltage Monitors

It was planned alongside the provision of substation monitors (including Enclosures & Comms) that GE would also deliver the GPRS and PLC feeder-end monitors. Unfortunately the GPRS monitors were no longer able to be delivered, due to unforeseen manufacturing issues in GE's Bilbao manufacturing plant. As a result GE provided a full refund for the undelivered GPRS monitors, and a replacement was sourced, and delivered by EDMI.

The selection criteria that identified EDMI as being the most cost-effective and suitable replacement solution were:

- Cost of Meter: Due to the on-going relationship with EDMI for business as usual activities, discounted rates could be passed onto the Project in lowering the overall price of the meter
- Quick Deployment: WPD already had a number of EDMI meters from their business as usual work; this meant that no time was spent in identifying a new meter vendor, negotiating on price and agreeing on contractual arrangements. Additional meters could then be simply procured through the existing framework agreement

GE still delivered all the PLC monitors as planned and on-time. Both types of meters were tested and quality checked by the vendors in their manufacturing sites before being deployed to WPDs plant centre. A final check was then carried out on a number of randomly selected meters per shipment received, by certified WPD staff, prior to being allocated to the installers.

Installer Training and Mobilisation

Fitting companies were engaged, from which external monitor fitters were hired for the installation of both the EDMI and GE voltage monitors. Initial hiring and screening requirements selected fitters with strong communication skills and a general metering background to partake in a metering training/ certification programme. From here topics such as and not limited to were covered:

- Electrical safety knowledge (DSR's and EAWR)
- General metering requirements (ST: MI13A)
- Sealing and security of metering installations (ST: MI 25A)
- Polarity testing and proving Dead (ST: MI 13B)
- Isolation switch requirements (ST: MI 15A)

The training methodology and content (refer to Appendix B) developed for the Project was classroom based, allowing for discussions, demonstrations, lectures and practical sessions for the following to be held:

- Installing and commissioning EDMI Mk 7 (single phase GSM connected)
- Installing and commissioning GE SM1011 (single phase GSM connected)
- Installing and commissioning GE SM110 + PLC Modem (single phase)

After the completion of this training material, fitters were required to undertake a practical competency assessment, to determine if the authorisation 'CP – LVCO Installing of Voltage Monitors' can be issued. Alongside the certification of metering skills, fitters participated in a workshop that enabled them to become more informed as to the purpose of the Project and the likely frequently asked questions that customers might ask them. Once completed and passed, all monitor fitters would operate and deliver work to the same standard, ensuring consistent delivery of service and message was provided to all customers engaged.

The number of monitor fitters employed was at its peak between January and March 2012, with up to 20 fitters employed on the Project. The contractual arrangements with the fitters ensured that they were paid per job completed; with a bonus available to them per monitor installed above their 30 monitor a week target.

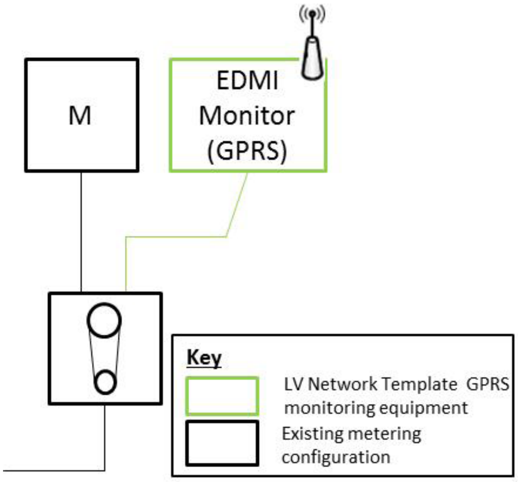
All voltage monitor fitters used WPD vans, uniforms and credentials so as to ensure that customers were aware that they were working for WPD. It should also be noted that approved and certified installers were assigned postcode areas for which they were responsible for. This coordinated approach was managed by WPDs specialist customer services team with the Smart Metering division.

Install Voltage Monitors

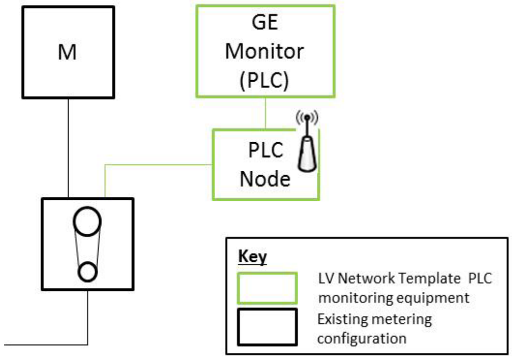
As previously discussed the installation of voltage monitors was managed by the WPD Smart Metering division and delivered by independent contractors. The installation of both the EDMI and GE voltage monitors required a short disruption of supply as either a PLC or GPRS monitor was connected in series to the existing fuse of the customer supply meter. This led to some monitors being housed internally and some being fitted in a customer's external metering box. As each job was completed, installers were instructed to take a photo [21] of the before and after housing, to ensure that a) the job was completed and b) to ensure that random quality checks could be completed. For example details of the electrical configuration, and actual photos of the installed monitoring equipment, please see the figure below (figure 11). For more technical drawings, please refer to Appendix B.

For the installation of PLC monitors a number of trials and tests were performed to better understand the optimal conditions in which a PLC monitor should be rolled-out or installed. Consequently four ground-mounted substations (with underground cable networks) were chosen to be part of the pre-rollout trial in which three voltage monitors were installed at the end of a feeder from each substation. The outcome of this trial highlighted that adopting PLC technology would work best with feeder lengths less than 250metres, as any further than this, and data would not be able to be effectively retrieved. With these findings, only 150 from 951 substations had feeder lengths that met this criteria, and therefore customers suitable for PLC installation. In identifying which customers met this criterion, the smart metering team would identify and inform the installer beforehand, which consenting customers could be eligible in having a PLC monitor installed. This was different to the installation of monitors using GPRS, as there were no special circumstances or pre-defined criteria needed in its installation. As such unless explicitly informed, fitters would install a GPRS monitor.

[21] All monitor fitters were given WPD standard issue cameras



EDMI GPRS Meter Electrical Configuration



GE PLC Meter Electrical Configuration

Example EDMI Photo (Fixed)

Example GE PLC Meter Photo (Fixed)

Figure 11, Voltage Monitor Installations (EDMI GPRS and GE PLC)

From the various supporting engagement methods deployed, a number of potential outcomes could result as attempts were made to install a voltage monitor; these have been highlighted in the process flow figure below (Figure 12, 13, 14 and 15). These process flow highlights that the installation of a voltage monitor is not as simple as a yes or no process, and that at times it would just not be possible to install a monitor due to for example but not limited to factors such as:

- Lack of space available to house the monitoring equipment (e.g. existing meters had custom build wooden housing frames installed around them)
- Customer not being at home at the time of the agreed upon time
- Landlord or housing association request needed (e.g. in addition customer renting the property also granting access)

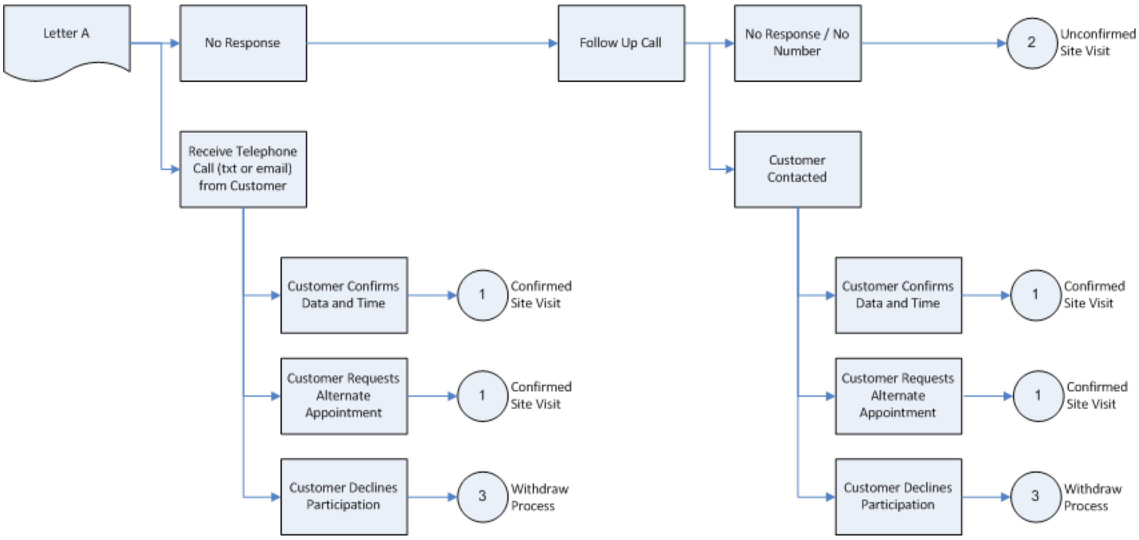


Figure 12, Customer Engagement - Voltage Monitor Installation Overview Site Visit Process Flow

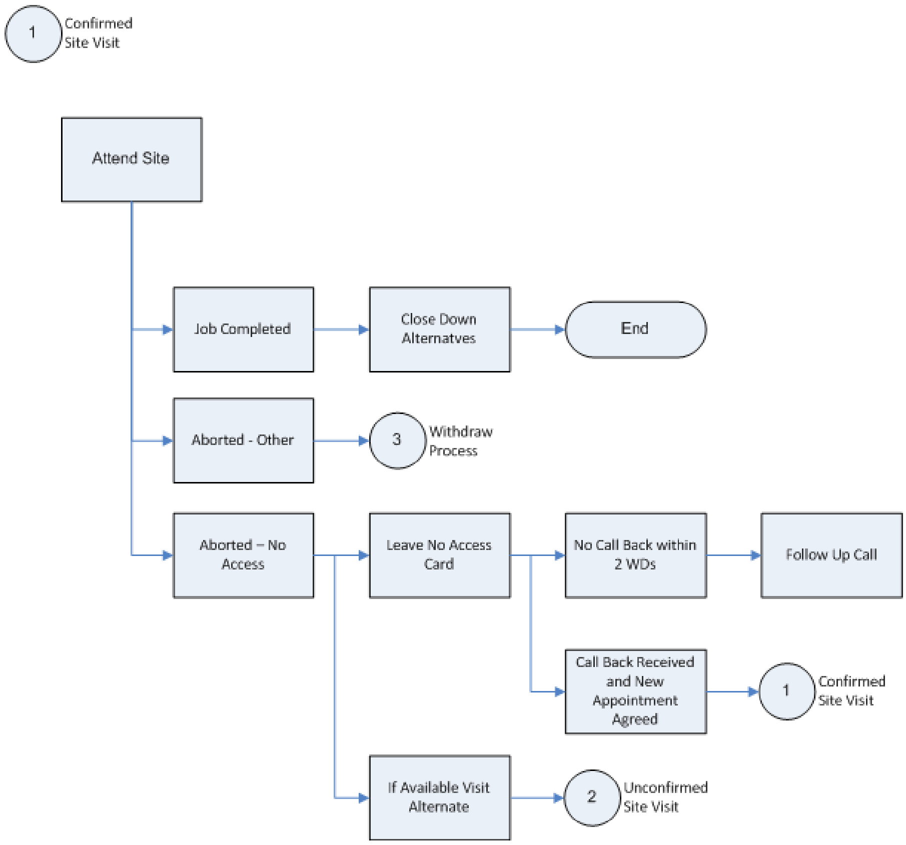


Figure 13, Voltage Monitor Installation Confirmed Site Visit Process Flow

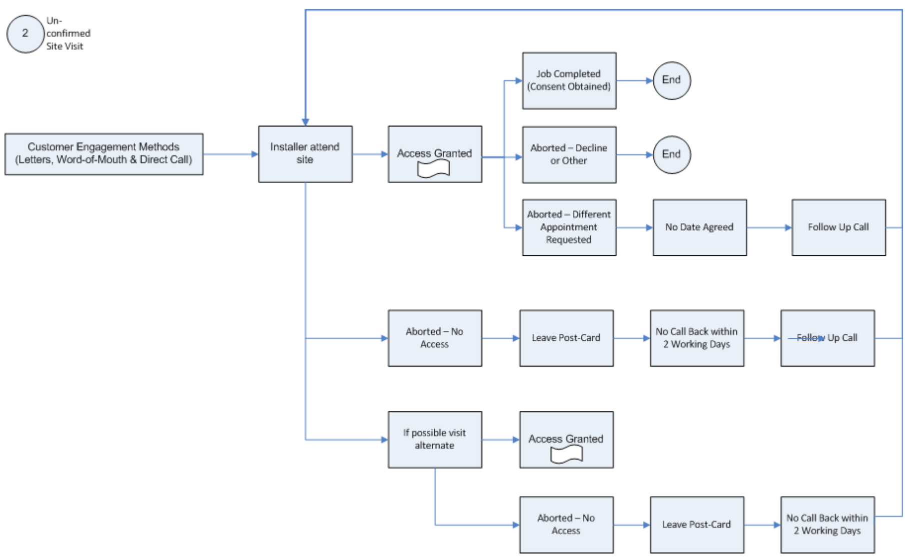


Figure 14, Voltage Monitor Installation Unconfirmed Site Visit Process Flow

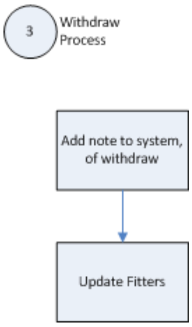


Figure 15, Voltage Monitor Installation Declined Site Visit Process Flow

Live Data & Sense-Checking
Sense checking and quality assurance activities took place throughout the installation process, from vendor, installer to information communication technology (ICT) sense checking activities. As monitors were installed in a customer's premise, the Project delivery team could identify very quickly identify if data was being successfully retrieved or not. Furthermore detailed power engineering analysis was undertaken by the University of Bath, and will be discussed in further detail later on within this report as some of the methodologies applied for analysis and development of templates are discussed.

Feeder-end monitoring method 2: Street Furniture Installations
As an alternative non-intrusive method to feeder-end monitoring, WPD's Network Services team installed ground and pole mounted monitors on the network. The rationale for deploying this additional solution was in part driven by the need for a greater number of phases and feeder-ends being monitored. Additionally this method of monitoring didn't require customer consent being granted allowing for a quick deployment to be rolled out. As a result WPD's network services team and Balfour Beatty installed over 135 ground and 30 pole-mounted 3 phase monitors by the end of June 2012.

It's important to note that this method of feeder-end monitoring was not initially proposed as part of the original submission, due to the cost per installation being significantly higher than that of a hard-wired monitor. These additional costs have been absorbed in the contingency allocation of this Project, for further information surrounding the final costs please refer to the 'significant variance in expected costs and benefits' section of this report.

Customer Engagement:
As a non-intrusive method, customers would not incur any form of interruption to their supply nor would access or permission need to be granted to undertake such work. This was due to street furniture monitoring equipment being erected on public land rather than on or within a customer's premise. None-the-less engagement materials were developed and sent out to customers that were in the 'nearby vicinity' of such a

feeder-pillar install (Refer to Appendix B).

Solution design, procure, quality check & site selection

In deploying both ground and pole mounted monitoring solutions, additional work was required from the designing and buying of monitoring enclosures to the identification of the best locations of the network to deploy this solutio].

Sites were selected that were closest to the end of the feeders, and where there was no or minimal monitoring taking place. As part of the site selection process, surveys were also undertaken in order to identify the business as usual impact and risk of installing such monitoring at those sites. The final sites selected were those that met the aforementioned criteria and surveys.

Installer training & mobilisation

A team of specialist Network Services engineers and Balfour Beatty contractors were given the task of installing ground and pole mounted monitors. Minimal training was required for these engineers as this form of monitoring is already tactically deployed in areas of the network where greater understanding of the on-going voltage flows is required. A high-level overview was however provided to both parties surrounding the Project and the key outcomes it's trying to achieve. As a result a one-day workshop was used to aid the fitters in responding to any questions that may arise from customers.

Similar to hard-wired installations, all Balfour Beatty voltage monitor fitters were given WPD vans, uniforms and credentials so as to ensure that customers were aware that they were working on behalf of WPD. It should also be noted that both teams were assigned postcode areas for which they were responsible for. This coordinated approach was managed by WPDs specialist customer services team with the Smart Metering division.

Installation of Street Furniture Voltage Monitor

One of the key drivers for this solution being deployed is that the installation methods are not dependent on receiving customer consent or require the customer to be at home during installation. As can be seen in Figure 16 below, the configuration and installation of ground and pole mounted monitoring are similar to one another in that they both joint a new cable into the existing main cabinet and feed this back out into a new LV Template specific monitoring cabinet: which houses an EDMI GPRS monitor. A key distinction for ground mounted installations was that additional work was needed in excavating a small area of the street, in order to get access to the underground lines.

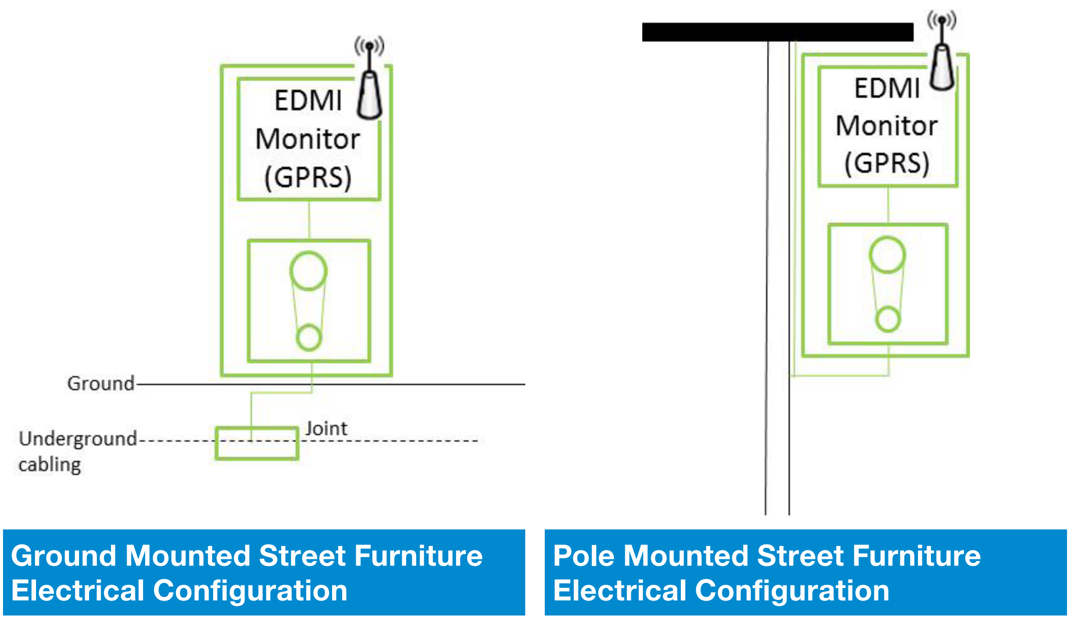


Figure 16, Ground and Pole Mounted Electrical Configurations

Live Data & Sense-Checking
When installing pole and ground mounted street furniture, similar checks and procedures were carried out as with the hard-wired domestic installations.

Feeder-end monitoring method 3: Plug in Monitors
In September 2012, a third non-intrusive monitoring method was developed and deployed, known as the plug-in monitor. The rationale for developing another additional monitoring method was to provide customers with an alternative method to the GE and EDMI solutions. Thereby increasing the number phases and feeder-ends being monitored within the agreed upon Project milestones and time constraints. This final method in combination with the previously discussed methods enabled 3600 feeder-ends to be monitored.

Customer Engagement:
A similar customer engagement approach to that of the hard-wired monitor installs was adopted. As letters, cold calls, post-cards engagement methods were updated to incorporate a plug-in monitor message.

Solution design, procure, quality check & site selection
From the hard-wired monitoring methodology applied (GE and EDMI), a number of lessons were learnt along the way, that in part drove the development and design of the plug-in monitor (See figure 17).

This resulted in EDMI being asked to develop 250 plug-in monitors that relied on GPRS communications, and required only a conventional plug socket to be made available in-order to install, monitor and transmit the voltage flows. As such the design features and methodology were a) more non-intrusive to the customer by not requiring any form of disruption to their supply and b) improved the ease of installation so that any customer could install the monitor themselves. A trade off, is however potentially made as part of this novel method of monitoring; by monitoring being potentially disrupted by the customer at any time by means of simply unplugging the monitor from the socket. In order to avoid this from happening, sockets would need to be chosen that are identified by the customer as not being used and that tend to be out of sight from the potential influences of being unplugged. As with the hard-wired monitors provided by EDMI, both factory testing and random sample quality inspections were undertaken WPD prior to monitors being allocated to some of WPD graduate interns.

Finally, by the time that the plug-in monitors were developed and received, the Projects specialist customer services team (part of the Smart Metering Team) had a clear understanding of which feeder-ends still needed monitoring. A list of these sites and customers was given and targeted through the mentioned engagement approaches.

Figure 17, EDMI and Plug in Monitor

Installer training & mobilisation

Due to the solutions ease of installation, WPD graduate interns were recruited to undertake this activity of work. The selected graduates were given a day’s training around the solution, Project and WPD as a business to allow them to address any questions that the customers may have.

Installation of Plug in Monitors

From the 250 plug-in monitors built, 249 were successfully installed; this was in part to do with the engagement approach applied and the numerous advantages the plug-in monitors over the hard-wired type such as:

- Installation involve no supply interruption
- Quicker and easier to install - No drilling/fixing
- Easier to explain and more consumer friendly – a tangible object that the customer can see before the installation
- A sense of greater customer control, by customer having the opportunity should they wish to unplug the meter to do so

Live Data & Sense-Checking

A similar approach to live data and sense checking was carried out for Plug-in monitors, for further information please refer to the template sense checking activities undertaken as part of the LV Template methodology.

PHOTOVOLTAIC FEED-IN-TARIFF MONITORING

WPD partnered with energy supplier npower to help the Project in installing PV monitors for those customers in the Project area who have installed PV under the feed-in-tariff (FiT) arrangement. The purpose of gathering such real-time data from the FiT monitors is to be able to address the primary objectives set out as part of this Project, with specific focus in understanding:

- The ability to use FiT proxy metering to reflect local area aggregate demand
- The effect of stresses on the network from low carbon technology installed

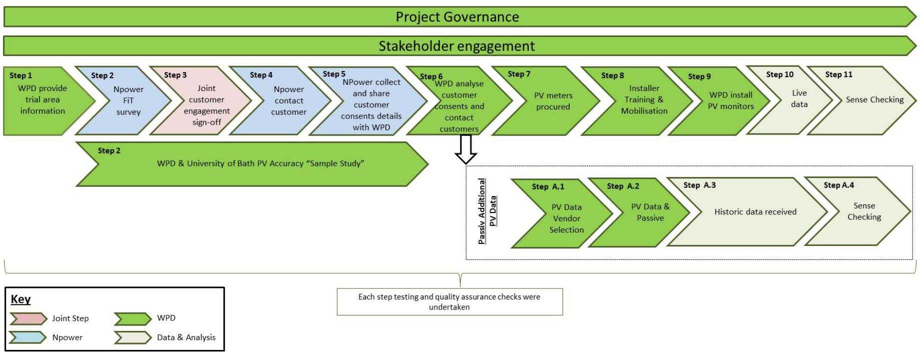


Figure 18, High-Level end-to-end FiT monitor installation methodology (npower & WPD)

In order to effectively address the mentioned objectives npower and WPD developed an end-to-end FiT monitoring methodology (Figure 18). This methodology was based on strong Project governance arrangements whereby the interests of the customers were central to any activity undertaken. As such each 'step' was clearly defined, for which either WPD, npower or both parties would be held accountable for. Additional key safeguards were also put in place, ensuring strict confidentiality and data privacy protocols were maintained i.e. by only sharing customer data for the purpose in which consent had been given. A key summary of the steps and activities undertaken is provided below:

Step 1 WPD provide trial area information: WPD provided npower with a list of post-codes that cover the monitored substations, this information allowed npower to retrieve a list off all the registered PV FiT customers against those substation.

Step 2 npower FiT Survey and University of Bath Accuracy Study: From the post-codes search undertaken, 400 npower registered FiT customers were identified. During this period, the University of Bath was also tasked with calculating the number of PV sites needing to be monitored to provide a statistically robust data set. The results from this piece of work indicated that about 250 PV installations would realise accuracy levels of better than 98%. The measurements from 120 installations would give an accuracy level of between 97-98%. Confirmation of these findings can be found in the University of Bath support letter found in the Appendix.

Step 3 customer engagement sign-off (joint): Similar to the engagement methods and tools deployed for the other monitoring activities (substation & feeder-end), four variations of the direct or indirect methods (letters, post-cards, cold calling & word of mouth) were applied across a number of steps (5, 6 & 9). This split approach was in part as a consequence of customer data privacy protocols needing to be upheld.

It is also important to highlight that no incentives were given to those customers having a PV monitor installed. The rationale for this being, that such incentives would be an additional cost to the Project and that a greater emphasis on other drivers such as the "low carbon agenda" would result in a similar outcome.

Step 4 npower contact customer: Letters were sent by npower to the identified 400 PV FiT customers, including content such as a Project overview leaflet, consent form and a pre-stamped return envelope. The purpose of sending this initial content to customers was to a) inform them about the Project; to b) confirm their interest in participating in the Project; and finally to c) gain consent for npower to share their contact details with WPD for the purposes of booking a time/date for a PV monitor to be installed. Customers were also given the opportunity of fast tracking the installation process by contacting WPD directly on wpdlcnProject@westernpower.co.uk. Please refer to the Appendix B for an example letter sent out.

Step 5 npower collect and share consents: Of the 400 letters sent to customers, a total of 120 consents were received (30% success rate), with a small number of customers using the fast track method and the remaining being sent to WPD in batches via secure password protected Zip files from npower.

Step 6 WPD analyse customer consents and contact customers: Prior to customer contact being made by WPD, a one day training workshop was organised for all members of the specialist customer service team. The purpose of which was to both train, and develop a detailed list of frequently asked questions that can assist a customer service representatives when engaging with an informed PV customer. Whilst a similar approach was taken for the installation of feeder-end monitoring activities, a more detailed overview was given here. This was based on the logic, that customers with existing FiT installations may generally be more interested in their electricity usage, and as a consequence ask a lot more technical questions about the installation process itself.

As consents arrived either via npower or the fast tracking process, WPD were provided with the following details: customer name, full address and telephone number. From this information and the previous engagement steps taken, WPD's specialist customer services representatives were able to effectively contact and confirm with customers a time/date for a WPD representative to come round.

A minimum sample of 250 PV installations was required for the University of Bath to be 98% confident in the conclusions that could be drawn from it. With this in mind, enquiries were made to several PV monitoring services organisations in order to secure additional PV data. As a result, Passiv Systems [22] were selected and able to provide a full 12 months' worth of data covering 525 PV installations throughout the Project area (Steps A1 – A4). This data included the bearing, inclination and installed capacity at domestic sites and proved invaluable in analysing the primary objectives.

Step 7 PV meters procured: EDMI meters using GPRS comms were procured and installed.

Step 8 Installer training and mobilisation: Whilst the installation of PV monitors was managed by the WPD Smart Metering division, the work was delivered by specialist GnR contractors. When mobilising these contractors, a frequently asked questionnaire was developed and shared in order to help the contractors understand the Project. A similar one day training workshop was held with the GnR contractors prior to any PV monitors being installed.

Step 9 WPD install PV monitors: As previously mentioned WPD and npower received nearly 120 consents to install FiT monitors, for customers with photo-voltaic (PV) generators in the Project area. Of these consents 80 FiT monitors could be successfully installed as 40 sites didn't have enough space available to house the PV monitors.

The installation of the EDMI PV monitor required for a short period of time that the solar power supply generated from the PV cells to be turned off. This occurred as the monitor was being connected between the generator meter and the main consumer unit. Due to the monitor's location as can be seen in Figure 19, customers didn't face an interruption to their household supply. As each job was completed, the PV monitor fitter was instructed to take a photo [23] of the before and after housing, similar to the rationale and quality checks enforced during feeder-end monitor installs.

[22] Passiv Systems are a monitoring services organisation that provides a number of services and products to the utilities industry. One of their offerings focuses on monitoring PV installations, providing a three tier service to its customers with installed PV.
[23] All monitor fitters were given WPD standard issue cameras

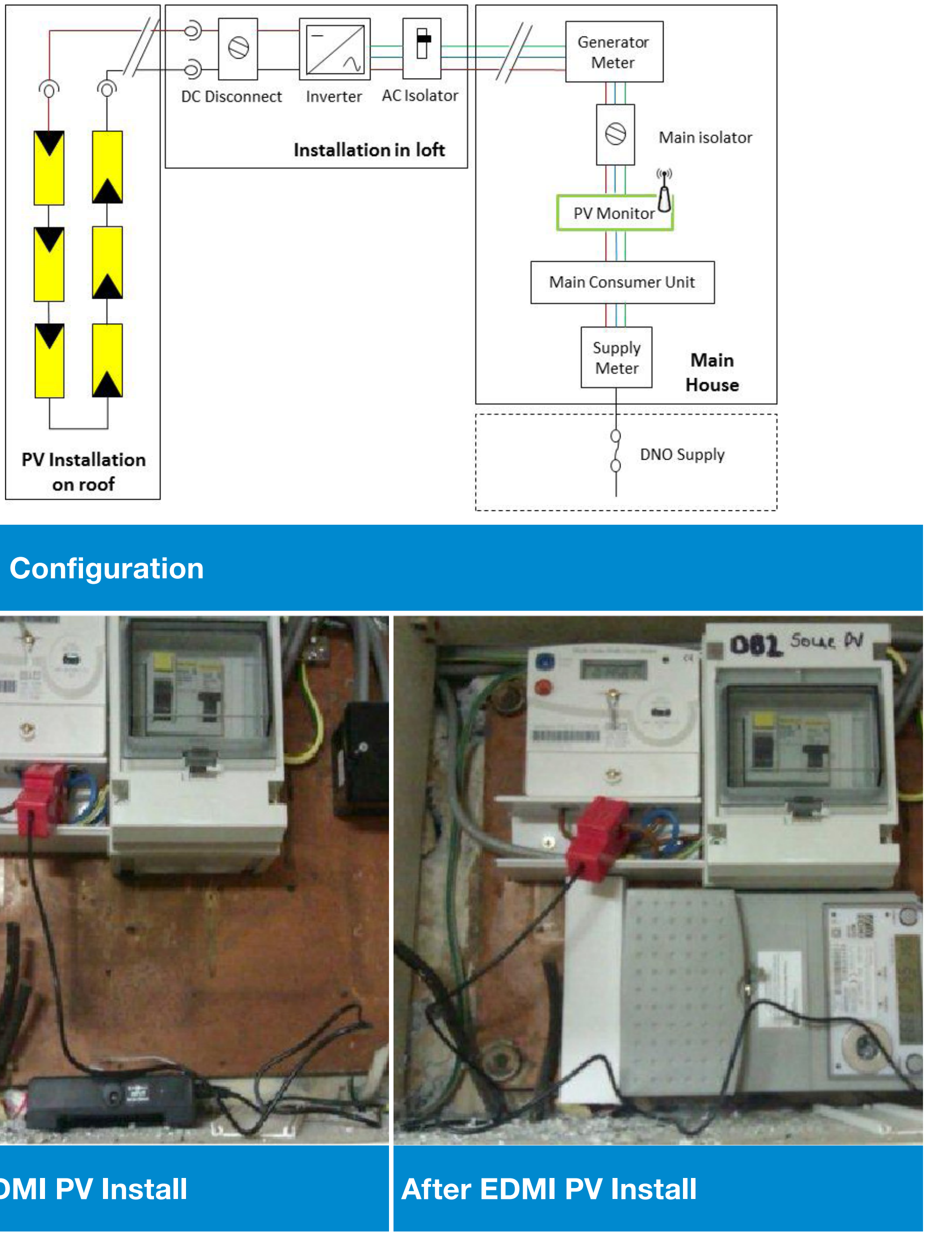


Figure 19, PV Installation (Electronic Configuration and Photos)

INFORMATION COMMUNICATION TECHNOLOGY (ICT) AND DATA ARCHITECTURE

Central to the development of a robust set of LV networks templates, is the data being monitored and the ICT telecommunication and data architecture in place to allow for its secure capture, distribution and subsequent analysis. In developing the architecture and systems needed, WPD's business as usual ICT delivery methodology and tools were applied supported by that of Accenture's delivery methodology (refer to figure 20). It should be noted that as part of overall delivery methodology, an effective system of controls and activities were adopted ensuring that any ICT work undertaken was also compliant to the US Sarbanes Oxley Act (SOX), required by WPDs US parent company. As such standard disciplines are applied consistently to all WPD systems using best industry practices which are equivalent to the standards within ISO27001.

As a result of these proven methodologies, the relevant ICT systems were upgraded and the comms paths to sensors were proven and tested by 13.09.2011. Data from 13.09.2011 was sent to the University of Bath for analysis, followed on by WPD also providing National Grid with actual live data of distributed generation on the 19.12.2011. These data transfers were initially manual activities until further refinements were built that allowed the process to be semi-manual and operational by the end of 30.03.2012.

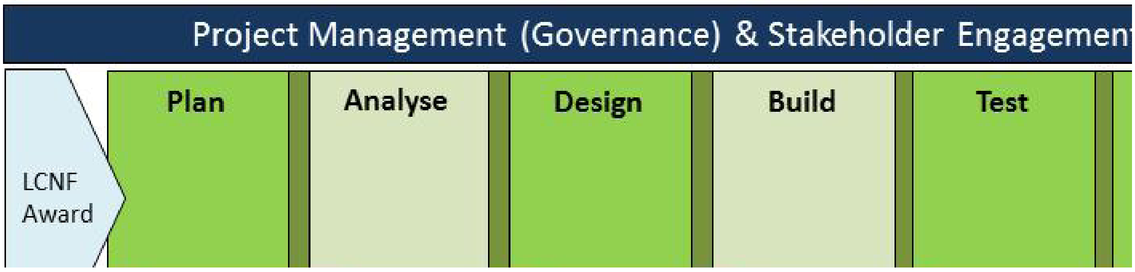


Figure 20, ICT and Data Delivery Methodology

The steps undertaken as part of this methodology and the transition points are discussed in further detail below.

Plan

Once the Project was awarded, planning activities went underway that firstly identified the key stakeholders needed to successfully deliver the ICT, telecoms and data requirements. These individuals included internal WPD representatives (including Surf Telecoms) and WPDs Project Partners (GE, Accenture, and the University of Bath). All of whom eventually formed Work Package 3 (Architecture), as illustrated in the Project delivery team organogram in figure 6. From this Project structure, key roles and responsibilities were clearly defined against the Project requirements and delivery timelines set.

Following this, high-level ICT requirements were gathered through a number of workshops, including discussions held with members from the wider Project delivery team e.g. Smart Metering team. These workshops identified the monitoring and data storage capabilities available for the GE or EDMI monitors themselves, as well as the requirements needed in order to successfully extract and store the data securely within WPD and eventually the University of Bath. During this time insight from Surf Telecoms also helped to shape the high-level communication requirements needed to be able to pull the data from these monitors, be it for substation, feeder-end or PV monitoring activities. Finally in gathering these high-level requirements, key inter-Project and non-Project (i.e. business as usual) risks and dependencies were identified.

Analyse
From the high-level requirements gathered, the Project delivery team for work package 3 were able map and define the Project requirements to the necessary technical requirements. This understanding was in part achieved through the comparison of the current as-is state of the ICT and communication systems with the future to-be state; resulting in system gaps, or potential points of system constraint being identified.

A key outcome of the effectiveness of this analysis was that it identified the need to potentially procure 6 new pairs of Ultra High Frequencies (UHF) from the JRC for substation monitoring. This potential need was due to existing substation RTUs already occupying a large number of the radio frequencies allocated to WPDs business as usual monitoring. Later, substation radio surveys carried out by WPDs smart metering team supported by Surf Telecoms recommendation to adopt long range radio technologies for substation monitoring confirmed this need, leading to 6 Ultra High Frequencies being procured.

During workshops in which functional and technical requirements were being gathered, the delivery team took the initiative of engaging with the other IFI, Tier 1 and Tier 2 LCNF Projects. This was so as to capture any potential requirements that other Projects may have, and that could a) pose a risk/dependency to the LV Network Templates Project; and b) duplicate work. By applying this pragmatic approach, WPD and Surf Telecoms were able to put in place a suitable ICT and Communication architecture. Having undertaken this level of in depth analysis, the Project delivery team were able to define the system architecture and to sign this off with the Project board, prior to design activities commencing.

Design & Build
Based on the functional and technical requirements, the delivery team designed an architecture that minimised the impact to systems and comms being used for business as usual activities. This was in part driven in maintaining performance levels but also in part in ensuring that WPDs ICT systems and network didn't expose themselves to security threats.

As the original proposal and further analysis identified, when undertaking monitoring, three forms of telecommunication technologies were deployed GPRS, PLC and Radio. Whilst a common feature of all monitors deployed, was their ability to store 40 days' worth of 10 minute interval data; a slight difference however did exist in how the final monitoring solutions were housed, and the journey each solutions data would take to get to UoB or other interested parties (Refer to feeder-end and substation monitoring sections). This is illustrated in the high-level data and communication architecture Figure 21, and described in further detail below.

- Feeder-ends being monitored using GPRS (Hard-wired EDMI, Street Furniture or Plug-in solutions) as a communication platform fed directly into GE's firewalled hosted server called SMOS
- Distribution substations communicated via the procured licenced radio frequencies (UHF) to the associated access point (normally a primary substation), from here data was pulled to GE's firewalled hosted server called SMOS

Both sets of data would be pulled from the monitors on a weekly basis. Once data had arrived at GE's SMOS server, a WPD representative would be able to extract the data securely through 'GEs LV Template Web Portal' into central LV Network Template Data Repository.

- For the feeder-ends being monitored using GE meters and Power Line Carrier as the communication platform, data was directly fed to WPDs firewalled and hosted STIP Server. Similarly this data would be pulled and extracted by WPD on a weekly basis.

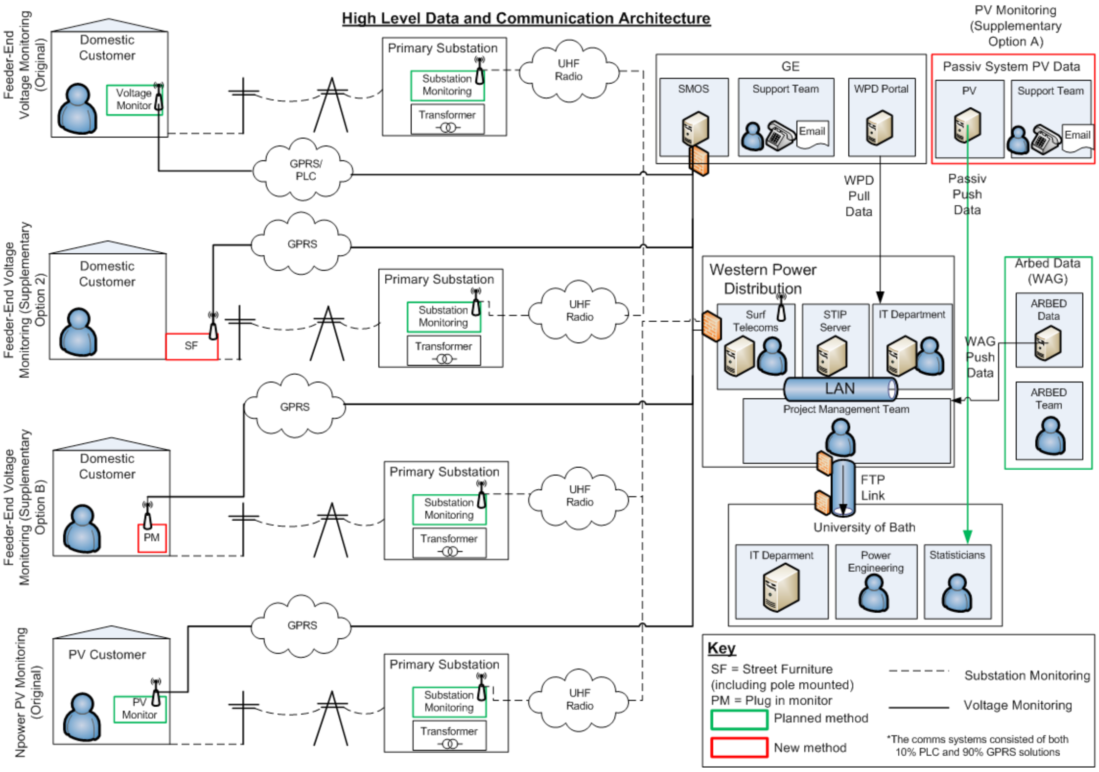


Figure 21, ICT and Communications Architecture

From here WPD along with Bath University designed and built a Secure File Transfer Protocol's (SFTP) to allow data to be transferred from WPDs central database and then on to Bath University. This link securely transferred the full volume of data across to the University of Bath on a weekly basis (every Monday). Whilst any additional data being received from the Welsh Assembly Governments Arbed scheme and PV data from Passiv Systems were securely received and forwarded to the University of Bath in encrypted zip files sent via MS Outlook.

Test

The testing methodology applied ranged from component, assembly to end-to-end performance testing. This approach was undertaken at different stages of the Project lifecycle and by multiple parties from the vendors, monitors fitters to the power engineers and statisticians at the University of Baths. A number of these testing and quality assurance activities have already been discussed, for this reason a more ICT and Communication focused testing approach is provided below.

Component & Assembly Testing
During the installation of the monitors, random sample testing was undertaking prior to their deployment, followed on with quality assurance checks as the monitors and aerials were installed (substation, customer premise, street furniture and plug-in). Additional component and assembly testing activities were run on the GE Portal and secure FTP links.

- STIP Server Testing: Feedback from the University of Bath identified a number of STIP registers not providing data. There are still some issues with STIP data being received by the University of Bath, as the cause of the problem is still unknown
- GE Portal Testing: A team of three WPD IR specialist employees (GE certified), tested the connection and security parameters of the portal. Tests were completed successfully by both WPD and GE delivery teams
- FTP Link Testing: WPDs Project delivery team sent a number of test files to the University of Bath. Tests were completed successfully

Performance Testing
End to end performance testing activities were undertaken from selected monitors collecting the data to its transmission over various communication platforms and eventual storage within WPDs central data repository. This was to ensure that a) the new technical architecture was integrated properly with the existing overall architecture and b) met all performance-related metrics, such as response time, availability, and load/throughput. The outcome of the end-to-end performance testing carried out resulted in no adverse impact to business as usual services.

Deploy
As the ICT, Comms and Data Architecture became fully operational; WPDs delivery team agreed a list of users who were to be provided with user training and granted the relevant levels of permission to access the data. This list was maintained and updated as and when needed throughout the Project.

METHODOLOGY OF LV NETWORK TEMPLATES (INCLUDING UPDATES)
A five step methodology, as illustrated in Figure 22, was applied in developing credible and replicable LV Network Templates. Each of these steps and the methods applied have undergone further refinement since the submission of the LV Network Templates Report in July 2013 [24]; as illustrated below (e.g. includes update and new). The illustrated steps below will be discussed in turn with the resulting LV Network Templates (step 4) being discussed in the outputs section of this report.

[24] For further detailed information surrounding the templates and supporting appendices, please refer to the LV Network Templates Report

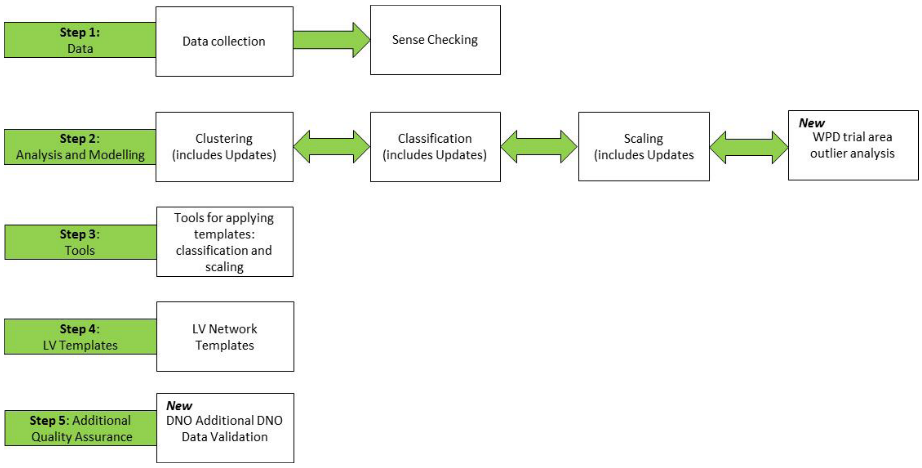


Figure 22, LV Network Template Methodology Overview

STEP 1 DATA: DATA COLLECTION

As identified in the Project background section, the primary study area chosen for the development of the templates was South Wales. The rationale for choosing this area was to collect and analyse data on areas of WPDs network that had similar characteristics to that of the other DNOs, and to obtain gearing from WAG's investment in deployment of LCTs via its Arbed initiative (See Figure 2). Additionally the number of monitors installed would provide WPD with a data sample size from which statistically relevant findings could be drawn; the aim was to develop LV Network Templates which are both credible and representative for application by the other DNOs in the wider GB network.

In the development of the LV network Templates two sets of data are used (i) fixed data and (ii) monitored data.

Fixed data	• 951 substation profiles with, data on circa 30 different factors, such as:
	  • Network topology characteristics (Transformer size, feeder length and capacity)
	  • Details of customer mixes, including Elexon customer profiles and estimated annual consumption
	
	The fixed data does not change during the research period and it is used to classify LV substations and to form typical LV networks to conduct topology and energy flow analysis.

Monitored data	• 824 substation monitored • 3600 feeder-ends monitored (including customer premises) Monitored data comprises of measurements made on 10 minute intervals of voltage, current, real power delivered (kW). The variable data is used for mathematical clustering analysis to identify the embedded patterns in real power delivered.

Table 3, two sources of data which are combined in developing LV Network Templates

The study area from which data was gathered includes geographical locations ranging from inner-city, urban, suburban, and rural to industrial sites. Additionally the monitored substations cover a wide range of customer mixes; from those highly dominated by residential customers, to those exclusively industrial and commercial.

For meaningful data analysis to occur, more than 824 substations and 3600 remote feeder ends were monitored throughout the year. Preliminary data was recorded and sent to the University of Bath in September 2011 allowing for the development of sense-checking procedures that would minimise poor or sporadic data being recorded. Since March 2012 the data delivery was fully semi- automated, via WPD using a FTP link to a dedicated server at the University of Bath. At the time of the original LV Network Templates report over 1/2 billion substation readings and in excess of 101 million feeder-end data points were being analysed.

The approach taken in installing the monitoring equipment at both feeder-ends (customer premises and street furniture) and substations, allowed WPD to immediately start recording data, as and when they were installed. During this period therefore, the amount of data retrieved from a substation or feeder end increased as they came 'on-line'. In addition to collecting variable data such as voltage and real power delivered (kW), fixed data was also collated. This additional information gave the University of Bath a better understanding of the load and voltage flow relationships versus network capacity available on a given LV circuit or substation.

STEP 1 DATA: SENSE CHECKING

Due to the large amount of real-time substation and feeder-end data being collected, sense-checking activities were applied to help ensure consistency, credibility and confidence in the final LV Network Templates. Especially as data errors can appear at any stage; from the moment data is being recorded, to the point it's received by the University.

The robust sense checking methodology captured three main issues:

- Low currents are represented by several sole readings due to the poor resolution of current meters
- The power calculated from voltage and current readings and the metered power, i.e. 'real power delivered (RPD)', conform well at most substations, but there are a few substations where the two powers differ significantly
- The majority of power readings at some substations are zero

Voltage Sense Checking

In the UK, the nominal phase voltage for LV substations is 230V with a tolerance of +10% and -6%. This tolerance can be used for sense checking both substation and feeder-end voltages. Any substation voltages significantly out of the range are flagged as suspicious or bad requiring further investigation. The voltage sense checking methodology applied is discussed in further detail below:

Voltage at feeder ends is lower than at the substation, due to voltage drop occurring as current flows along the network. The voltage drop along a feeder is determined by the formula below, meaning that feeders can be clustered into different categories according to their length and power delivered for voltage analysis. For each group, averaged voltage is used as benchmark to represent voltages within the group. Therefore, the abnormal voltage data can be spotted by comparison with the average voltage of the feeders from the same category.

$$VD = \frac{P \cdot R + Q \cdot X}{V}$$

Where, VD is voltage drop, P and Q are active and reactive powers along a feeder, and R and X are the feeder's resistance and reactance. For further information and examples of the extensive voltage sense checking activities that have taken place, please refer to the "Stresses on the LV network caused by low carbon technologies report" [25].

Current Sense Checking

The currents flowing at LV substations are determined by customer demand and vary considerably during a calendar day. Therefore, it is impractical to set a low threshold for accurately recording currents. An upper limit can be estimated using the maximum demand of each household. The approximate peak demand for each domestic household in the UK is 2kW which can be used to validate the measured substation currents with the domestic customer numbers served by each substation. This approach is not suitable for substations in commercial and industrial areas, where there is limited information available concerning the demand pattern of customers. In these areas the current readings are harder to sense check, as they require the application of more engineering judgment on a case by case basis. A summary of current data that underwent sense checking at substation level is provided below.

Although it is normal for current readings to vary within substations' capacity, several issues with the resolution of meters have been spotted. In order to demonstrate an overview of the current issues, all current readings of the whole data set at total 824 substations are plotted in Figure 23, where the X axis is the values of current readings and Y axis is the number of times each reading occurring.

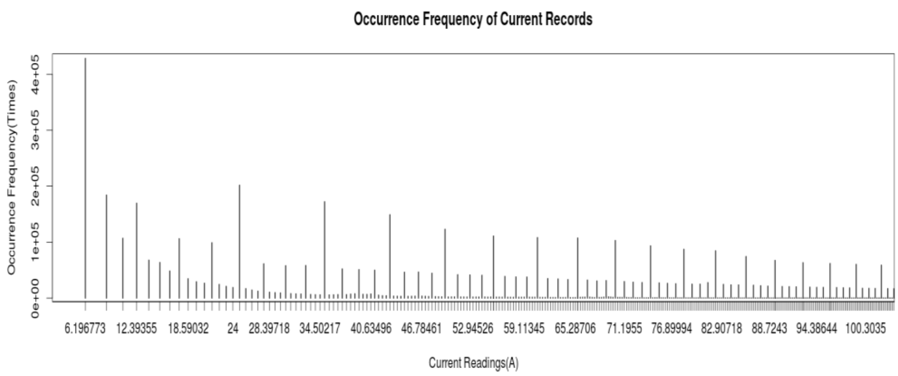


Figure 23, Occurrence Frequency of Current Records from 0A to 100A

[25] "Stresses on the LV network caused by low carbon technologies report" (01.05.2013) www.wpdinnovation.co.uk

As can be seen, the resolution is changing throughout the readings. At the lower end, the resolution is around 2A, which decrease to 0.5A as the current readings increase. The resolution reaches its minimum of approximately 0.2A when the current readings are over 90A. When the metered currents are below 20A, they are just represented by several discrete readings, particularly at low currents. The readings of 8.76A and 10.73A appear approximately 200,000 and 100,000 times respectively in the plotted substations while there are no other readings between the two values. Table 4 below highlights the percentage of low readings across the current data.

Readings	0A	6.19A	8.76A	10.73A
Percentage	20.7%	1.6%	0.8%	0.5%

Table 4, Percentage of low current readings

To demonstrate how the Project investigated current readings in the time series, substation 536787 is taken as an example. The substation current readings are depicted in Figure 24. The current readings are a “saw tooth” shape rather than smooth as would be expected. This is due to the poor resolution. It can be seen that the low current readings simply “flip flop” between 0A and 12A. Although the resolution becomes smaller when readings are above 30A, the overall profile shape is still not smooth. As this has less of an impact on the power measurements than the measurements of current, the University of Bath are satisfied that this will not impact on the quality and credibility of templates.

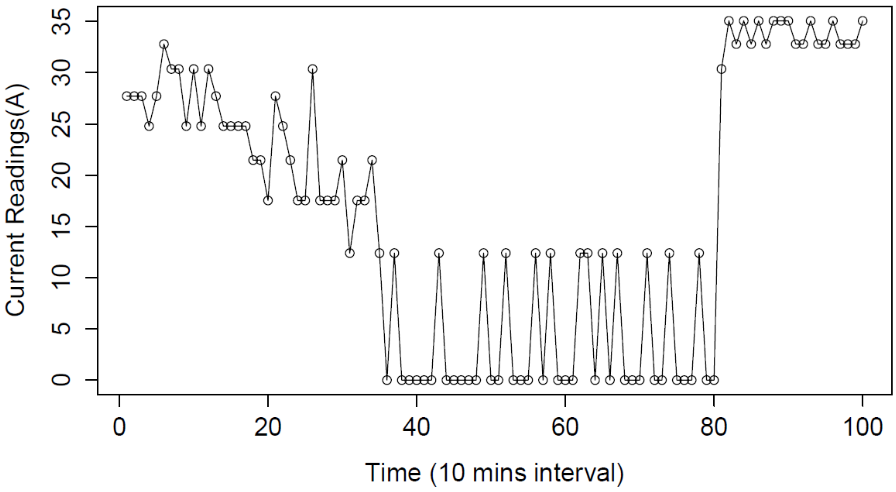


Figure 24, 10-minute interval of current for Substation 536787

Power Sense Checking

Three-phase power sense checking at substations can be calculated using the recorded phase voltages and currents; with an approximate power factor, given by the formula below. If voltage, current and power data are reasonable, the power factor should be an appropriate value according to customer types. This calculated power delivered can be used to validate the metered power delivered at LV substations.

$$PD = (V_A \cdot I_A + V_B \cdot I_B + V_C \cdot I_C) \cdot PF$$

Where, PD is the real active power delivered, V and I are the phase voltages and currents of three phases A, B and C, and PF is the power factor. A summary of the power sense checking results of all 824 substations in the Project are given in the table 5 below.

	Number of substations
Group for use (Group A)	730
Group not for use (Group B)	94
Total	824

Table 5, Power Sense Checking Results

Theoretically, the metered real power delivered should be equal to the power calculated from voltages and currents multiplied by a power factor. The power factors, normally ranging from 0 to 1 are defined by the customer type. The factor is usually higher than 0.9 for domestic customers, which means the metered real power delivered should be very close to the real power calculated. However, the comparison of the two values at all 824 substations showed excess variation. All substations can be roughly categorized into two groups after sense checking according to the difference between the power calculated and delivered: “Group for use” (Group A) and “Group not for use” (Group B).

Group for use (Group A)

There are 730 substations that fall into this group as their real power delivered readings are very close to the real power calculated. The ratios between the two values are usually higher than 0.7, which perfectly reflects the impact of power factor. Figure 25 below demonstrates the relationship of the two values on substation 511028 (the unit is kW and it applies to all following figures). The red line is a benchmark, whose slope rate is 1. The black line, representing the ratios of power delivered over power calculated for the whole period, almost overlaps with the benchmark line. For substations within this group, either power delivered or power calculated can be applied to effectively cluster. The metered power delivered may even be better described by the real power consumption as it has already taken power factor into account.

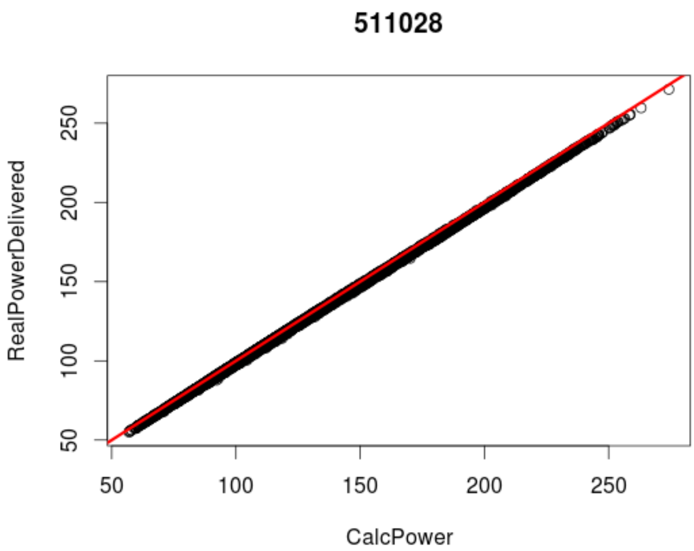


Figure 25, Real power delivered against real power received (Group A)

Group not for use (Group B)
There are 94 suspected substations not for use due to the abnormal power factors or readings recorded. At some substations the real power delivered deviates greatly from the power calculated, as can be seen at substation 513569 (Figure 26), where the ratio deviates greatly from the red benchmark line. Both power values span in reasonable ranges and could be caused due to the substation having a low power factor. It is nonetheless hard to assess the data's overall reliability.

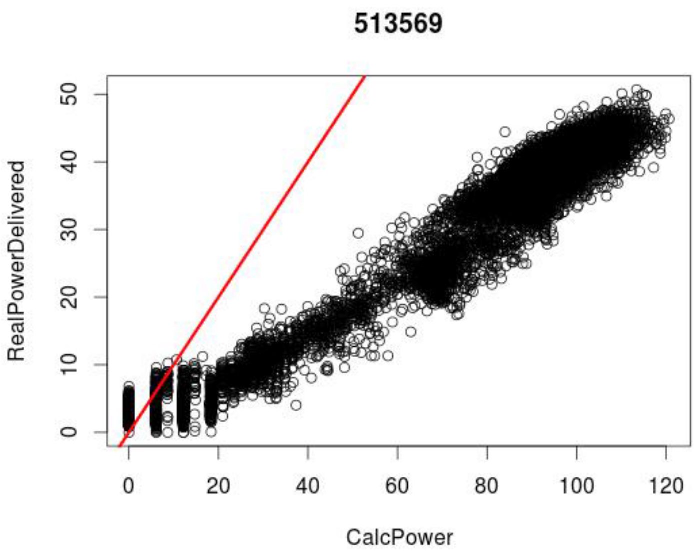


Figure 26, real power delivered against real power received (Group B)

The other type of substations in this group have zero or close to zero real power delivered readings resulting in low power and current readings being calculated. Substation 511361 is an example of this (Figure 27) with most readings being either zeros or 0.1 kW.

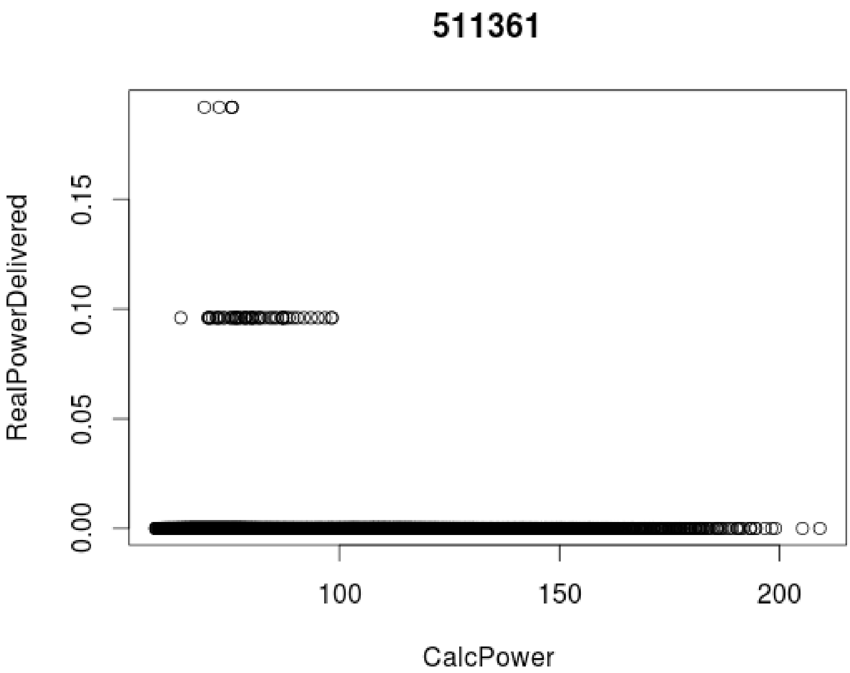


Figure 27, real power delivered against real power received (Group B)

A potential cause for low real power delivered readings being received could be due to the poor metering resolution or a defective meter. Due to the identified issues in Group B, it is evident that further solutions would need to be identified, applied and tested in order for the data to provide the necessary confidence.

STEP 2 ANALYSIS AND MODELLING: MOVING FROM DATA TO THE DEVELOPMENT OF LV NETWORK TEMPLATES

As part of Step 2, a four stage process was required to develop the LV Network Templates:

- **Clustering** – grouping substations according to patterns of real power delivered leading to clusters of substations
- **Classification** – characterising the relationship between these groups and fixed data including substation characteristics and customer profiles
- **Scaling** – transforming the results from the clustering and classification steps to appropriate scales than can be used in practice
- **Quality assurance** – evaluating the estimated demand profiles against those seen in practice, performing a thorough analysis of outliers in order to understand where templates are most accurate and to identify potential issues. Applying the templates methodology to data from other DNOs to assess whether the approach is applicable in other licence areas

The first stage used monitored substation data and is distinct from the latter two that use fixed, routinely available data. The aim of the first step was to create clusters using the monitored data. The second and third stages, creating classification rules and scaling factors, are solely based on fixed data, and as such are transferable to areas and time periods for which monitored data is not available. A more detailed overview of the stages is provided below.

STEP 2 ANALYSIS AND MODELLING: CLUSTERING: TECHNIQUES AND APPLICATION

Taking daily patterns from the substations as the object of interest, the aim is to create clusters of substations within which the daily patterns are more similar than those in other clusters. In statistical terms, this means that the inter-cluster variation (or between) should dominate the intra (or within)-cluster variation.

Agglomerative Hierarchical Method

As the aim in this Project was to define the clusters based solely on patterns detected in the data, agglomerative hierarchical clustering was used which does not assume any prior information. This works by grouping data objects for load patterns within a day, into clusters via a dendogram (an example of which can be seen in Figure 28). There are two possible approaches depending on whether clusters are created using either a top-down or bottom-up approach. In the former, initially all objects are considered to be in a single cluster and then split into smaller clusters iteratively based on measures of dissimilarity until, ultimately, each object forms its own cluster. In the latter (the approach that this Project applied), sees each object being classified as its own cluster and then merged, according to some similarity measure, until ultimately there is again a single cluster. The applied bottom-up approach is less sensitive to errors in the agglomeration.

Two crucial aspects that need to be considered when using the agglomerative method are (i) the choice of dissimilarity measure, i.e. the measure of how close two objects are and (ii) the criteria which decides whether, based on this measure, two clusters are considered close enough to be merged together to create a single cluster.

The precise nature of the dissimilarity measure was determined to a large extent by the output and purpose for clustering. For example, if the aim was to identify clusters according to peak usage then the measure might be based on differences between daily peaks. As for creating the LV templates the primary interest is in detecting temporal patterns resulting in normalised data being used. The measures can also be constructed to reduce the effects of outliers and noise to a greater or lesser extent depending on the analysis requirements.

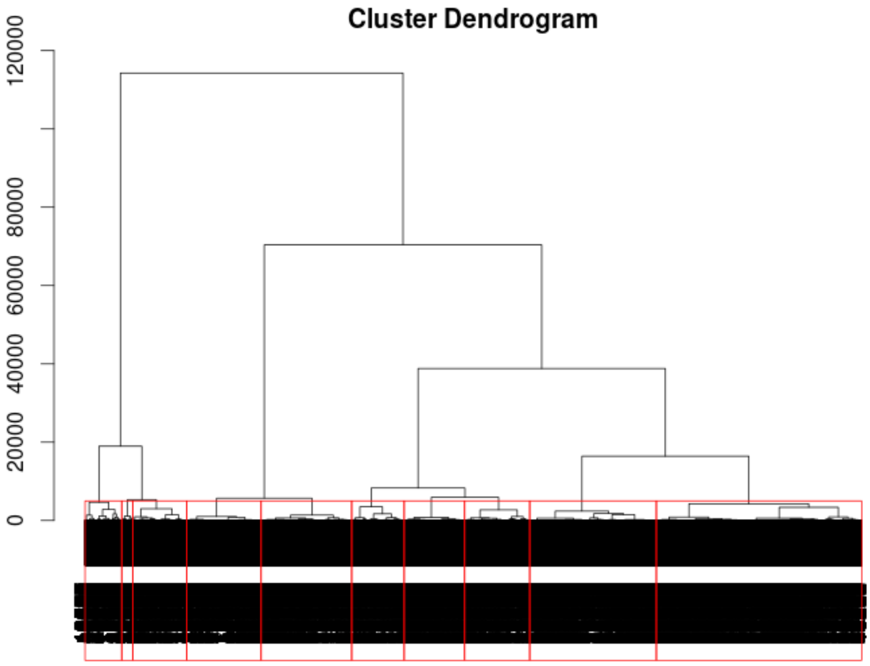


Figure 28, Dendogram: Substation Cluster Analysis on real power delivered

The dendogram above (Figure 28) illustrates the clusters of substations using normalised data from South Wales.

The units of the data used as input for the clustering will determine to a large extent the nature of the clusters that are found. For example, direct use of measurements of real power delivered will result in clusters that reflect the magnitude of loads. To be able to detect other features, such as within day load patterns, scaling down or normalisation of the data will be necessary. Two different approaches to normalisation were considered, along with using direct measurements. The choice of which is adopted will be determined by the primary interest in how the substations are grouped together. The three approaches are as follows:

- Magnitude– where data on the original scale of the measurements is used
- Normalised I – where the data is normalised to the maximum value of real power delivered recorded at each substation over entire period of study
- Normalised II – where the data is normalised to the maximum value of real power delivered at each substation for each day

When using the first approach, the creation of clusters is dominated by the average real power delivered associated with each substation, therefore patterns within days will be overlooked. As a consequence the resulting set of clusters will largely reflect the number of customers, and secondly the customer mix for each substation, but at the expense of detecting patterns of demand. This approach is not particularly useful for planning purposes and does not add much useful information to the fixed data which is already known. Therefore this approach was not suitable.

The second approach goes some way to correcting this but is affected by daily/seasonal changes in the maximum values and as such can result in a set of clusters that largely reflects the overall effect of time. Therefore a cluster may be constructed solely based on the difference between demands in different seasons as the maximum value will largely be based on winter driving summer values to be low. As such it means detecting patterns of demand within days can be very difficult. A further limitation of both the first and second approach is found when applying a scaling factor as templates versions of each other are created. This is problematic as substations could change cluster according to the time of year which would make the practical application of the LV Networks Templates difficult.

The third approach is designed specifically to be able to detect patterns of demand within days and is the chosen approach for LV template development. The result of this approach is a set of clusters that are constructed based on differences in demand over a 24 hour period. These clusters are considered further by separating weekdays and weekends (with Saturdays and Sundays treated separately) as well as different seasons (Spring, Summer, High Summer, Autumn and Winter) leading to the creation of templates from the clusters.

Applying this normalised approach, meant that a scaling factor needs to be applied to adjust the templates back to actual values. While this additional step may initially sound problematic, this actually adds a great deal of flexibility to the use of the templates. Rather than having a set of around ten templates that must reflect both load shape and magnitude for all substations, scaling the normalised templates means that a good range of different load shapes is derived and that the template output is tailored for each substation.

Update

Since the publication of the LV Network Templates Report [26], further data has become available for an entire year. The clustering approach described has been applied to all five seasons from summer 2012 to spring 2013. Clustering is performed for each season separately, allowing the process to respond to potential differences between the seasons that may require clusters to differ fundamentally depending on the specific nature of season. Load patterns are available for each season (see Appendix). Clusters can be mapped over the seasons and this allows an analysis of the dynamic changes of substations between clusters over time.

STEP 2 ANALYSIS AND MODELLING: CLASSIFICATION

After creating a set of clusters, or groupings of substations, the University of Bath developed a methodology for assigning substations to clusters when monitored data is not available. The aim was to develop a statistical model that could be used to predict cluster membership using only routinely available data by creating rules that will be applicable to other substations and the wider GB network.

[26] Demonstration of LV Network Templates through statistical analysis (www.lowcarbonuk.com) (01.07.2013)

Multinomial logistic regression models were used to examine relationships between cluster membership and fixed data. For a given set of variables from the fixed data, the `model' consisted of set of nine logistic regression equations, each of which predicts the probability that a substation is in one of the ten clusters. There are nine rather than ten equations as they are all relative to the probability of being in cluster 1 (which is used as the baseline). A substation was allocated to the cluster with the highest probability. The collection of probabilities for all ten clusters give an indication of how certain this choice is. Validation and accuracy was assessed by comparing predicted cluster membership with actual membership.

The selection of variables for inclusion in the classification model was made from the complete list of factors available in the fixed data. The set of variables considered is shown in table 6.

Number of customers in each Elexon class
Estimated annual consumption for each Elexon class
Transformer type
Transformer rating *
Percentage of industrial and commercial customers *
Percentage half hourly metered load
Total length of HV feeder
Number of LV feeders *
Percentage overhead lines (at HV feeder)
Total number of customers
Total annual KWH
Total metered load
Total HH metered load
Total unmetered load estimate
Percentage switched
Total connected PV
Total other connected generation

*Table 6, Variables considered for use in classification model. Selected variables are highlighted with blue background. Variables marked with * indicates that categorised versions were used in the model.*

The choice of which factors were required for the model was made using a combination of statistical significance, in terms of improved model fit and the ability to accurately predict cluster membership. This process also takes into account the completeness of the data for the individual variables. A major component of this analysis comprised of examining possible non-linear relationships between variables such as transformer rating and the response (probability of cluster membership). This was addressed by considering non-linear functions and categorisation, the latter of which involves finding statistically and practically meaningful groups for the variables in question. Extensive testing was performed to create a set of categories that would preserve, and indeed, enhance the utility of the information in those variables with regards to predicting cluster. The final set of categories includes the following:

- Transformer rating: classified as <=200, 200- <=500, >500 (indicates rural, suburban, urban)
- Number of LV feeders: classified as <=2, 3-5, >5 (indicates to rural, suburban, urban)
- Percentage I&C: classified as <0.4, 0.4-<=0.8, >0.8 (indicates domestic dominated, mixed, industrial and commercial dominated)

A series of candidate models were considered; starting with a model that includes a single variable and increasing in complexity to a ‘full’ model that included all combination of variables. Models containing each of the possible combinations of variables were considered and compared in terms of their effect on the ability to improve the ability to predict cluster membership. This effectiveness of each model was compared using comparison of deviance techniques. The final model contains the optimum selection of variables in terms of predicting cluster membership each of which is assigned a weight. These weights combine to produce the output from the model; the set of probabilities, each of which indicates the likelihood that a substation should be a member of a particular cluster.

Update:
Since the publication of the LV Network Templates Report [27], the classification rules have been updated on a season-by-season basis to match the clustering by season. This allows a substation to be allocated to a specific cluster for each season and therefore a more precisely defined load patterns are available for selection.

STEP 2 ANALYSIS AND MODELLING: SCALING

The classification rules allocate substations into the most appropriate cluster and thus provide an indicative view of load patterns. As a normalized load profile was obtained by dividing each measurement point by its daily peak, these load patterns only indicate the shape of substation consumption, but not its actual loading level. This is where the value of having a scaling factor comes into play; to scale -up these patterns reflecting the magnitude throughout the day.

The scaling method adopts kWh-to-peak-kW Conversion (C factor) and Diversity factors (D factor) to estimate LVS peak load from customer billing cycle kWh consumption data.

[27] Demonstration of LV Network Templates through statistical analysis (www.wpdinnovation.co.uk) (01.07.2013)

Update:
Since the publication of the LV Network Templates Report [28], the scaling methodology has continued to be refined. As a full year's data became available, it was possible to create season specific scaling models. A major extension of having cluster-specific scaling models was developed (for each season) in addition to incorporating data on the consumption of half-hourly metered customers in the scaling model. The underlying statistical models were also enhanced, using constrained regression, to ensure that the coefficients associated with the different predictor variables were always positive. In addition to ensuring that the resulting predicted power loads were always positive, this also aids the interpretation of the contribution of the individual factors to the scaling.

STEP 2 ANALYSIS AND MODELLING: QUALITY ASSURANCE (UPDATE)
The following describes the methodology used to assess the errors between estimated and metered load profiles (refer to figure 29). Two main components of this method are to a) analyse peaks and templates individually rather than considering them to be together; and b) instead of comparing estimated and metered load profiles, the method depicts the difference between them and enables the threshold to be quantified in a more objective way.

For every substation, its metered loads can be broken down into two parts, the daily peak and normalized load. Likewise, the estimated load profiles comprises of the estimated peak (based on scaling) and estimated pattern (based on the allocation to a particular template). The difference between real and estimated peaks is defined as peak error while the difference between real load profile and template is the shape error. The template is scaled up by real peak so that the error will be fully inherited from the underlying shape.

To further assess and quantify the errors, the method a) quantifies the errors in absolute and percentage terms and with respect to the transformer rating of each substation; and b) determines the appropriate error term to identify outliers - percentage error profiles.

It is inappropriate to assess the errors solely in terms of absolute value (kW) because error tolerances are different for different substations. For example, the absolute values of errors in substations with high ratings are generally larger reflecting the fact that loads tend to be larger. However the impact of, for example, a 20kW error in terms of potential overloading will be less significant for a 1000kVA transformer than it would for a 20kVA transformer. Therefore it is more appropriate to assess the error in relation to the transformer rating of each substation.

[28] Demonstration of LV Network Templates through statistical analysis (www.wpdinnovation.co.uk) (01.07.2013)

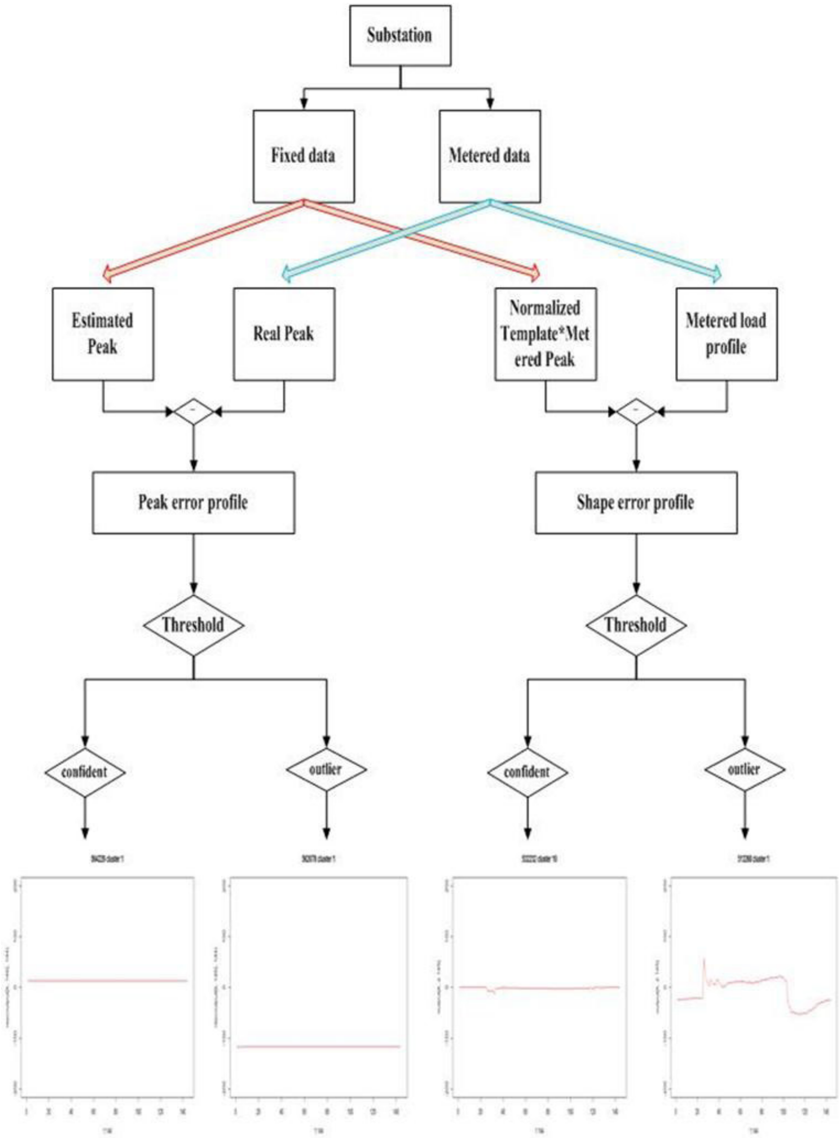


Figure 29, Quality Assurance Process Flow

Figures 30 and 31, illustrate in the case of cluster 1 how the volume of outliers changes as the threshold increases from 0% to 100% of the transformer ratings (Figure 31), and how the volume changes as the threshold increases by absolute error from 0 to 100 kW (Figure 30). The x-axis is the maximum error tolerance, which is a percentage of substation normal rating on the right and absolute values on the left. The y-axis shows the number of outliers, whose error index exceeds the maximum error tolerance. In these figures, the red line reflects the error in representing the shape of the load curve in comparison to the selected template, while the black line shows the error in calculating the peak. It can be seen on the left figures that the number of outliers deceases quite steady as the threshold increases, which makes it difficult to set a definite threshold for outliers. In addition, the volume of outliers will largely depend on substation size. Clusters containing large substations, such as cluster 1 and 6, will have more outliers in terms of absolute errors. In contrast, Figure 30 shows curves with a definite point of inflexion, such that if we take threshold in terms of transformer rating of each substation, all clusters will have a sharp decrease in outliers at approximately 20% of its transformer rating. This indicates that most of the substations in the trial area can be predicted by LV templates with an error lower than 20% of its transformer rating. By adopting this approach of normalizing the absolute error value by the transformer rating, it is more feasible to set a unique threshold that is consistent for all substations and clusters.

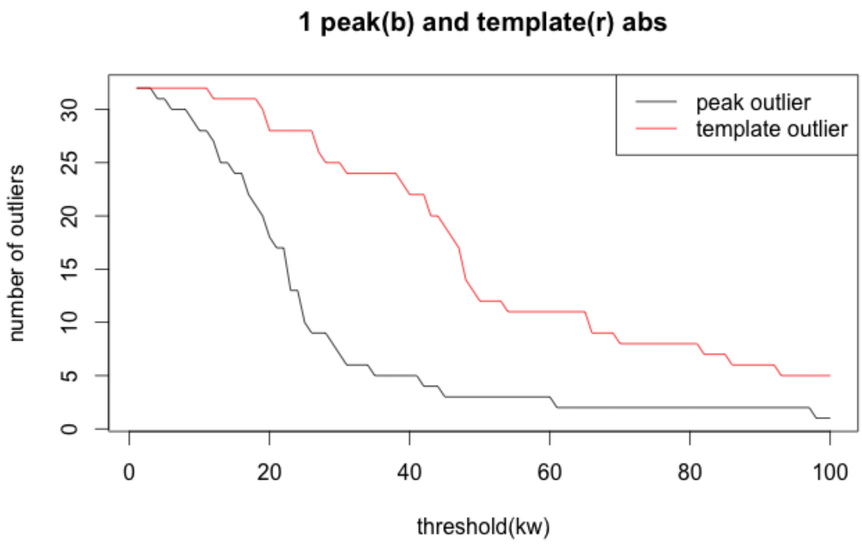


Figure 30. Volume of peak (black) and template (red) outliers at different thresholds in terms of absolute value

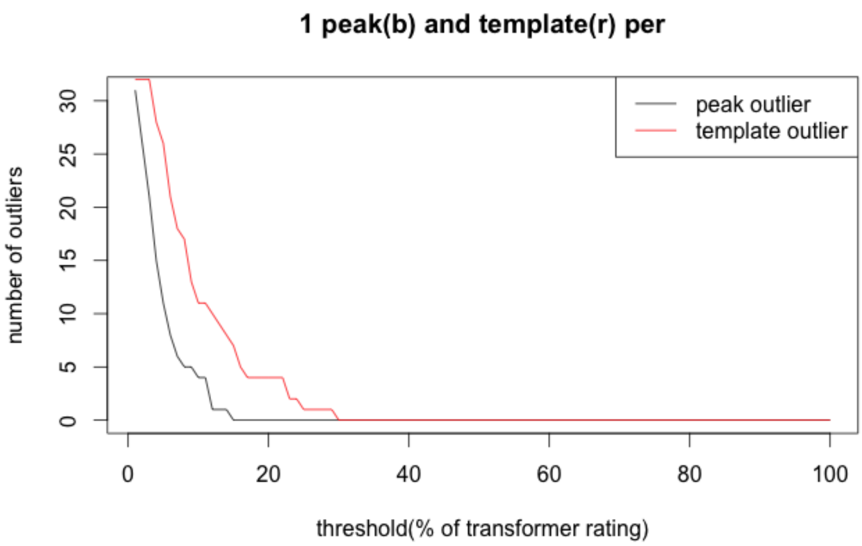


Figure 31. Volume of peak (black) and template (red) outliers at different thresholds in terms of percentage of transformer rating

STEP 3 TEMPLATES AND TOOLS: DNO NETWORK CLASSIFICATION TOOL

To develop LV Network Templates, substations need to be assigned to clusters when monitored data is not available. The previously mentioned methodology of classification was developed with the statistical package R and direct links to data held on a server. Behind this statistical package over the course of the Project, over 400,000 lines of code were written in order to be able to cluster, classify and scale an unmonitored substation effectively. In order to help the other DNOs, in potentially being able to immediately embed the LV Network Templates into their business as usual planning activities, a common classification tool was developed. Whilst this work was not in scope of the Project, it was deemed as being both relevant and timely to do so. And would minimise the additional work, cost and time that other DNOs would need to spend in order replicate the steps needed in order to embed it into their business.

As a result of this rationale, a classification tool was developed using MS Excel in which a large number of the calculations required, are pre-processed, and embedded in a series of worksheets. On top of this is an input sheet where users are able to enter commonly available substation and customer characteristics, such as:

- Number of customer in each Elexon class
- Estimated annual consumption for each Elexon class
- Transformer type
- Transformer rating
- Percentage of industrial and commercial customer
- Percentage half hourly metered load
- Total length of HV feeder

- Number of LV feeders
- Percentage overhead lines

As an output of the classification tool, demand profiles will be plotted together with the probabilities that the substation is in each of the ten clusters, and voltage profiles at feeder ends. Additionally the resulting demand and voltage profiles can either be scaled or un-scaled for all days, weekdays, weekends and seasons. Figure 32 to 34 illustrates examples of the classification tool with results for a substation within the Project area.

A prototype first version of the classification tool was shared with other DNOs at the May LV Network Template 2013 Dissemination Event held at the University of Bath. The tool has provided other DNOs with the ability to test the classification tool, identifying what fixed data is readily accessible for their planners. The importance of this and the LV Network Templates applicability to the wider GB network is two-fold:

- DNO network planners are able to provide feedback, and to understand the accuracy impact of not including a data input into the classification tool when allocating a substation to a cluster without monitored data (e.g. When only including customer numbers (including EACS) with no substation characteristics the accuracy levels drop to below 60%)
- Provides DNOs with the ability to tailor the classification tool to include data inputs that DNO specific planners seek to have incorporated

Update: Since the publication of the LV Network Templates Report [29], the classification tool has been updated to reflect the additional analyses described in the previous sections. It now has the option to produce demand curves for different seasons, using the season-specific clustering and scaling results.

[29] "Demonstration of LV Network templates through statistical analysis" (01.07.2013) www.wpdinnovation.co.uk

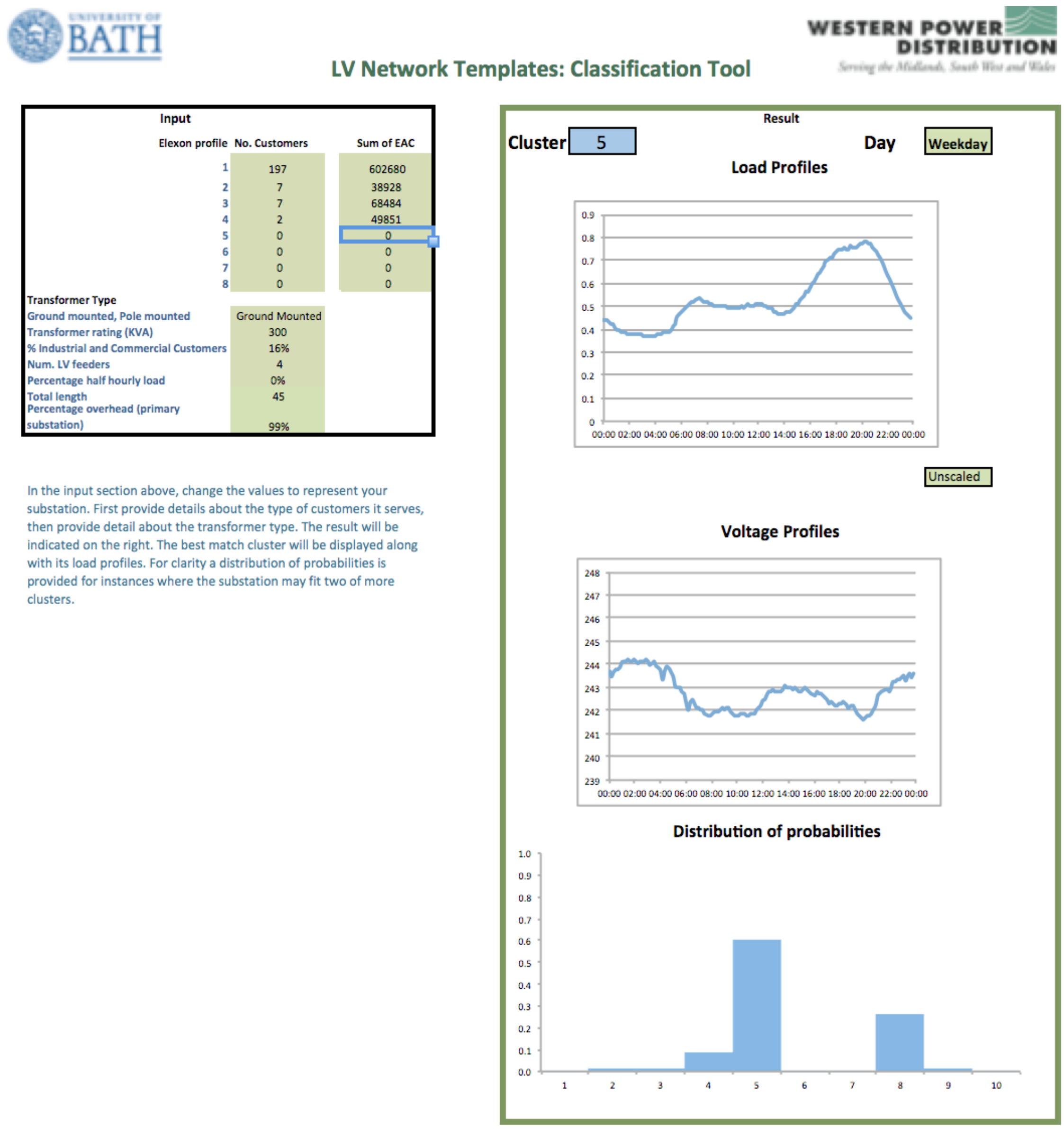


Figure 32: The LV Network Templates Classification Tool (Template 5)

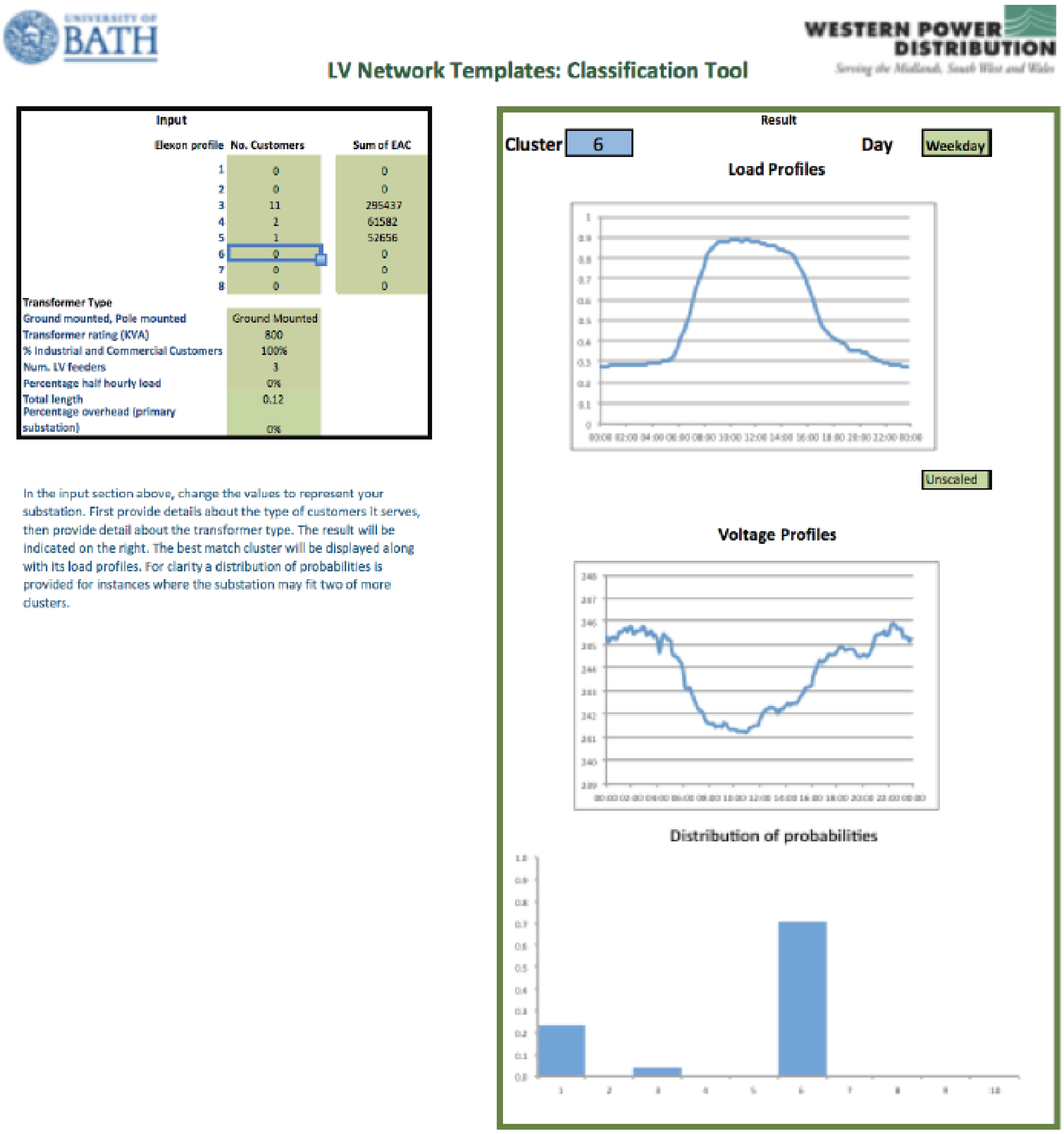


Figure 33: The LV Network Templates Classification Tool (Template 6)

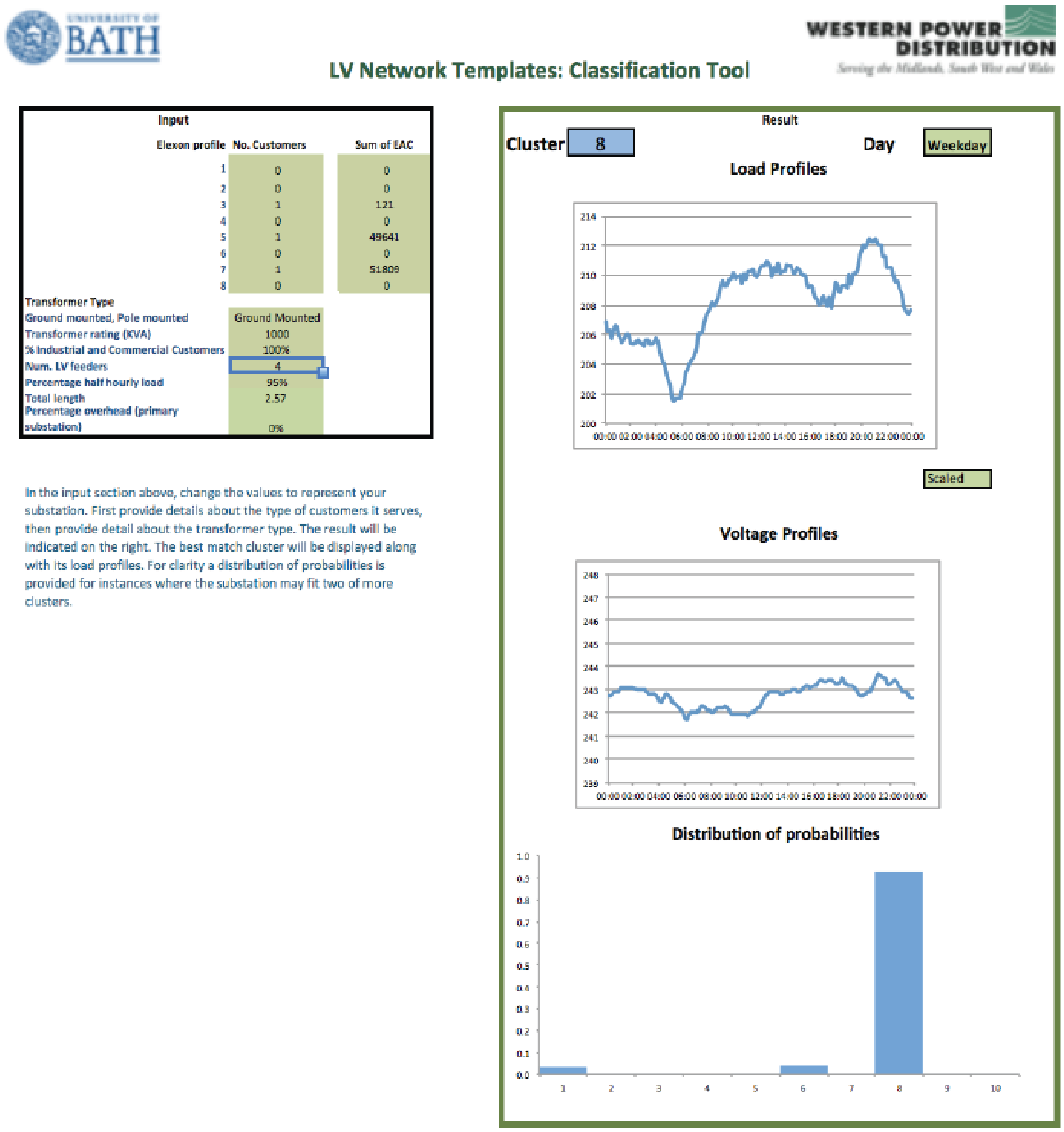


Figure 34: The LV Network Templates Classification Tool (Template 8)

STEP 4 LV TEMPLATES: LV TEMPLATES

Please refer to the outputs section of this report for the final LV templates.

STEP 5 ADDITIONAL QUALITY ASSURANCE: DNO DATA VALIDATION

As part of the development of the templates and their overall readiness; an additional validation step was taken to further test the templates credibility, suitability and applicability for wider DNO adoption. Whilst this additional DNO validation analysis was not in-scope of the original Project objectives, due to the south Wales trial area having a network topology and topography that already makes the outputs applicable to 50% of the GB network. It was none-the-less, when suggested at the May 2013 learning and dissemination event, regarded by all DNOs and Ofgem as a valuable and timely exercise to carry out.

In so doing, as in the development of the LV network templates, there are two distinct types of data that are required for this analysis; fixed and variable. DNOs were asked to provide both fixed and variable data for 100 substations during the May learning and dissemination event, to which all DNOs agreed to share such data, as part of further DNO validation activities. This activity has been on-going since May 2013.

Fixed Data

The fixed data required for this validation step is a subset of that collected for the development of the LV templates. A large component of the analyses described in the previous steps, was identifying which variables were actually useful in predicting cluster membership from those available. The resulting final variables, that were deemed to providing the biggest impact and thought to be readily available for all DNOs were requested. This information request was supported by user guides as to where to find specific pieces of fixed data and a template for each of the DNOs to complete (Figure 35).

Variable data

As in the main LV templates analysis, estimated load profiles can be created using classification and scaling based on the fixed data. These can then be compared to actual measurements. DNOs were also asked to provide measurements of RPD from the substations detailed in the fixed data. No time period was specified beyond asking for more than one week of data. The analyses of the other DNO data followed four stages as in step 2 of LV Template methodology:

1. **Sense-checking** - Checking the quality of the data received and it's appropriateness for analysis. Firstly, this involved ensuring that the variable data matched the fixed data. Then the fixed data was checked for missing variables followed by an assessment of how these would affect the accuracy of the classification and the scaling or whether it would leave either impossible to perform.
2. **Classification** - Applying the appropriate classification models to the fixed data. The choice of model(s) is determined by the season(s) in which the variable data is recorded. The predictive ability of the classification models is compared with that seen in the LV network templates area (South Wales). This involves examining the probabilities of allocation to the chosen cluster, with higher probabilities indicating higher certainty of cluster membership.
3. **Scaling** - The results of classification are a normalised load profile for each day. This then needs to be translated back to the original scale (kW). This is achieved by applying the specific scaling model depending on the cluster and season to predict the daily maximum which is then used as a multiplying factor on the normalised load patterns.
4. **Assessment** - Analysis of the comparison of estimated versus actual loads following the procedures described in the quality assurance.

The findings of this analysis is provided in the outputs section of this report.

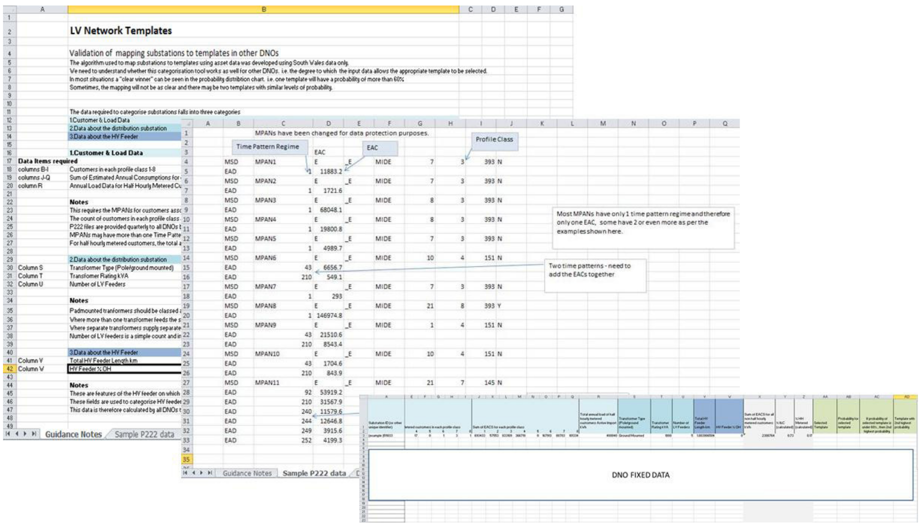


Figure 35, WPDs Fixed Data Capture Template for DNO Validation Activities

METHODOLOGY OF STRESS ANALYSIS

The low carbon stress analyses draw heavily from Wales Strategic Energy Performance Investment Programme - Arbed initiative, aiming for increasing 'domestic energy efficiency, community-scale renewables and alleviating fuel poverty'. The initiative is set out in "A Low Carbon Revolution -The Welsh Assembly Government Energy Policy Statement part of Welsh government", as part of the Welsh government's ambitious energy plan - 'making low carbon energy a reality' [30].

The total number of properties registered with Arbed at the time of analysis was 4036. At these properties 912 PVs, 616 SHWs (Solar Water Heaters), 2198 EWI (External Wall Insulation), 539 fuel switching, 213 boiler replacements and 62 ASHPs (Air Source Heat Pumps) were installed. These installations were associated with 115 substations of which circa. 100 were monitored as part of this study.

As part of the methodology applied in developing LV Network Templates, cluster analysis identified ten distinct groups or clusters of substations. Statistically, the demand profiles of substations within a particular cluster are more similar than those in the other clusters. Furthermore Voltage profiles for each cluster were obtained by linking measurements at remote feeder ends associated with substations in each of the different clusters and calculating average profiles for each cluster. In order to further illustrate the impact of system loading level, voltage profiles are calculated by phase and both load and voltage profiles for each cluster have been assessed for weekdays, Saturday and Sundays. Given this information a comparison can be made of the profiles of power and voltage between two groups of substations within the same cluster: (i) those with registered low carbon initiatives that might be expected to have an effect on the network and (ii) those without. An example of the creation of these two groups can be seen in Figure 36. This type of comparison analysis was

[30] A Low Carbon Revolution –The Welsh Assembly Government Energy Policy Statement, March 2010

undertaken for each of the 10 developed templates for High Summer, the results of which can be seen in the outputs section of this report.

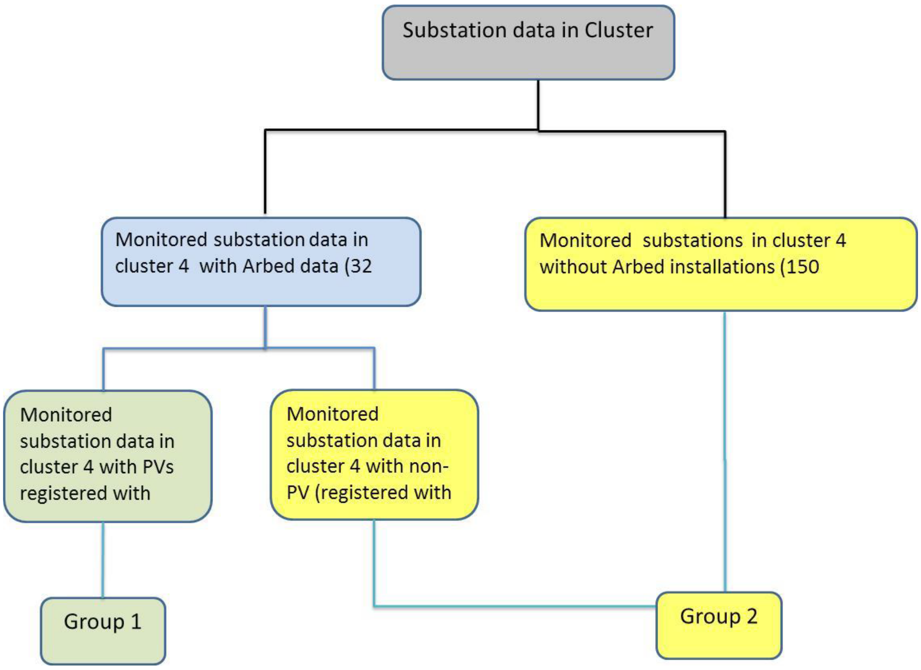


Figure 36, Schematic of the creation of two groups for analysis of the effects low carbon installations on demand and voltage profiles. Groups 1 and 2 contain substations in cluster 4 with and without Arbed registered PV installations respectively.

METHODOLOGY OF PV FIT ANALYSIS

A key strand of this Project was to understand the stresses on the network and whether or not a single "proxy" PV meter could be adopted to effectively obtain a real time view of the output of multiple small-scale local PV installations. Fully monitoring the outputs of every PV installation would provide the most accurate representation, however this method is very expensive and would need to overcome the difficult task of obtaining customer consent (Unfeasible at a wider GB network scale).

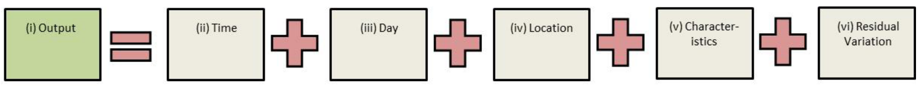
The aims of developing a statistical model for the PV outputs are to assess whether measurements from single meter can be used to represent the outputs from other meters within a small area (which, in terms of the resolution of the available data are postcode districts). The hypothesis follows the logic; PV generation is in part dependent on sun elevation and cloud cover which might be expected to be the same over a small enough area. Within such areas, differences in output over time will still be observed due to differences in the capacity and orientation of individual installations. The aim of the statistical model developed is to estimate the effects of these differences on the outputs. Given these estimates, the industry will be able to assess how accurately the output from a single PV installation can be used to predict those from installations in the surrounding area.

As such the objectives of the statistical modelling are as follow:

- To examine the contribution of variations over space (both between individual installations within postcode districts and between postcode districts) and time (within and between days)
- To obtain underlying profiles of outputs
- To obtain estimates of the effects of the capacity and orientation for use in predicting outputs from other installations and enable subsequent assessments of bias

The developed statistical model acknowledges the contribution of these different components to the overall variation in PV output within the study region. Due to the constraints of non-negativity, skewness and the appropriateness of a multiplicative structure for combining the effects of different factors when predicting outputs, the log of the output is modelled as a function of time, space and characteristic factors.

Figure 37, below shows the components of the model that define the output as functions of time, day, and location. The combination of which will act as a proxy for sun elevation and cloud cover at any particular point in time and space, together with the characteristics of a particular PV installation.



(i) **Output:** log (kWh) per 30 minute interval measured at an individual installation
(ii) **Time:** Time interval within the day (from 5am to 10pm)
(iii) **Day:** Effect of time within day is permitted to vary across days
(iv) **Location:** The effects of time and day may vary between postcode districts
(v) **Characteristics:** Adjustment for the maximum capacity and orientation of the individual installation
(vi) **Residual variation:** The difference between the measured data for a 30minute interval and what can be explained using the model

Figure 37, Proxy FiT Formula

A comparison method was applied to highlight the differences between the predicted outputs for each PV with its measured values. From this it would be possible to effectively estimate the bias associated with using this approach.

Measuring Bias in predicted outputs

There are a number of ways of representing the bias that may occur using a predictive model in this way. The choice of methods used to assess the bias will be determined by the intended use of the predictions. As part of LV Network Templates, two methods for estimating bias are explored:

1. At individual time intervals (Method A): Assessing errors at individual time intervals, single or aggregated over multiple areas, might be important for real-time operations or for periods of high stress on the network
2. Cumulative over longer periods of time, e.g. days (Method B): Alternatively, for billing purposes interest may lie in the total difference over a day or longer period of time.

The outcomes of this FiT methodology will be discussed later on in this report, for further information please refer to the FiT Report.

LEARNING AND DISSEMINATION METHODOLOGY APPLIED (INTERNAL AND EXTERNAL STAKEHOLDERS)

A fundamental component that needs to exist within any low carbon network funded Project is a robust method in which the knowledge that has been generated, is effectively captured and shared within the DNO and/or the wider industry. This collaborative way of working was central to any activities being delivered for LV Network Templates, be it by WPD, or any of the Project Partners.

As learning and dissemination is an on-going activity of work, WPD selected the University of Bath to act as knowledge brokers for LV Network Templates. In this capacity the university was responsible for managing the received information in its various forms, storing, analysing, repackaging and disseminating the learning to the appropriate audiences in a convenient format. In this role a methodical and engaging approach was required in order to solve the challenge that arises when having an inherently complex Project with multiple stakeholders involved in its delivery (e.g. LV Network Templates). As a result of the nature of this Project, the University of Bath established effective mechanisms that would facilitate knowledge capture, rather than seeking to record everything themselves. Prior to setting up such mechanisms, the University of Bath explored the multiple forms knowledge can take, in order to understand how best to capture and share knowledge.

MULTIPLE FORMS OF KNOWLEDGE: A MOVE AWAY FROM TRADITIONAL APPROACHES

Knowledge is information stored in people's minds. It can vary dramatically in its level of formality and how structured and explicit it is. Knowledge can be formal and explicit – such as the steps listed in a manual telling somebody how to work a machine – or it can be informal and tacit, such as the accumulated experience of an expert which lets them make rapid intuitive judgments of a problem.

In engineering organizations like DNOs, the most important tool for capturing and sharing knowledge has usually been the formal report. The findings of a Project are summarized in a written document and this is shared with people who need to learn from it. This has many advantages - it allows an organization to ensure that the message presented is consistent and clear, for example. A written document also lasts indefinitely, which means it can be accessed and used by a person months or years after the Project is complete.

However, reports inevitably omit many pieces of information. Some of these ought to be omitted, because they are irrelevant or add no value. Others, though, could prove useful in the future. Reports generally do not, for example, fully explain the rationales for decisions. The criteria for choosing one course of action, one product or one supplier over another are usually not spelled out, even though a decision-maker will at some stage have had to weigh up multiple options and will have had some objective grounds for making their choice – and even though this information could well be useful to other decision-makers in the future. Because reports present firm conclusions, rather than the processes by which these were reached, potentially useful information is lost. Certainly, some of this less formal information is occasionally captured in meeting minutes, but they do not get all of it, or even most. Moreover, minutes are almost invariably for internal use only, and are rarely consulted once a short period has elapsed from a meeting. They do not usually inform future Projects within the same organization, never mind a wider community. They also fail to capture more informal and unconscious forms of knowledge.

Given these issues with formal reports, it was clear that additional mechanisms would be needed to capture potentially useful information in this Project. As a result of this initial analysis, the University of Bath carried out a survey of the methods and tools that are commonly used by Projects of a similar nature [31]. This survey assessed the strengths and weaknesses against the types of information generated, producing a tripartite classification of knowledge types as illustrated in figure 38 below.

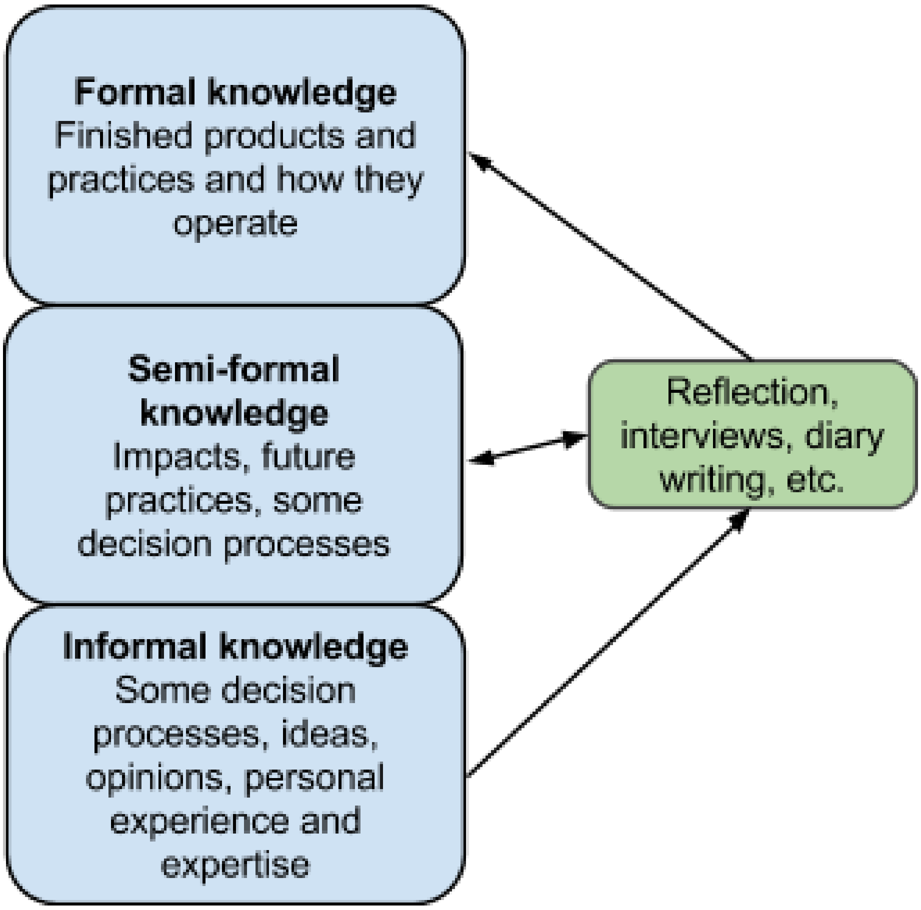


Figure 38, 1st Layer of capturing knowledge effectively

There is also another layer to this process of capturing knowledge in LCNF Projects. Within each of the three categories above, there will be knowledge that the Project planned to produce, but also useful knowledge that was not the goal of the Project, but which emerged along the way. Learning's of this kind can be valuable for future

[31] As LV Network Templates was awarded in the first year, no direct LNCF Project comparison could be carried out, resulting in surveys being carried out on methods and tools used by Projects of a similar nature.

Projects and practices, but are particularly unlikely to be captured and reported using traditional approaches such as technical reports because they are outside the Project's aims and output criteria. These two types of knowledge are known as planned learning and incidental learning, and this distinction is separate from the formal-to-informal hierarchy described above.

Finally, there is a third division that can be made from the survey undertaken - whether formal or informal, and whether planned or incidental. Specifically, new knowledge about engineering can be separated from new knowledge about how best to undertake research and development Projects – or, more casually, we can separate what was done from how it was done. Ofgem recognized this important distinction, noting that:

"We have divided the requirements on learning into two sections. One would require the DNO to report on learning relevant to replicating the method, the other on general learning relevant to undertaking network innovation Projects" [32].

In summary, the requirements needed to effectively capture and disseminate knowledge needed three key criteria to be met:

1. New information can range from the formal to the informal
2. New information can specifically be sought, or can arise incidentally as research takes place
3. New information can be about engineering, or about the management of research Projects

In each case, more than one method of capturing knowledge might be necessary to allow for these multiple sources of variation.

KNOWLEDGE CAPTURE METHODS

From the knowledge survey undertaken by the University of Bath, a variety of traditional and non-traditional knowledge capture methods were developed in order to meet the above three key criteria. Each of these developed methods supported the Project in capturing a range of information and knowledge generated from both internal and external stakeholders (Refer to figure 39).

[32] https://www.ofgem.gov.uk/ofgem-publications/75313/consultationlcnfclosedownreports180613.pdf

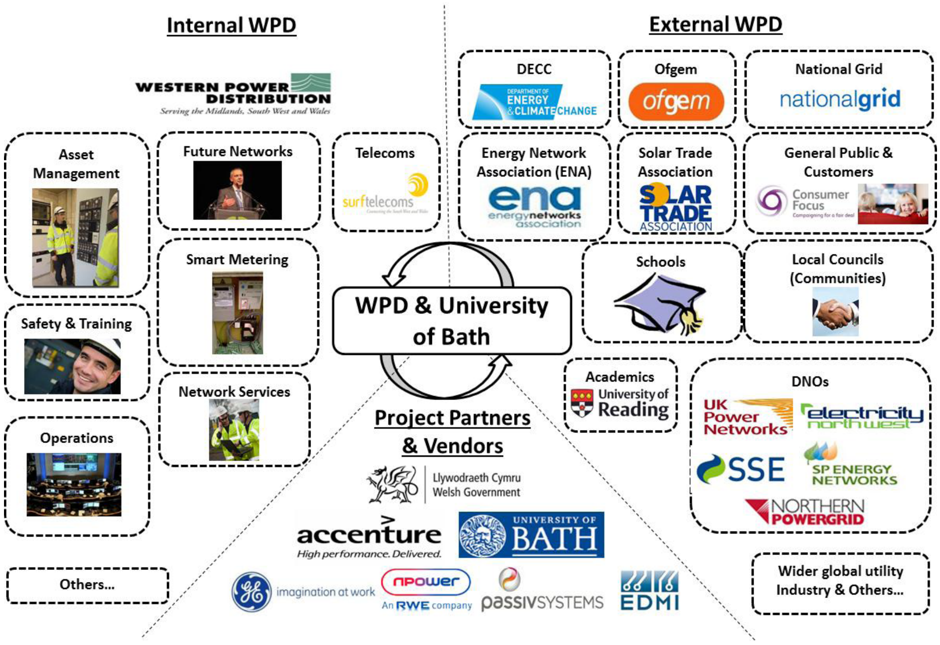


Figure 39, Learning and Dissemination and Stakeholders

Furthermore as the diagram below indicates (Figure 40), the tools used during this Project cover a broad range of learning, and in some instances provide an overlap between the various learning types. These tools were chosen to provide a range of methods which could be used by each of the Project members. Each technique provides a simple and unobtrusive method for documenting learning.

In the next section the 4 non-traditional knowledge capture techniques will be discussed in turn for further information around effective knowledge management please refer to Appendix A.

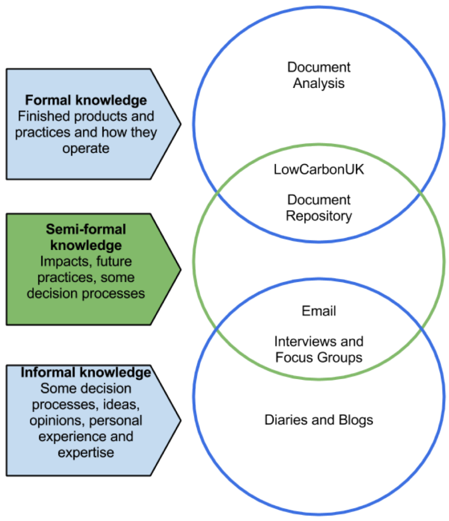


Figure 40, Tripartite classification Method for different knowledge types and the tools used to capture them

Knowledge capture methods: LowCarbonUK.com
The LowCarbonUK.com website (LCUK) was created by the University of Bath knowledge team as a key tool to facilitate their knowledge capture and sharing activities. It operates across the various WPD LCNF Projects for which the university has some knowledge management responsibility, with the LV Templates Project being one of the key Projects. This website has been a valuable tool for both capturing and disseminating information. And has proved particularly useful for addressing the problem of multiple people working across various sites because it allows a central point in which information can be gathered and retrieved.

LCUK has an external and an internal face, depending on whether the user is a member of one of the Project teams or not. Most visitors see documents and pages that were suitable for general dissemination; team members can also see internal documents, wiki pages, and blogs which sit behind password protection. These areas can be more informal, with the focus on providing information and sharing knowledge, rather than providing a public-facing document. By having an area like this, Project members are encouraged to document the stages of development and the options that they consider, rather than provide a final document which is limited in the content that it covers for telling the story of the whole Project (refer to Figure 41).

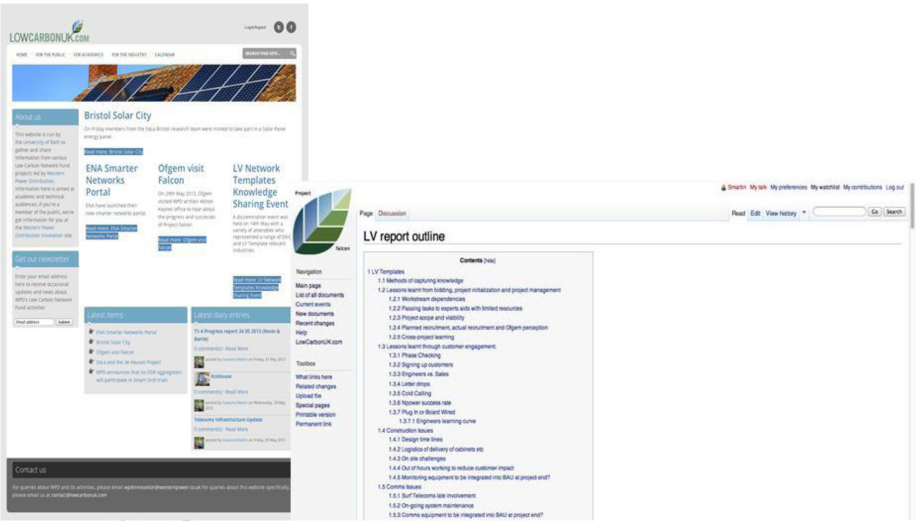


Figure 41, Snapshots of the LV Network Templates Website

Knowledge capture methods: Interviews and focus groups
As part of the Projects Knowledge Management Philosophy, human memory can play an important filtering and sorting function, helping people to see which aspects of an event or decision were important. This is particularly useful when people can reflect on their actions or decisions in light of later developments.

Asking people to think back to important events and decisions, and to describe these under questioning, therefore encourages the subjectively important aspects of events to gain more salience. As such throughout the Project lifecycle, the University of Bath carried out focus groups and interviews as a component of the overall knowledge capture methodology.

One-on-one interviews allowed for detailed exploration of decisions and experiences. In particular, the University of Bath applied the police procedure of ‘cognitive interviews’ in which people are encouraged to place themselves back into the mindset they were in at the time of events, assisting them to recall certain events. It was noted by more than one Project member that taking part in the interviews helped them in reflecting upon their own experiences.

Focus groups do not necessarily provide the same depth as interviews, but can be valuable for encouraging people to remember things they would not otherwise remember. They also allow individuals to spark off one another’s comments (“Yes, I found that but had a slightly different experience...”). Additionally this method can also be good for indicating the extent to which various people in the same situation had similar or different experiences.

In the LV Templates Project, the interviews and focus groups proved to be one of the best methods for capturing knowledge about the Project, its decisions and learning outcomes. For examples in which interview and focus group helped to capture knowledge, please refer to the Knowledge Management report in Appendix A.

Knowledge capture methods: Document analysis

In a Project like this, many documents, emails and notes were written. The University of Bath analyzed these to identify potentially interesting or useful patterns which could inform future Project managers around a specific activity of work. For example, looking at how the issues being raised in reports might change over the lifespan of a Project could help future Project managers anticipate the shifts in focus that they will have to address. Document analysis is an excellent example of extracting additional value for money from knowledge management practices, as it can provide new levels and types of information from documents that are already planned to be written.

Various methods are available for identifying recurring themes in text, but the method the University of Bath found to be most useful was to produce word clouds from Project documents. This approach is easily understood and accessible to anybody. It makes it possible to quickly and easily to spot the key issues being discussed in documents, and how this changes over time.

As an example, a word cloud summarizing participants’ feedback comments from the LV Templates knowledge sharing event is shown in figure 42 below. This particular cloud was used to provide an easy visual overview of the feedback to conference attendees and other interested parties after the event. Using word clouds allows the audience to view a simple and aesthetically pleasing illustration of the key points within a document providing an indication of the kind of content that is discussed in the document.

The audience for this tool varies; in the case of the word cloud shown below, the main audience was the conference attendees. In contrast, the analysis undertaken of the SDRC reports, which is presented in Appendix A, illustrates how the focus of the Project changed over its life-span – information which should be useful for those planning or managing future Projects.

Figure 42, Word cloud showing how attendees at a WPD knowledge-sharing workshop described the event

It's important to note that in addition to the previously discussed non-traditional knowledge capture techniques, more commonly used methods of emails, photos (e.g. monitor installs) and technical reports were applied at various key milestones of the Project.

KNOWLEDGE DISSEMINATION METHODS

For the reasons described earlier, WPD were keen that the knowledge capture and dissemination efforts for LV Network Templates went further than placing formal reports on a website. In particular, WPD wanted to ensure that the messages and information were conveyed in the most appropriate way to maintain clarity and convenience for the audience(s) in question.

Accordingly, a range of methods and metrics were used to effectively disseminate the knowledge gained as a result of this Project to both internal, Project and external stakeholders (Figure 43). As an outcome of the methods deployed, over 250 dissemination activities have taken place over the Project's lifespan.

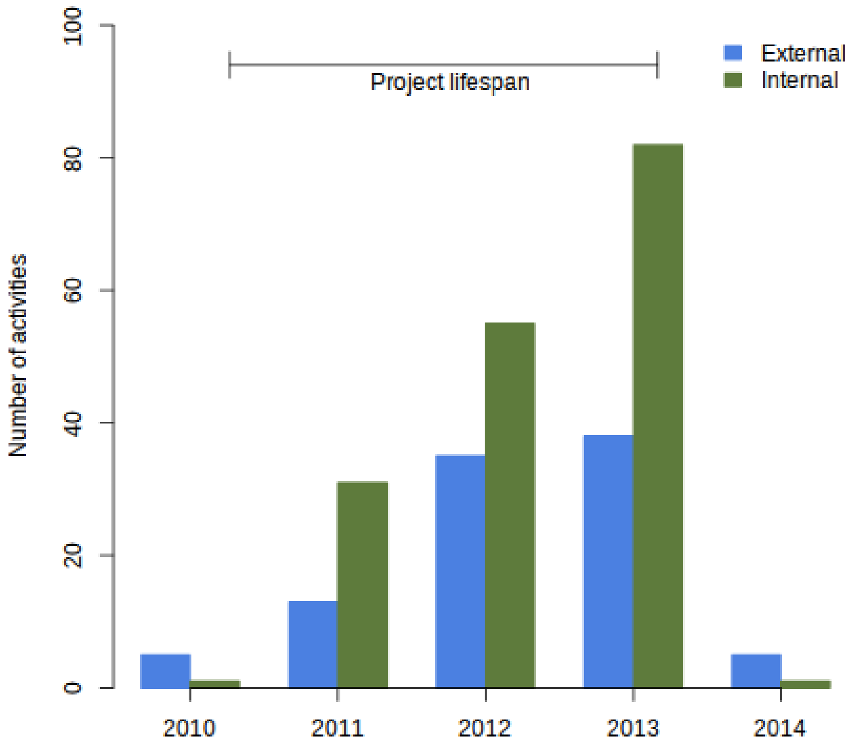


Figure 43, Knowledge Dissemination Activities

From this chart, it's important to note that, although this Project ends in October 2013, dissemination of its findings will be ongoing; with Project learning's being discussed at key industry events and stakeholder meetings into 2014 and beyond. A high-level summary of the 9 key methods and tools used is provided below.

Websites (external audiences):

Two key websites were developed or refined, the existing westernpowerinnovation.co.uk website, which is used by WPD to disseminate their Project updates to the general public, and a specifically developed website LowCarbonUK.com (LCUK). The LCUK website provides details to the industry and to academics about three of WPD's LCNFs Projects (Falcon, SoLa Bristol and LV Templates).

Press Releases (external audiences):

Throughout the Project, press releases have been used to provide updates to the public and interested parties. WPD's internal magazine Powerlines has been used to ensure WPD employees are kept informed about the Project whilst public press releases have been used to disseminate learning's more widely.

Industry Conferences and Seminars (internal and external audiences):

WPDs Future Network Team and Project Partners have each disseminated the Project findings at a variety of industry conferences and seminars. These events have proved to be ideal locations for discussing the LCNF Projects and sharing ideas and results with other interested parties.

Industry Reports (external audiences):

The key findings from this Project have been written up into industry relevant technical reports. These have been disseminated at a number of events and can also be found on the Project websites [33].

Gallomanor (external audiences):

Gallomanor are public engagement companies that are working with the University of Bath to provide education materials to help schools with explaining energy and the LCNF Projects. Questions about the LV Network Templates Project, and wider topics such as future of energy, including low-carbon generation, are being included in debate packs being distributed to schools in 2014.

Project Meetings (internal audiences):

Project meetings were used to keep all the team members up to date with the Project progress. The meetings were an opportunity to learn about the different parts of the Project and to share ideas about how it will progress.

Quarterly Internal Dissemination Meetings (internal audiences):

Meetings provided an update to the wider WPD employees about what was happening in the LV Network Templates Project. For example, this included contact with members of the Smart Metering, Communications, Operations, and Asset Management teams. Providing regular updates allowed WPD staff to contribute to the Project with their own job-specific expertise.

Workshops (external audiences)

During the later stages of the Project, workshops with National Grid, ENA, DECC, OFGEM, Welsh Assembly and Solar Network Association have been organized. These one-to-one meetings provide opportunities to discuss the Project findings with an external audience and to hear their thoughts and feedback.

Direct DNO Engagement (external audiences)

During the final stages of the Project, WPD and Accenture have been engaging with all of the DNOs to further validate the suitability for LV templates to be adopted across their networks (including the Classification Tool). From this validation exercise, WPD has also taken the opportunity of sharing best practices on data management. This activity of work began in May 2013 and is still currently ongoing with the DNOs and other interested parties.

For a more detailed view of the internal and external events that were held, please refer to table 7 below which holds a more detailed summary of internal/external events. For further information around knowledge management, please refer to Appendix A.

[33] http://lowcarbonuk.com/lcuk/

Key to the activities table

Presentation
Internal Meeting
Press Release
LCNF Web Articles
Key internal Interviews
Publications
High visitor counts to lowcarbonuk
Customer Communication
Industry Report
SDRC and 6 Monthly Reports
Newsletter
Workshops

	External Events		Internal Events
2010		22 January 2010	Exploring Smarter Networks
	LCNF details - Wales Online	10 December 2010	
	LCNF details - Enterprise Europe Wales	10 December 2010	
	General Project- University of Bath Website	10 December 2010	
	Press Release - The Free Library	10 December 2010	
	Project Direction Document	December 2010	
2011	Discussions with US National Grid in Boston about LV Templates	28 January 2011	
	Ecobuild Event at Excel Centre at invitation of BEAMA	1 March 2011	
	LCNF update - Utility Week	2 March 2011	
	Ofgem Amendments	April 2011	
		12 April 2011	Progress Meeting
		24 May 2011	LV Contact with relevant community leaders such as the police and local council
	Progress Report	17 June 2011	
		Summer 2011	LCN newsletter - internal WPD
	ENA 2011 Peter Aston	21 July 2011	
	PPL Press Release	15 August 2011	
	News Wire today press release	6 October 2011	
		7 October 2011	Project Progress Call
		11 October 2011	NPower and FIT customers
		14 October 2011	Project Progress Call
		18 October 2011	WPD Project Meeting
		21 October 2011	Project Progress Call
		28 October 2011	Project Progress Call
		31 October 2011	WPD Project Meeting
		4 November 2011	Project Progress Call
	GE involvement in LV	6 November 2011	

2011		8 November 2011	Meeting: Sample Size Approach, Data Collation Format, Phase 1 Pilot Template Plan and Approach
		9 November 2011	NPower and FIT customers Teleconference
		11 November 2011	Project Progress Call
		17 November 2011	Welsh Assembly Meeting
		18 November 2011	Project Progress Call
		23 November 2011	Meeting with UoB PV Locations and Monitoring
		25 November 2011	Project Progress Call
		28 November 2011	Welsh Assembly Meeting
		28 November 2011	Meeting with NPower
		29 November 2011	Data Transfer between WPD, GE systems and UoB
		30 November 2011	Wales Substation Site Visit
	LCNF funding - Wired	30 November 2011	
	Smart Grid Brazil Workshop with Brazilian Utility Delegates. Hosted by Accenture	1 December 2011	
		1 December 2011	Welsh Assembly Meeting
		1 December 2011	Brazillian Delegates Meeting
		2 December 2011	Project Progress Call
		5 December 2011	Welsh Assembly Meeting
	Innovative Smart Grid Technologies	5 December 2011	
		9 December 2011	.Project Progress Call
		13 December 2011	Engineer Lessons Learnt Meeting
	Ofgem Progress Report	16 December 2011	
		16 December 2011	Project Progress Call
		20 December 2011	Learning and Dissemination Meeting
		21 December 2011 - 13 June 2012	Arbed - Data and discussions around LV Network Templates
2012		January 2012	Weekly meeting to discuss Smart Metering
		January 2012	Weekly visit to Wales
		3 January 2012	PV installation process and methodology
		6 January 2012	Voltage Monitor Lessons Learnt Update
		6 January 2012	NPower Lessons Learnt Update
		10 January 2012	Annual review meeting - UoB, Accenture and WPD
		17 January 2012	Project Meeting
	Letter to customers	20 January 2012	
		February 2012	Weekly meeting to discuss Smart Metering
		February 2012	Weekly visit to Wales
		1 February 2012	Progress Meeting
		2 February 2012	Project Update

2012		6 February 2012	STIP Training
		16 February 2012	WPD ICT LCNF Teleconference
		20 February 2012	WPD ICT LCNF Teleconference
		28 February 2012	Meeting with the Energy Trust
		March 2012	Weekly meeting to discuss Smart Metering
		March 2012	Weekly visit to Wales
		6 March 2012	WPD meeting
		12 March 2012	Data Export Meeting
		12 March 2012	LCN Catch up Meeting
		13 March 2012	SMOS Discussion
		15 March 2012	NPower WPD FIT Meeting
	Bath Uni Press Release Ofgem	15 March 2012	
	Introducing the LV Templates Project	19 March 2012	
		19 - 21 March 2012	GE Pulsenet training
	Using this site	20 March 2012	
	Cardiff Focus Group draft protocols	20 March 2012	
	Website wishlist	21 March 2012	
	Bath Research Leaflet Update	Spring 2012	
		27 March 2012	Installer Focus Groups
		April 2012	Weekly meeting to discuss Smart Metering
		April 2012	Weekly visit to Wales
		19 April 2012	Project Update
	Electricity Industry Glossary	25 April 2012	
		May 2012	Weekly meeting to discuss Smart Metering
		May 2012	Weekly visit to Wales
	LCNF Projects news and media coverage	3 May 2012	
	LV Team contact list	4 May 2012	
	Involvement in LCNF - Current Grid	7 May 2012	
		15 May 2012	LCNF Meeting
	Cross-LCNF Workshop 17 July 2012	16 May 2012	
		17 May 2012	WPD Clustering Meeting
		22 May 2012	Project Update
		24 May 2012	Interview with outgoing Project manager
	78 lowcarbonuk visits	31 May 2012	
		June 2012	Weekly meeting to discuss Smart Metering
		June 2012	Weekly visit to Wales
	Accessing the filestore for LV	6 June 2012	
	Ofgem Progress Report	15 June 2012	
		July 2012	Weekly meeting to discuss Smart Metering
		July 2012	Weekly visit to Wales
		3 July 2012	Meeting with WPD Staff
		10 July 2012	Project Update

2012	35 lowcarbonuk visits	12 July 2012	
	45 lowcarbonuk visits	13 July 2012	
	30 lowcarbonuk visits	16 July 2012	
		16 July 2012	LCNF Event Meeting
	LCNF UoB Event	17 July 2012	
		30 July 2012	Project Meeting
		31 July 2012	Discussion about nomenclature and definitions
		August 2012	Weekly meeting to discuss Smart Metering
		August 2012	Weekly visit to Wales
	Powerlines - profile on Anne Williams and LV Project	1 August 2012	
	Summary of the LCNF Day, held on 17 July 2012	21 August 2012	
		September 2012	Weekly meeting to discuss Smart Metering
		September 2012	Weekly visit to Wales
	47th International Universities Power Engineering Conference at Brunel University	4 September 2012	
	Smart Grid Demonstrators Forum	4 September 2012	
	Furong Li et al Poster Presentation IET (IET's Power Systems and Equipment Technology Network)	19 September 2012	
	Ofgem Interim Progress Report	September 2012	
		October 2012	Weekly meeting to discuss Smart Metering
		October 2012	Weekly visit to Wales
		2 October 2012	Progress Meeting
	WPD Customer panel	17 October 2012	
	LCNF Conference Press Release	24 October 2012	
	ENA Event	25 October 2012	
		November 2012	Weekly meeting to discuss Smart Metering
		November 2012	Weekly visit to Wales
	Reading Event hosted by Southern Electric Power Distribution	5 November 2012	
	LV network templates. Low Voltage demand behaviour, forecasting and smart control Workshop, 7thNovember, Henley Business School.	7 November 2012	
		13 November 2012	Meeting to discuss templates
	LV Network Templates - Preliminary Data now available	15 November 2012	
	LV Network Templates - Interim Report now available	23 November 2012	
	LCNF Conference Press Release in Powerlines	1 November 2012	

2012		December 2012	Weekly meeting to discuss Smart Metering
		December 2012	Weekly visit to Wales
	Low Carbon UK in the Press	5 December 2012	
		11 December 2012	Project Update
	Ofgem Progress Report	17 December 2012	
2013		10 January 2013	Yearly Review Meeting
		29 January 2013	Meeting with GE - issues with antennas
		30 January 2013	Progress Meeting
		31 January 2013	GE Conference Call
	Clustering energy demands. Centre for the Mathematics of Human Behaviour, University of Reading	5 February 2013	
		6 February 2013	Templates Phone call
		7 February 2013	Smart metering meeting
		7 February 2013	Meeting to discuss antennas
		7 February 2013	Learning Meeting
		11 February 2013	Smart metering meeting
		12 February 2013	Knowledge Capture Meeting
		19 February 2013	Internal Knowledge Interview - WPD
		20 February 2013	Internal Knowledge Interview - Furong
		20 February 2013	PV Meeting with Gavin and Furong
		27 February 2013	Progress Meeting
	Clustering Power Usage Data - Presentation at UBC Statistics Department, Canada	March 2013	
	WPD Business Plan	1 March 2013	
		4 March 2013	Planning Meeting - LV DNO Event
		4 March 2013	Teleconference - Jenny
		12 March 2013	Teleconference with Gerritt Carbon Trust to discuss the LCNF process (approach came from the company)
		18 March 2013	Update on stress report
		19 March 2013	Ofgem Meeting
	Ofgem Customer Learning Report	19 March 2013	
		20 March 2013	Templates system hand over meeting
	123 lowcarbonuk visits	20 March 2013	
		8 April 2013	Progress Meeting
		22 April 2013	Stress report update
		24 April 2013	Progress Meeting
	GreenTech Business Network Event	25 April 2013	
	Available Downloads	29 April 2013	
	Stresses on the LV Network caused by Low Carbon Technologies Report	1 May 2013	

2013	Proxy PV FiT meters to reflect local area Generation Report	1 May 2013	
		7 May 2013	Internal knowledge interview - Gavin
		7 May 2013	Budget Meeting
		8 May 2013	Progress Meeting
	LV Templates final reports	8 May 2013	
	Press - Interview with Rob Samuels	9 May 2013	
	LV Dissemination Event	14 May 2013	
	GE Annual Conference Hosted a presentation on data analytics, LV Network Templates and the lessons learnt around Asset Management	15 May 2013	
	Building Research Establishment National Solar Centre, St Austell - Discussion of PV Findings	15 May 2013	
		16 May 2013	6 Month Review Meeting
	LV Network Templates Knowledge Sharing Event	16 May 2013	
		20 May 2013	DNO validation meetings
		24 May 2013	Update Meeting
		28 May 2013	DNO validation meetings
	WPD announces that six DSR Aggregators will participate in Smart Grid trials	31 May 2013	
	Shaddick et al publication: Quantification of Low Voltage Network Reinforcement Costs: A Statistical Approach	May 2013	
		3 June 2013	DNO validation meetings
	Accenture Leadership Dinner: Sharing of Project findings and lessons learnt	5 June 2013	
		7 June 2013	UK Power Networks Data Validation Analysis
		10 June 2013	DNO validation meetings
		11 June 2013	Dissemination Report Update
		12 June 2013	Scaling Factor Lessons Learnt
	Ofgem Progress Report	16 June 2013	
		17 June 2013	DNO validation meetings
		18 June 2013	General Update
		18 June 2013	Future Plans for Templates
		19 June 2013	Project Update Meeting
		20 June 2013	Planned implementation meeting
		21 June 2013	Templates Update Meeting
		24 June 2013	DNO validation meetings
	ENA Smarter Networks Portal	25 June 2013	
	Green Cornwall WPD Showcase Event	26 June 2013	

2013	Green Cornwall WPD Showcase Event	27 June 2013	
	Green Cornwall WPD Showcase Event	28 June 2013	
	Demonstration of LV Template through Statistical Analysis	1 July 2013	
		1 July 2013	Validation Meeting
		2 July 2013	Validation Meeting
		2 July 2013	Scottish Power Data Validation Analysis Kick-Off Meeting
	Solar Trade Association London – to discuss templates, and PV headroom.	4 July 2013	
	Project Update - Smarter Networks	4 July 2013	
		5 July 2013	Knowledge Sharing Interview (Gavin and Furong)
		8 July 2013	DNO validation meetings
		8 July 2013	PLC Meeting
	South West Solar Developers Forum	9 July 2013	
	Substation Monitoring Event	11 July 2013	
		12 July 2013	Meeting with PW
		12 July 2013	Teleconference with JW
		15 July 2013	DNO validation meetings
		19 July 2013	Close down report meeting
		22 July 2013	Dissemination and Close Down Meeting
		22 July 2013	Voltage reduction learning workshop
		22 July 2013	Close down meeting
		22 July 2013	DNO validation meetings
		23 July 2013	Teleconference with Nortek to discuss monitoring data capture. They were keen to learn about LV templates to see how their products could be improved
		29 July 2013	DNO validation meetings
		1 August 2013	Monthly Update Progress
		2 August 2013	Templates Update
		5 August 2013	DNO validation meetings
		8 August 2013	Templates Update
		12 August 2013	DNO validation meetings
		19 August 2013	DNO validation meetings
		22 August 2013	LV Templates discussion about future dissemination opportunities
		27 August 2013	DNO validation meetings
	Accenture and WPD lessons learnt from DNO Data Validation disseminated to each DNO:	1 September - 15 October 2013	
		2 September 2013	DNO validation meetings

2013		11 September 2013	Workshop - Planned Implementation and Impact Assessment
		9 September 2013	DNO validation meetings
		16 September 2013	DNO validation meetings
	Presentation to Welsh Assembly on voltage reduction	20 September 2013	
		23 September 2013	Workshop - Planned Implementation and Impact Assessment
		23 September 2013	DNO validation meetings
		30 September 2013	DNO validation meetings
		3 October 2013	Workshop with National Grid on value of real time visibility embedded LV PV
		3 October 2013	Workshop with National grid - on benefits of national voltage reduction
	Discussion with National Grid- current and potential to be PV Forecasting Methods	6 October 2013	
		7 October 2013	DNO validation meetings
	LV Network Template Project findings and steps moving forward	9 October 2013	
	Dr Gavin Shaddick and Prof Furong Li Presention at Distribution Automation Europe	14 -15 October 2013	
		14 October 2013	DNO validation meetings
		15 October 2013	Workshop - Planned Implementation and Impact Assessment
		21 October 2013	DNO validation meetings
	Grid Analytics Europe 2013 Jenny	23 October 2013	
	ENA DG Technical Forum	24 October 2013	
		28 October 2013	DNO validation meetings
	DECC UK PV Solar Strategy Group - Grid Connection sub group	4 November 2013	
	Creating and using LV network templates to identify network stresses SMi's Distribution Automation Europe conference	14 November 2013	
	Clustering and Classifying patterns of energy demands. Invited speaker. 2nd Conference of the International Society of Nonparametric Statistics (ISNPS), Cadiz Spain.	15 June 2014	
	Western Power Innovation	TBC	
	Ofgem Updates	TBC	
	Energy Networks	TBC	
	Smarter Networks	TBC	

2013		TBC	Accenture impact assessment of LV Network Templates in WPD
	ENWL Voltage Reduction Workshop	TBC	
	LV Network Templates: Scottish Power Data Validation Analysis Results	TBC	
	Feedback to the general public through local media	TBC	
	Media briefing on voltage reduction benefits	TBC	

Table 7, Dissemination Activities (Detailed Summary)

THE OUTCOMES OF THE PROJECT

Comprehensive details of the Project's outcomes are to be reported. Where quantitative data is available to describe these outcomes it should be included in the report. Wherever possible, the performance improvement attributable to the Project should be described. If the TRL of the Method has changed as a result of the Trial this should be reported.

There are a number of outcomes that this Project has promised to deliver as part of the initial submission. These outcomes take the form of both qualitative and quantitative GB benefits, each of which will be discussed in turn.

THE TEMPLATES

Within the "Demonstration of LV Network Templates through statistical analysis" 1st of July report, one of this Project's key outcomes was highlighted, being that:

WPD have been able to successfully develop templates that can with an 82.2% level of accuracy estimate the load and voltage flows at a given LV substation without the need for costly monitoring.

Since this report was published, WPD have received and analysed more monitored and fixed data from all other DNOs that was not included as part of this Project initial submission. Nonetheless this additional analysis was deemed essential in order to further validate the templates accuracy levels for wider GB application.

QUALITY ASSURANCE

Scaling factors

An updated scaling approach was introduced which dramatically improved the ability to predict the daily maximum demand and thus scale the normalised demand profiles. The scaling detailed in the report LV Network Templates Report, consisted of a single model for all clusters and all seasons. Whilst this delivered good overall results, there were limitations for certain individual substations. This has now been updated to be cluster specific for each season. In addition, half-hourly metered customer annual consumption has been included within the prediction model and outputs are now constrained to be positive. The performances of the original and new scaling models are compared against one another in terms of R squared error (Table 8); where a value closer to 1 means a better prediction.

Templates	Descriptions	New SF by cluster (R squared error)	Old SF (R squared error)
1	High I&C Dominance	0.84	0.67
2	Modest Domestic Dominance (~60%) (Suburban)	0.87	
3	Modest Domestic Dominance (~60%) (Urban)	0.94	
4	High Domestic Dominance (~90%) (Modest Customer Size ~170)	0.79	
5	High Domestic Dominance (~90%) (Low Customer Size ~70)	0.94	
6	Very High I&C Dominance (~90%)	0.71	
7	Modest Domestic Dominance (~60%) (Rural)	0.93	
8	Industrial Flat	1.00	
9	Domestic Economy 7 Dominance (~65%)	0.99	
10	Lighting	1.00	

Table 8, Old versus New Scaling Factor Comparison to Templates

The previous scaling factors are applied to all substations resulting in an average R squared error of 0.67. With the updated scaling factors, different clusters have varied outcomes, but the new scaling factors overall deliver much better results. The average R square error over all clusters is now 0.88.

Outlier analysis

Based on the methodology described in the 'work carried out' section of this report, a 20% threshold of the actual transformer rating for both peak and shape errors to identify outliers was applied. The outliers are analysed with the aim of finding any common characteristics that can be associated with fixed data. The results of this analysis can be seen in Table 9 below. It can be seen that overall, the majority of templates perform well, with less than 10% being regarded as outliers under a 20% threshold. Additionally, analysis has shown that the intersect between peak and template outliers is very high, indicating that the vast majority of peak outliers are also template outliers. Potential outliers may be identified by examining the classification probabilities where uncertainty in cluster membership translates into increased likelihood of outliers.

Templates	Descriptions	Template outlier substation percentage	Peak outlier substation percentage	Percentage of intersect between peak and template outlier
1	High I&C Dominance	0%	0%	
2	Modest Domestic Dominance (~60%) (Suburban)	11%	11%	100%
3	Modest Domestic Dominance (~60%) (Urban)	0%	0%	
4	High Domestic Dominance (~90%) (Modest Customer Size ~170)	2%	2%	100%
5	High Domestic Dominance (~90%) (Low Customer Size ~70)	0%	0%	
6	Very High I&C Dominance (~90%)	9%	9%	100%
7	Modest Domestic Dominance (~60%) (Rural)	8%	4%	50%
8	Industrial Flat	0%	0%	
9	Domestic Economy 7 Dominance (~65%)	8%	8%	100%
10	Lighting	0%	0%	

Table 9, Outlier Analysis Outcomes

Overall, **90% substations** of all clusters can be predicted with an error less than 20% of its transformer rating. Even if the threshold is decreased to 10% of transformer rating then the accuracy is still above **70%** (averaged over all clusters and all seasons)

DNO VALIDATION OUTCOMES

As previously mentioned, the Project asked in the "May 2013 Template dissemination workshop", all of the DNOs to help with further validation work by providing WPD with additional monitored variable and fixed data currently being collected on their networks.

All DNOs provided both fixed and variable data to enable validation of the templates within other licence areas. The templates methodology was applied in each area: (i) sense-checking; (ii) classification into a cluster; (iii) scaling, followed by evaluation of estimated and actual measurements. In cases where data was incomplete, analyses was adapted when possible to maximise the usefulness of the available data.

The results from the analysis undertaken are extremely encouraging. Similar levels of accuracy were observed when comparing estimated with actual measurements of demand, resulting in accuracy levels of between 80 and 90%. Network planners will for the first time have a statistically robust visual representation of the indicative load and voltage flows on any given LV substation.

A summary of the data and outcomes is provided below alongside the findings when applying the templates and classification tool to a DNOs network, resulting in a comparison being done for actual versus estimate readings. For further information around the DNO data validation activities undertaken please refer to the "details of work carried out" section and Appendix C.

DNO	SP	SSE	NPG	UKPN	ENWL
Intended	100 substations	100 substations	9 substations	90 substations	50 substations
Received: fixed	102 substations	98 substations	9 substations	25 substations	50 substations
Received: variable	Two weeks. 70 substations. One minute interval.	Four months for 98 substations. 30 minute intervals	One year for 9 substations. 15 minute intervals	One year 79 substations. 10 minute intervals	None
Suitable for analysis: fixed	All	88 substations, as 10 substa-tions were missing transformer ratings	None. All missing EACs	None. 75 missing all fixed data of which 25 just missing HH	None. All missing HH
Suitable for analysis: variable	31 substations	69 substations	9 substations	70 substations	See text
Current maximum possible classification accuracy	80% (the maximum observed in LV templates study area)	63%	72%	63% for 25 substations, 0% for remaining	63%
Scaling	Possible	Possible	Not possible. All missing EACs	Not possible All missing HH	Not possible. All missing HH
Accuracy (within 20% of transformer rating)	~80%	~90%	~80% (without scaling)	~90% (without scaling)	Not available

Table 10, DNO Data Validation

Given the findings of both the trial and additional DNO data validation work, it is clear that the level of accuracy that the LV Network Template model delivers is both robust and useful for planners whether it's applied in LV networks that are in the South Wales, London or in other parts of Great Britain.

Scottish Power
A full set of fixed data meant that classification was possible and the probabilities of allocation to the best cluster were high; the average (median) being 87% which is slightly higher than that observed in the South Wales (85%). The range of the probabilities was also slightly better than that seen in the study area (interquartile range; IQR 37%-98% compared to 33%-98%).

Variable data suitable for evaluation was available for 31 substations, covering urban and very rural areas, and the results were encouraging. Only two substations were allocated clearly to the wrong clusters (domestic as opposed to industrial and commercial), although the allocation probabilities in these cases were low which in the quality assurance of the South Wales data proved to be an indicator of potentially poorer performance. The percentage of substations for which the total difference (error) between actual and estimated measurements (averaged over days), expressed in terms of the root mean squared error (RMSE) was within 20% of the stated transformer rating was 81% (25 out of 31 substations).

A summary of the data quality and plots of the estimated versus actual measurements for each substation can be seen in Appendix C. An example of estimated and actual measurements over time can be seen in Figure 44 below.

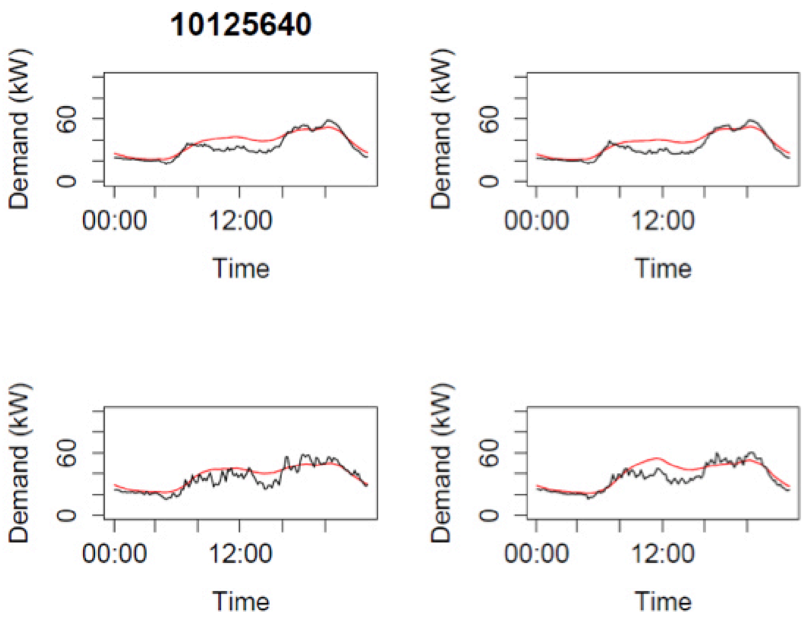


Figure 44: Estimated (red) and actual (black) demands against time for a substation within the Scottish Power area. Top left panel is for all days, top right for weekdays, bottom left for Saturdays and bottom right for Sundays

Scottish and Southern Energy

Both fixed and variable data were available for 98 substations; however 10 substations didn't have transformer ratings and thus were not suitable at all for classification. Of the remaining 88 substations, the lack of data on half hourly consumption meant that scaling wasn't possible, and the ability to perform classification was limited to a maximum accuracy of 63% for these 88 substations. Due to this distribution of probabilities had an average (median) of 71% with an IQR of 57-90%; lower than those observed in South Wales and for other DNOs.

Variable data suitable for evaluation was available for 69 substations and the results were again extremely encouraging. The percentage of substations for which the total difference (error) between actual and estimated measurements (averaged over days), expressed in terms of the root mean squared error (RMSE) was within 20% of the stated transformer rating was 93% (64 out of 69 substations).

A summary of the data quality and plots of the estimated versus actual measurements for each substation can be seen in Appendix C. An example of estimated and actual measurements over time for a substation can be seen in Figure 45 below.

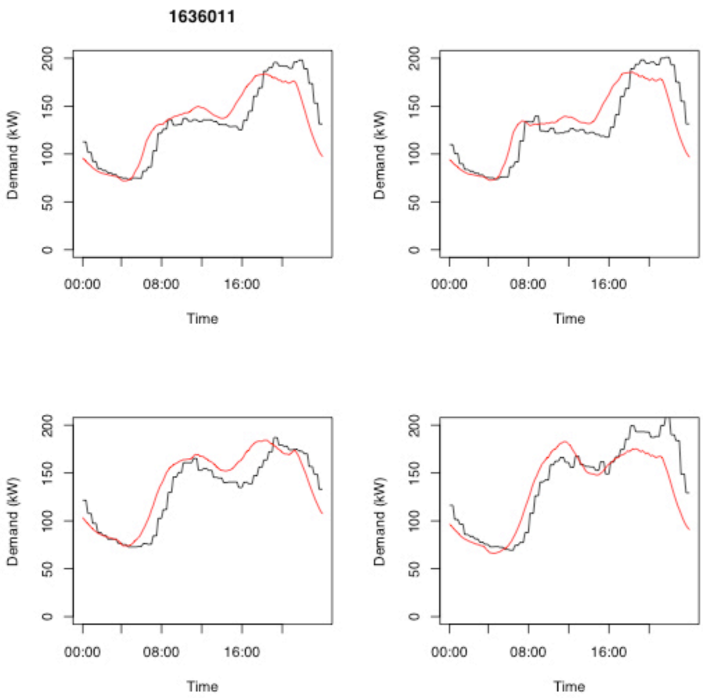


Figure 45: Estimated (red) and actual (black) demands against time for a substation within the Scottish and Southern Energy area. Top left panel is for all days, top right for weekdays, bottom left for Saturdays and bottom right for Sundays

Northern Powergrid (NPG)

Fixed and variable data were available for 9 substations which comprised a mix of 20kV and 6.6kV substations. The lack of data on estimated annual consumptions meant that scaling wasn't possible and the ability to perform classification was limited to a maximum accuracy of 72% (in South Wales using full data, the maximum possible accuracy was 100% of which 82.2% of substations were correctly allocated to the appropriate cluster). Despite this limitation, the distribution of allocation probabilities were good; an average (median) of 91% and IQR between 62% and 99%. Part of the reason for this apparent increase in predictive ability is because having reduced information in the classification model means that substations are more likely to be allocated to the larger, more prevalent, clusters with higher probability. Without the missing information it is easier to predict into more 'general' clusters and harder to allocate some of the more specific clusters. This will come with a loss in precision when considering the load demands associated with each cluster.

As scaling was not possible using the available data, a comparison was made on the estimated versus actual measurements on the normalised scale (based on the daily maximums for each substation). To enable this comparison, the actual measurements were themselves normalised to be on the same scale as the templates (pre-scaling). Accuracy was determined by the overall assessment of the error (RMSE) being less than 0.80 (on the normalised scales this would be seen as equivalent to being with 80% of the transformer rating if scaling had been performed). In this case, 7 out of the 9 (78%) of the substations met this requirement.

A summary of the data quality and plots of the estimated versus actual measurements for each substation can be seen in Appendix C. An example of estimated and actual measurements over time can be seen in Figure 46 below.

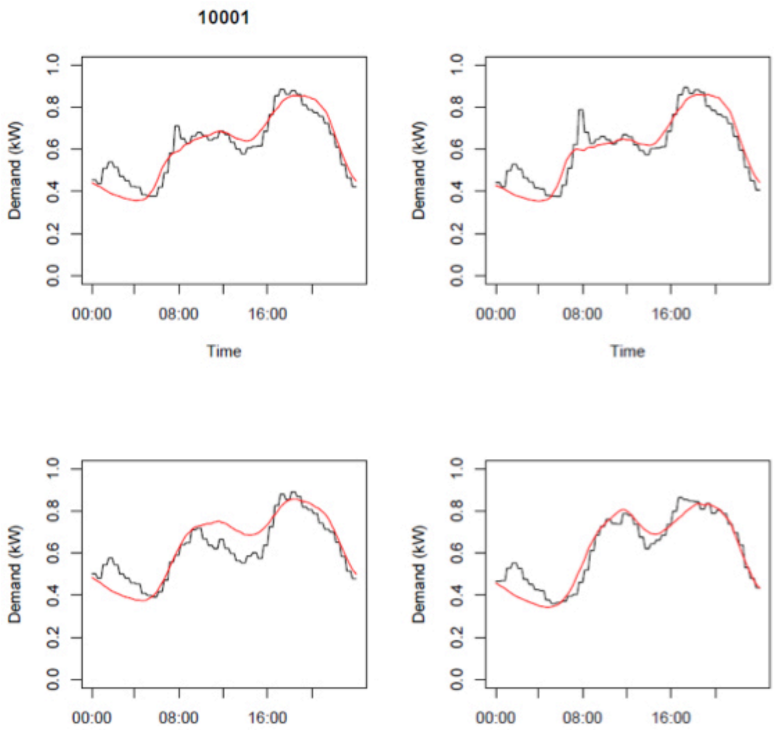


Figure 46: Estimated (Red) and actual (Black) demands against time for a substation within the Northern Powergrid area. Top left panel is for all days, top right for weekdays, bottom left for Saturdays and bottom right for Sundays

UK Power Networks (UKPN)

Both fixed and variable data were available for 25 substations, which were all located in central London near Piccadilly Circus, as can be seen in Figure 47 below.

Bloomfield Place 6.6kV

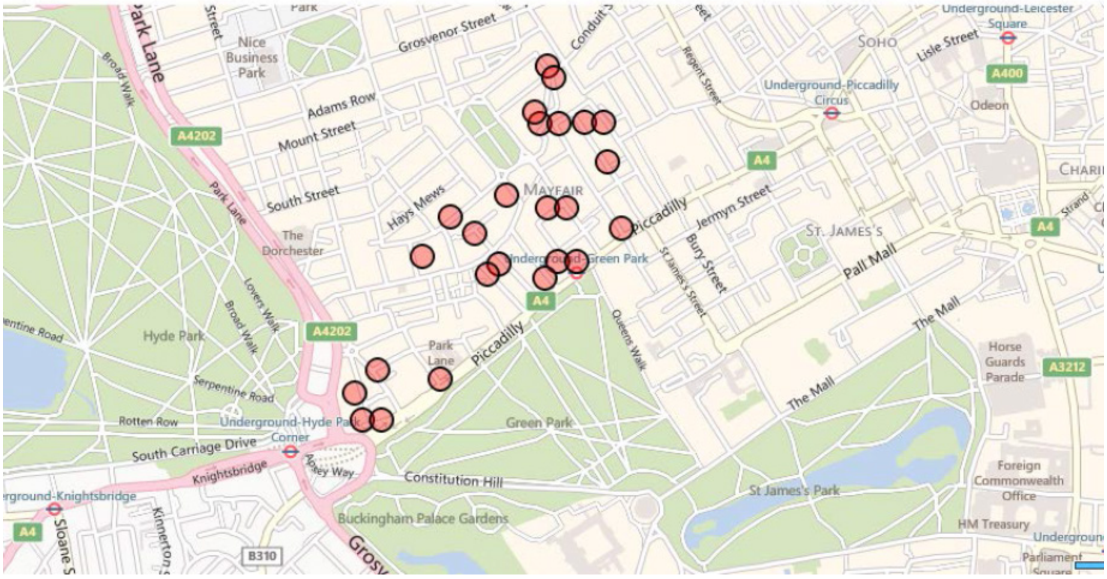


Figure 47: Locations of the substations (in central London) used in UK Power Networks analysis

The lack of data on half hourly consumption means that scaling wasn't possible and the ability to perform classification was limited to a maximum accuracy of 63%. Acknowledging this limitation, the distribution of probabilities was good; average (median) probability of allocation to chosen cluster was 83%; IQR 65-95%. The classification model did suggest with strong possibility that the distribution of clusters dominated by industrial and commercial customers, something that is confirmed by patterns observed in the measured data. To enable a comparison between estimated and actual measurements where scaling wasn't possible due to the lack of information, the actual measurements were themselves normalised to be on the same scale as the templates (pre-scaling). Accuracy was determined by the overall assessment of the error (RMSE) being less than 0.80 (on the normalised scales this would be seen as equivalent to being with 80% of the transformer rating if scaling had been performed). In this case, 23 out of the 25 (92%) of the substations met this requirement.

A summary of the data quality and plots of the measurements for each substation can be seen in the Appendix C. An example of estimated and actual measurements over time can be seen in Figure 48 overleaf.

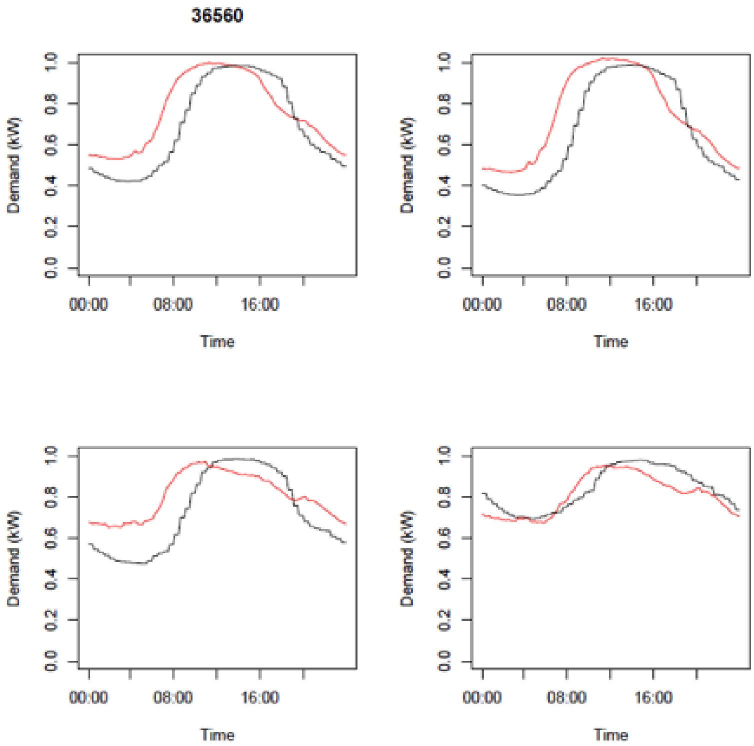


Figure 48: Estimated (Red) and actual (Black) demands against time for a substation within the UKPN area. Top left panel is for all days, top right for weekdays, bottom left for Saturdays and bottom right for Sundays

Electricity North West (ENWL)

At the time of this report, fixed data was only available for 50 substations; however half hourly consumption data was missing, leading to classification being limited to a maximum accuracy of 63%. The distribution of probabilities were encouraging and had an average (median) of 97% with an IQR of 87-99%; which were higher than the corresponding numbers in South Wales. Without the missing information it is easier to predict into more 'general' clusters and harder to allocate to some of the more specific clusters. This will come with an associated loss in precision when considering the load demands associated with each cluster.

Unfortunately, due to the late arrival of variable data (16/10/2013) it was not possible to include a full analysis of ENWL data in this report. This work will continue after the Project close down and costs will be borne by WPD as an act of good will. This will ensure that analysis has been completed for all DNOs that have provided data to validate the templates and to embed the outputs from this Project into the wider industry.

TEMPLATE RE-USE BENEFITS

Based on the results gained in applying the templates from monitored and fixed data of WPDs and other DNOs networks, this Project can confidently confirm that the templates are representative of 50% of the wider GB network. As a result of this confirmation there is a potential saving realized in the re-use of the templates. This saving has been calculated based on the following rationale:

The original proposal was that monitoring would be installed to capture data from 2,6% of South Wales ground and pole mounted substations and relevant associated LV feeder end sin South Wales. If the Project confirmed, which it has, that the knowledge would not have to be gained on those through the installation of sensors on those transformers and associated feeder-ends, the Project could save the variable cost element of monitoring 50% of UK ground mounted and pole mounted substations, by only installing at a rate of 2.6%. The outcome has been that the Project has demonstrated applicability to levels far in excess of the 50% target and proportionately a higher cost savings than forecast.

TEMPLATES TRANSFORMER LOSSES AND AGEING BENEFITS

As the LV Network Templates were developed, a classification tool was developed that provides a network planners with a ready-to-use tool that delivers a visual view of the scaled or un-scaled load and voltage flows at a given substation. This visibility allows for a greater understanding of the impact that various Low Carbon Technologies, without the need for monitoring and uses commonly available fixed data.

Amongst the benefits that would accrue from this work, WPD identified that this enhanced knowledge of demand profiles would improve the accuracy of load factors and thus the ability to identify which distribution transformers were suitable candidates for early replacement on the basis of savings in transformer losses. (Only a modest estimate was included in the LCNF Project for the benefit of this work, equivalent to the cost of 27 ground- mounted HV/LV transformers a year for the UK as a whole, for a five year period). As Appendix B, and figure 49 overleaf illustrate, by knowing the load factors the calculation of optimum advancement of transformer replacement is easily assessed. This process is substantially enhanced by using the classification tool in tandem with the asset register to identify candidate transformers; further aided by the substantially better than anticipated templates fit (circa 80% as opposed to 50%). Whilst there is a real qualitative benefit in having such a tool, it is planned for WPD to further trial such calculations in the near future. For further information, please refer to the “planned implementation” section of this report.

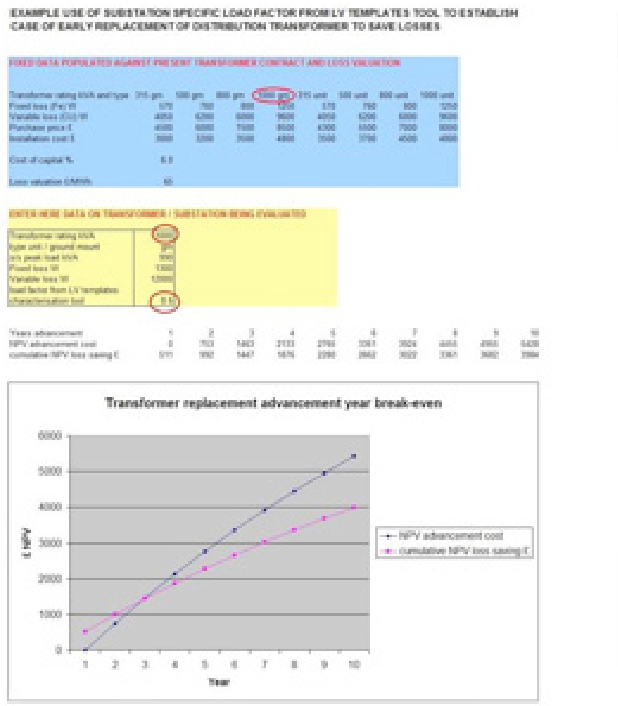


Figure 49, Transformer Load Loss and Age Tool

OUTCOMES OF PV ANALYSIS

Having developed and applied a statistical PV model, LV Network Templates can confidently confirm that the output from a single PV installation can be used to accurately predict the outputs of others located within a postcode locality. This output can then be employed in future active network management solutions at local distribution and primary substation level. This will have further value when distribution network operators seek to capture real-time thermal ratings of their assets facilitated by installation of installing weather stations tactically within selected substations.

From extensive analysis undertaken, it was found that in the majority of installations, the proportion of actual to potential output being greater than 50% is very low (<0.2%) and for greater than 70% extremely low (<0.01%). In fact, the maximum proportion observed at any installation over this time period was 81.1% (1x property in Newport). Overall the average (median) maximum proportion of actual output compared to potential output was 44% with an interquartile range of 39.7% -47.9%. As network planning and design is in part based upon the declared maximum stated installed generation capacity, the effect of the above finding would be an overstatement of installed peak rating, even if the annual kWh calculation for PV FiT was accurate. This notion is reinforced as manufacturers of solar panels, are quoted against international standard which are based on stated irradiation levels & operating temperatures. Such a finding leads to two further inter-related conclusions and a key answer that should be further explored:

- There is likely to be even more than 19% overstatement of peak rating in more northerly parts of the UK from South Wales, and slightly less to the South Due to the variation in solar irradiation, and secondly
- The impact to network planning in its simplest view is that an additional 20% network headroom as been identified, allowing for further distributed generation to be connected to the network without the need for reinforcement
- Is there an opportunity to provide an improved GB industry standard for PV FiT registration that will more accurately reflect the true PV output?

It's also important to take stock here, of the value to the wider industry that the ability proxy FiT metering also presents when being incorporated into the Transmission System Operators models for scheduling, forecasting and the effective management of carbon intensive spinning reserves. Especially as LV Network Templates, and another WPD Tier1 Project has also proven the ability to provide real time PV generation data, through any distribution network operators ENMAC system at the Grid Supply Point to National Grid. The significance of this is that the total LV PV installed nationally is currently in excess of 1200MW [34]. The real-time output of this is currently hidden to National Grid, resulting in significant volatility in day to day demand forecasting [35]. And impacting on their scheduling of generation-led spinning reserves particularly during the summer when demand is low.

Bearing this and the findings in mind (e.g. actual outputs versus declared maximum capacity and the ability to apply the statistical model for Proxy FiT monitoring); WPD has taken proactive steps in disseminating the outcomes with National Grid to open discussion on the value of sharing real-time PV output information further in the longer-term [36]. In addition to this discussions have also been arranged with the DECC UK PV Strategy grid connection subgroup (4th Nov), the ENA Distributed Generation Working Group (October agenda item rescheduled for Nov.), BRE Solar Centre ((May 13) and the Solar Trade Association about ways in which the findings of the Project can be further embedded into the wider industry. A number of events have been scheduled between now and 2014 to discuss the PV findings further.

For a deeper analysis of the outcomes and conclusions that have also been presented in the PV FiT Report, please see below:

[34] Ofgem FiT register July 2013 (Figures taken from installations up to and including 10.0kW)
[35] National Grid base some of their forecasting models also in part on the registered FiT arrangements and an installations maximum capacity
[36] Thursday the 3rd of October was the first kick-off meeting discussing the Projects findings

PREDICTING PV PROFILES

This section presents an example of how the output from a single PV installation within a small area can be used to represent the measurements for other installations within close proximity. Examining the output profiles within a small area showed clear variation between the outputs from the individual PVs, much of which will be due to differences in the maximum capacity and orientation. The estimates of the effects of these characteristics gained from the statistical modelling can be used to 'correct' the output from a single installation to give an underlying (or average) profile. This underlying profile can then be used as a basis for prediction of the outputs for installations within that area, by adjusting the underlying profile to take into account differences in size and efficiency. This modelling is performed on the actual measurements from the PVs, further on consideration will be given to the outputs as a proportion of the maximum capacity.

Illustrative example: PV output in CF38, August 17th 2012:

For the purposes of illustration, postcode district CF38 which contains 12 installations is used. Figure 50 below shows the outputs for these 12 installations between 5am and 10pm on August 17th 2012.

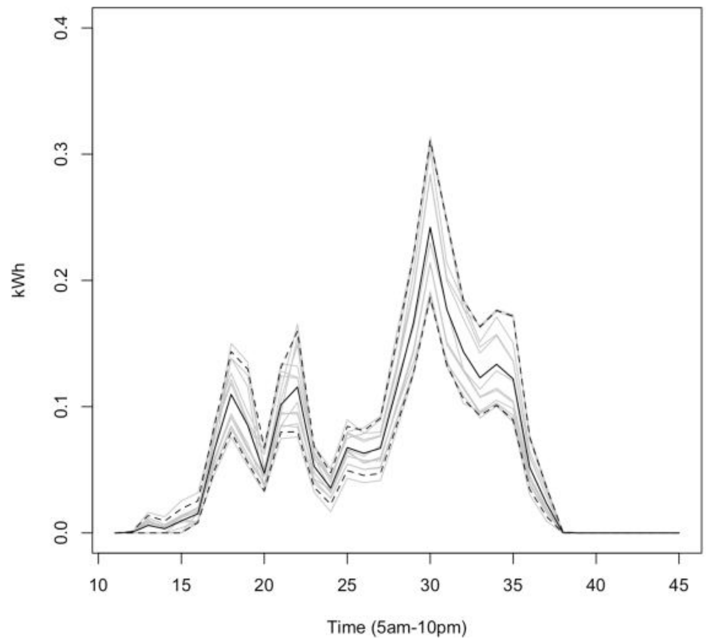


Figure 50: Output from 12 PV installations per half hour period for August 17th 2012 in postcode district CF38. Grey lines show outputs from individual PVs, solid black line is the mean over all installations and dotted lines show the 5th and 95th percentiles.

To illustrate the potential for using the output from a single PV to predict the outputs from other installations within a postcode district the Project considered the 12 PVs in the CF38 postcode district for a single day (August 17th 2012). Each panel in Figure 51 shows the results of taking the output from a single PV (black line) and using this to predict the outputs for the remaining eleven PVs for that day (grey lines), adjusting for differences in size and the effects of orientation. It can be seen that set of predictions throughout the panels, i.e. using different installations as the basis, are very similar.

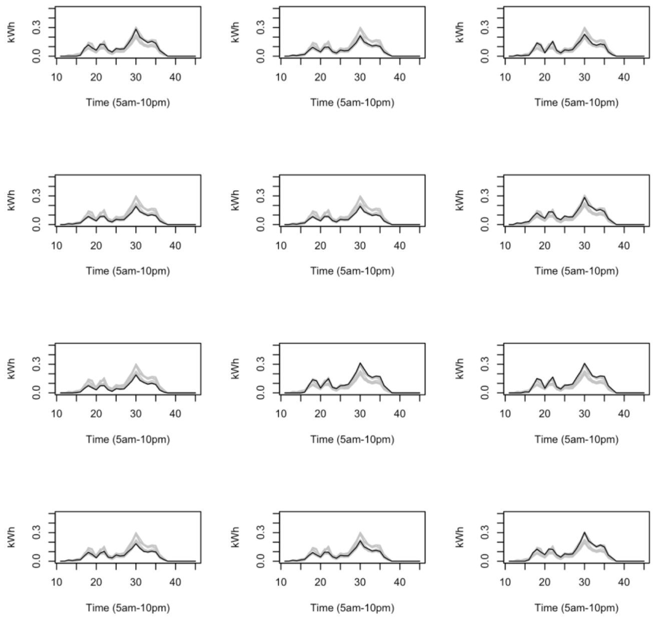


Figure 51, Predictions of PV outputs within a postcode district (CF38) for August 17th 2012. Each panel shows the predictions of outputs for PVs based on measurements from a single PV. Black lines show the data used for the predictions (from one PV) with grey lines the predictions for the other eleven within this postcode district.

Measuring bias in predicted outputs

Comparing the differences between the predicted outputs for each PV with its measured values allows the Project to estimate the bias that would be associated with using this approach. In the example presented there are twelve choices of which installation could be used on which to base the predictions. Ideally this choice would not have a large effect on the accuracy of the predictions, although it might be expected that more stable predictions might be made from installations which are likely to represent the majority of other installations, i.e. do not represent unusual factors such as very large or small PVs or very inefficient ones. For the twelve installations within the CF39 postcode district, each was taken in turn as the basis of predictions for the other eleven. Plots of the predicted versus measured outputs can be seen in figure 52 in which each panel shows the results from choosing one of the twelve installations as the basis of the predictions. The coloured dots represent the predictions of the outputs from the other eleven installations.

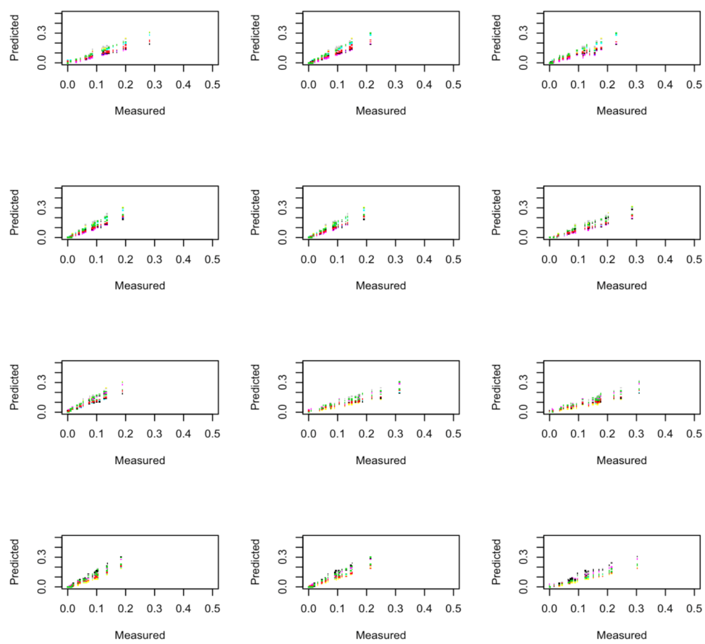


Figure 52 Comparison between predicted and measured PV outputs for twelve installations in CF39 postcode district on August 17th 2012. Panels show results from using different installations as the basis for predictions.

The root mean square error (RMSE) corresponding to each panel (Method A), as previously discussed in the 'works carried out' section for PV methodology.

In terms of the worst case scenario, i.e. the choice of which installation on which to base the predictions, the maximum value of the average of the biases is 0.032 and occurs when installation 9 is chosen on which to base the predictions of the other installations. Table 11 shows the summed bias (using method B) between predicted output and real output for the PVs in CF38 on 17th Aug. Results are given for using each of the 12 PVs as basis for predicting the others. The maximum bias observed is circa. 30% and the minimum 1.2% (mean is 18.2%). Here the minimum bias occurs when the PV chosen (which has a maximum capacity of 2.82) on which to base the predictions of the others in the area lies at the centre of the distribution of the values of maximum capacity of all the installations in the area (mean = 3.06, range = 2.3-4.0) and has high RPO (98%). This pattern is seen through the analysis.

Monitored PV	Summed Bias (%)	Monitored PV	Summed Bias (%)
1	13.1	7	29.6
2	11.7	8	25.3
3	1.7	9	28.1
4	20.5	10	16.1
5	21.1	11	11.4
6	19.6	12	20.1

Table 11, Summed Biases as an output of monitored PV predictions of other installations

Installed capacity against actual output

Figure 53 shows the distribution of maximum capacity multiplied by the RPO (henceforth referred to as 'actual capacity). The distribution of the received energy as a proportion of that which would be received by an optimal orientation (RPO) is shown in Figure 54.

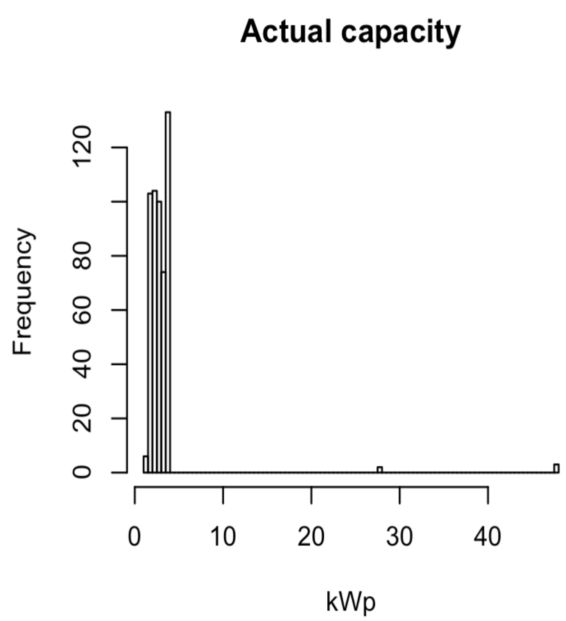


*Figure 53: Histogram showing the actual capacities (maximum capacity * RPO) of the 525 PV installations in South Wales, 2012.*

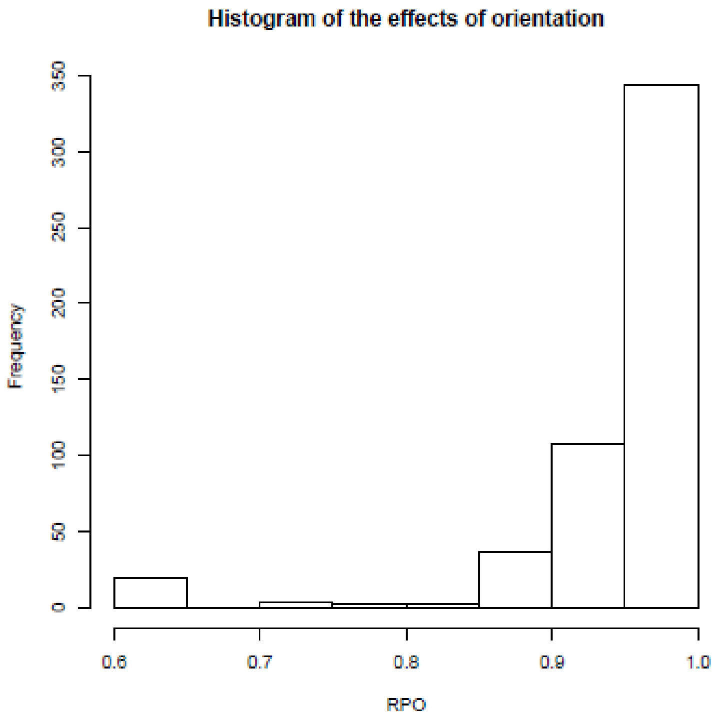


Figure 54: Distribution of RPOs: the received energy as a proportion of that which would be received by an optimal orientation (RPO) for the 525 PV installations in South Wales, 2012.

Illustrative example: PV output in CF38, August 17th 2012

Figure 55 below shows the output from the 12 installations in CF38 for the 12th August as percentage of actual (green line) and maximum (red line) capacities. The maximum percentage of the actual capacity was 11.6% with a mean of 2.1% over the period 5am-10pm. The maximum in this case occurred at 14:30.

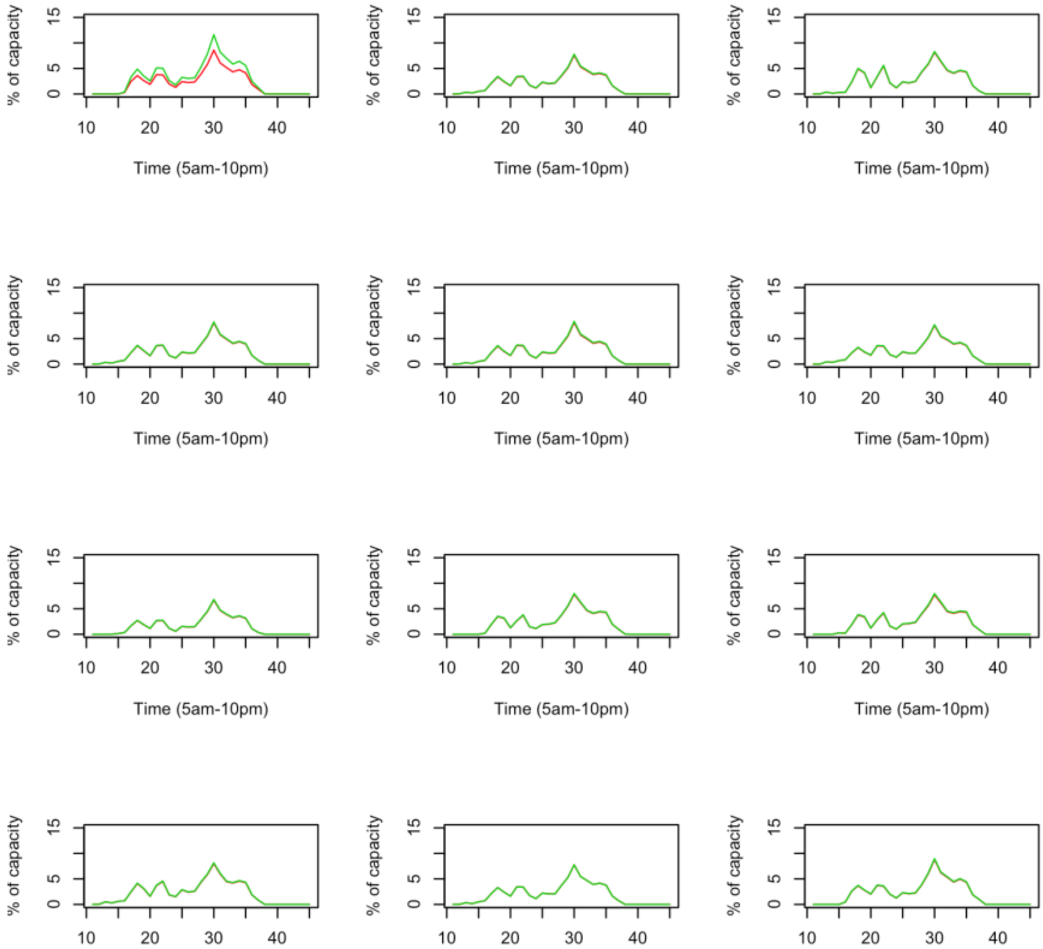


Figure 55, Output from the 12 installations in CF38 for the 12th August as percentage of actual (green line) and maximum (red line) capacities

Maximum proportions of actual capacity

Using readings from the entire time period (January 1st-December 31st; 5am-10pm) and all areas within the study, the mean proportion of output against actual capacity was 5.3% with a maximum of 81.1% (which occurred in NP11 at 1230 on the 19th April). The distribution of these proportions is highly skewed with a median of 0%, and interquartile range (IQR) 0.0-5.5%. The corresponding figures for proportions of maximum capacity are mean=5.0%, median=0.0%, IQR=0.0-5.3% and maximum=78.9%.The distribution of proportions of actual capacity for all 30 minute intervals can be seen in Figure 56 below.

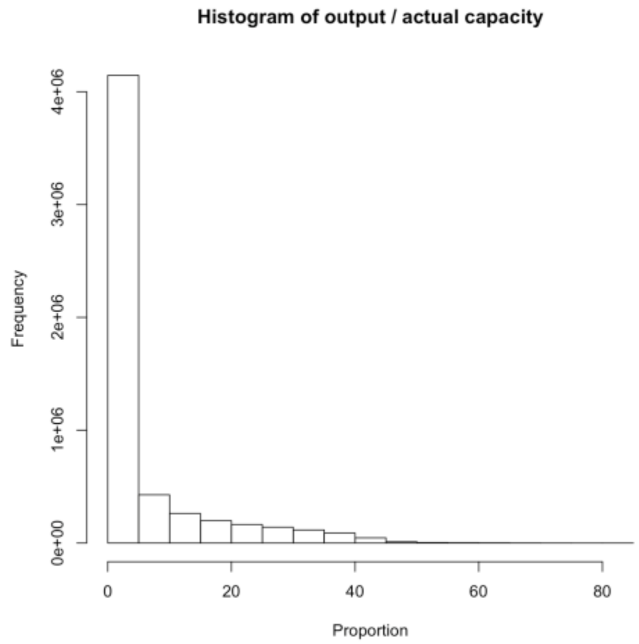


Figure 56, Distribution of outputs as a proportion of actual capacities.

The proportion of intervals for which output exceeded 50% of actual capacity exceeded was 0.2% (0.05% for maximum capacity). The corresponding proportions for exceeding 70% are less than 0.01%.

Maximum proportions of actual capacity - by day

In considering the maximum values of the proportion of actual capacity, the distribution of maximum values for each day (over the entire area) can be seen in Figure 57. The frequency of the times at which these maximums occur can be seen in Table 12 in which it can be seen that the maximums largely occur between 1030 and 1230.

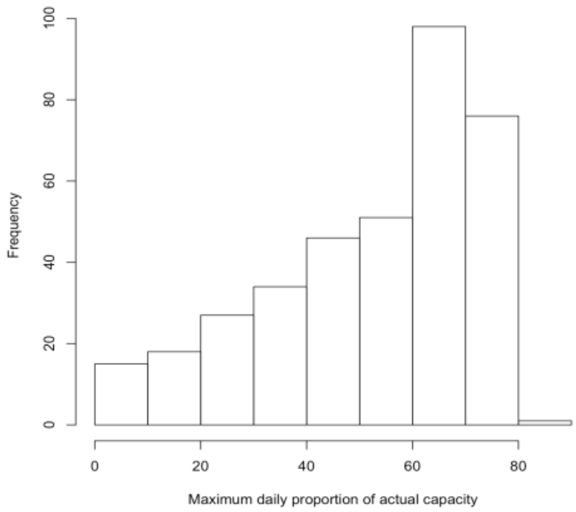


Figure 57: Distribution of maximum values of proportion of actual capacity for each day (over the entire area).

Time	Frequency	Time	Frequency
08:30	0.8	13:00	6.6
09:00	1.1	13:30	6.3
09:30	1.9	14:00	2.7
10:00	4.4	14:30	4.1
10:30	9.6	15:00	1.1
11:00	12.6	15:30	1.1
11:30	14.5	16:00	0.5
12:00	17.5	16:30	0.3
12:30	15		

Table 12, Frequency (percentages) of times at which daily maximum proportion of actual capacity occurs.

Maximum proportions of actual capacity - by postcode district

When considering the maximum proportions by postcode district, the mean is 53.3% (SD 10.9%) with a median of 50% and IQR 47.2-55.5%. The minimum is 22.4% (in SA67) and the maximum 81.1% (in NP11). The distribution of maximum values for each postcode district (over the entire year) can be seen in Figure 58.

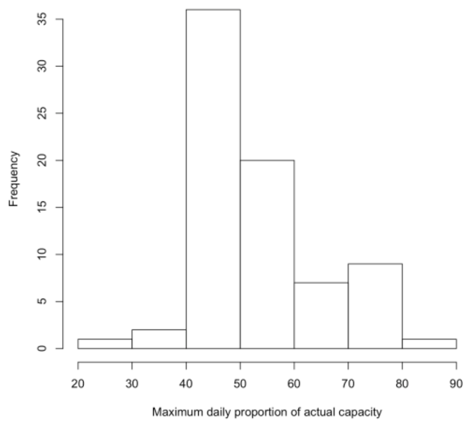


Figure 58: Distribution of maximum values proportion of actual capacity for each postcode district (over the entire year).

Maximum proportions of actual capacity - by installation

When considering the maximum proportions by individual installations, the mean is 44.0% (SD 10.3%) with a median of 45% and IQR 39.7-47.9%. The minimum is 0.0% and the maximum 81.1%. The distribution of maximum values for each installation (over the entire year) can be seen in Figure 59.

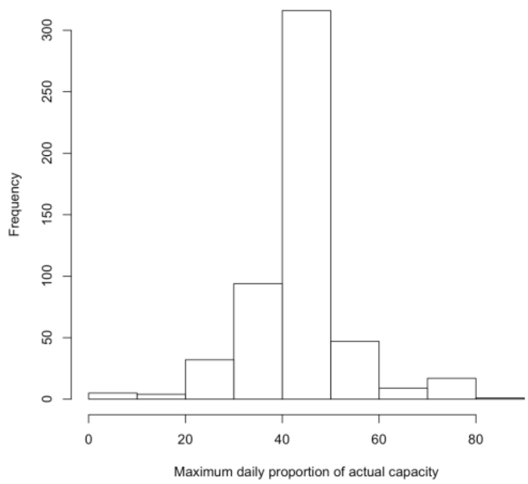


Figure 59: Distribution of maximum values proportion of actual capacity for each installation (over the entire year).

OUTCOMES OF STRESS ANALYSIS

As identified in the "Stresses on the LV Network caused by Low Carbon Technologies [37]" report, a number of key outcomes could be concluded from the applied methodology and eventual comparison analysis of stressed versus non-stressed parts of the network. Three four key outcomes were able to be concluded from are as followed:

- Firstly, the maximum aggregated generation from PV within a postcode was on average only 81% of the declared capacity, consequently leading to the voltage impact on the monitored network being approximately 36% lower than anticipated. In comparison in areas where there were only a few heat pumps installed, there was a noticeable difference
- Secondly, from the statistical and power engineer analysis undertaken, the 10 cluster types have the ability to identify the impact of low carbon stresses ,as table 13 below illustrates
- A third key output that this report highlights is that over an 11 month period, 96 million voltage measurements at remote feeder ends were taken. From this WPD have been able to identify that for those monitored points, 99.62% of the voltage readings were within statutory voltage limits. And of the small number outside, the majority were overvoltage and just 0,015% were below the lower limits. This indicates that historic network planning has been successful in meeting statutory limits (those feeder-end points that were outside of statutory voltage limits were immediately addressed)
- Finally as a result of the second key output, for feeder-end points that were operating at the upper echelons of the statutory voltage limits, opportunities could be leveraged in which a tactical or long term voltage reduction could be applied to those sites; whilst still complying with existing statutory voltage limits. Furthermore as the majority of cases were deemed to be over-voltage issues, any future move to expand the LV voltage limits from -6% to -10%, would not in actuality either "legalise" supplies that were currently outside statutory limits, or result in customers facing actual voltages that were even outside the wider EU limits

[37] Stresses on the LV Network caused by Low Carbon Technologies" www.wpdinnovation.co.uk

Low Carbon Technology	Template 1	Template 2	Template 3	Template 4	Template 5	Template 6	Template 7	Template 8	Template 9	Template 10
	High I&C Dominance	Modest Domestic Dominance (~60%) Suburban)	Modest Domestic Dominance (~60%) (Urban)	High Domestic Dominance (~90%) (Modest Customer Size ~170)	High Domestic Dominance (~90%) (Low Customer Size ~70)	Very High I&C Dominance (~90%)	Modest Domestic Dominance (~60%) (Rural)	Industrial Flat	Domestic Economy 7 Dominance (~65%)	Lighting
Workplace/ Retail EV Charging	Unsuitable time of day pattern as need is coincident with prevailing peak	Suitable time of day pattern with limited need to curtail charge rate around 1730 peak - for workplace potentially not an issue if staff travelling then anyway, but possible minor constraint on commercial for shopping malls etc being visited at that time en-route from work.	Less unsuitable time of day pattern as load curve shows limited drop off during working hours	Unsuitable time of day pattern as need is coincident with prevailing peak	Suitable providing that work / sole operating hours are not coincident with peak	Unsuitable time of day pattern as need is coincident with prevailing peak	The wider variability within this cluster precludes firm conclusion though the tendency is a curve that is not complementary to workplace EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak	Suitable providing that work / sole operating hours are not coincident with peak	Suitable, complementary with power profiles
Overnight EV Charging	Very suitable	Suitable	Suitable	Suitable	Suitable	Very suitable	Suitable	Less suitable	Not suitable	Unsuitable time of day pattern as need is coincident with demand
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation	Suitable with insulation or heat storage with limited time of day constraint	Suitable if linked with insulation or heat storage to permit off peak operation	Only if linked with insulation or heat storage to permit off peak operation	Might require link with insulation or heat storage to permit off peak operation	Only if linked with insulation or heat storage to permit off peak operation	Only if linked with insulation or heat storage to permit off peak operation	More limited capability due to lack of depth and duration of off peak demand	Requires further examination of nature of activity - might require link with insulation or heat storage to permit off peak operation	Suitable
PV	Suitable - complimentary to both power and voltage curves	Suitable - complimentary to power and voltage curves	Suitable - complimentary to both power and voltage curves	Suitable - complimentary to both power and voltage curves	Less suitable - as not complimentary to power curves	Suitable - complimentary to both power and voltage curves	The wider variability within this cluster is less suitable for PV-	Suitable - complimentary to power curves	Less suitable - as not complimentary to power curves	Unsuitable, demand is not there when PV radiation is at peak
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	More suitable than most given that generation is not naturally limited to time of day and demand curve has reduced depth and duration of off peak period	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak	Suitable

Table 13 Templates and a High-Level Overview of the impact of low carbon technologies

As the PV findings have already been discussed through the PV analysis report, a focus will be provided on the opportunities that have been identified as a result of voltage reduction schemes.

SOUTH WALES SELECTIVE VOLTAGE REDUCTION DEPLOYMENT

As an outcome of the stresses analysis, WPD have identified a list of 147 primary substations in South Wales where the target voltage will be reduced from 11.4kV to 11.3kV. These substations have been selected due to the voltage flows at the end of the feeders being monitored in the Project identifying them as being at the upper statutory voltage limits. For this reason, and by using the already installed feeder-end monitors, a tactical voltage reduction programme of work is currently progress and will take place over the course of the next three years. As such benefits in the form of a reduction in demand, customer's energy bills and CO2 emissions will be realised and quantified below. A brief overview of the calculations is provided; for more detailed analysis around these benefits, please refer to the "Use of Project findings to implement voltage reduction at primary substation in South Wales" report in Appendix B.

a) Reduction in demand on the network

The maximum demands on the selected 147 substations have been taken from the 2011/12 Maximum Demands listed for each substation in WPD's Long Term Development Statement((LTDS) published online as a licence requirement. The sum of those MVA figures has been converted to MW by applying the power factors listed in the LTDS; giving a maximum demand of 1747MW. From the above reference work, the calculated demand reduction will be in the proportion to the voltage reduction i.e. 11.3/11.4; a reduction of 0.88% or 15.7MW.

The reduction in HV in target voltage will reduce maximum demand by **15.7MW**

b) Reduction in customers energy bills

The related energy saving over a year in this voltage reduction can be calculated by applying the South Wales Load Factor, derived from half hourly monthly settlements data returns for total Grid import + embedded generation over a full year, vs system maximum demand. The annual energy consumption of the 147 primary substations is thus calculated to be 10,618 GWh and so the above saving would amount to 93,143 MWh (please note change of units).

On the basis that cost of marginal units of electricity to Customers remains at DECCs most recently published levels, the cost saving to Customers can be calculated. The annual savings to domestic customers amounts to circa £4.2Mp.a and to I&C Customers circa £5.2Mp.a; a combined saving to customers of some £9.4Mp.a.

The reduction in HV and LV system voltage will reduce Customer bills by a calculated **£9.4M** each year, based on DECCs current valuation of domestic and I&C rates.

c) Reduction in CO2 emissions

As a result of the voltage reduction, it is anticipated that a reduction of 93,143MWh will be realised, resulting in a reduction of CO2 emissions. It is estimated that this would save some 41,000 tonnes a year of CO2.

The reduction in HV and LV system voltage will reduce CO2 emissions by some **41,000 Tonnes** each year, based on DECC 2011 data. DECC provisional 2012 data would give a figure 10% higher than this.

OPPORTUNITY TO ADOPT EU STATUTORY VOLTAGE LIMITS

Prior to the WPD LV Templates Project there had not previously been such an extensive monitoring Project to investigate just how close, or not, actual low voltages are to the statutory limits and how those vary through the day, week, season and year. This Project has taken the opportunity to address this information gap through monitoring 10 minute averages voltages at over 4,400 points on the LV network. As a result of this and the findings, and the current on-going discussions around capacity constraints, customer bills etc., WPD feel that this is a suitable time to re-open discussions around the potential adoption of EU Statutory Voltage limits.

If it were accepted that UK would adopt the wider EU low voltage tolerances of +/- 10%, the WPD LV Templates Project provides good evidence that supplies are within the existing lower -6% tolerance, it means that the additional 4% tolerance is all truly available to use. For reasons further discussed below, a widespread reduction of 2.5% in HV and LV supply voltage is explored here. It would provide some leeway and still maintain 3.5% of the National Grid / GCRP OC6 voltage control demand response.

Such reduction in voltage could be readily achieved across the majority of networks through alteration of the automatic voltage control relay target HV (normally 11kV) voltages at primary substations. If it were necessary in the exception to increase end LV supply voltages to customers this might still be possible by taking outages for off circuit adjustment of HV/LV transformer taps since UK HV/LV ground mount distribution transformers are equipped with +/- 2.5 and 5% off circuit tapping switches, and UK pole mounted transformers normally have in tank +/- 5% bolted link taps. This is also a reason why a figure of 2.5% voltage reduction is discussed here. Figure 60, below illustrates a “before” and “after” scenario of voltages and tap positions on an LV network from a distribution substation.

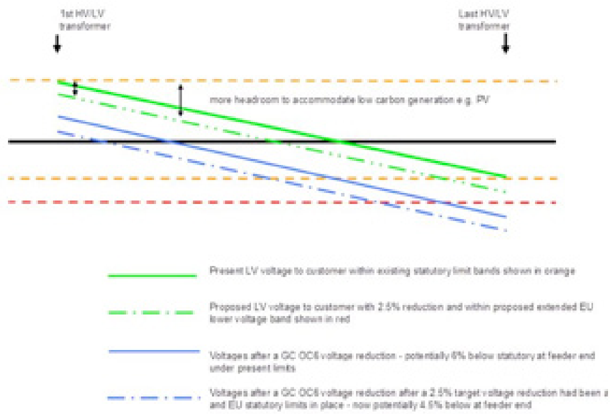


Figure 60, Before and After Voltage Scenarios

The National Grid / GCRP studies referenced indicate that such a 2.5% voltage reduction would produce both a 2.5% average reduction in demand and energy on the networks to which it was applied. Such reductions could be attractive to both Government and end users because it would -

- produce an immediate increase in generation capacity margin
- produce a reduction in UK electricity generation sector greenhouse gas emissions an aid achievement of Kyoto targets
- provide the cost benefits of energy reduction to millions of end users who cannot afford investment in such “voltage optimisation” equipment currently marketed
- provide additional headroom capacity for connection of LV distributed generation and LV loads including low carbon transition demands such as EV charging and heat pumps

The Project has taken this analysis one step further by providing conservative orders of figures and savings behind such a voltage reduction, for further detailed as to the impact, outcomes and calculations, please refer to the “Discussion paper on adoption of EU Low Voltage Tolerances” in Appendix B.

a) Reduction in demand on the network

The transmission entry capacity of major generators for the same period was 81.742 giving a margin of 24,252MW, and thus a saving of **618MW** would (coincidentally) also represent an increase of 2.5% in current capacity margin, though that figure would increase with impending station closures.

b) Reduction in customers energy bills

At that rate, the value to domestic customers alone of such a reduction in energy would be some **£315M** per annum based on DECCs current valuation of marginal domestic and I&C rates.

c) Reduction in CO2 emissions

Taking that voltage reduction applied at primary substation level would also apply to HV connect customers, the annual carbon reduction figure of an annual **1.98 Million Tonnes** of CO2 is conservative for the current generation mix.

As conservatively identified there are a number of extensive savings to be realised as a result of such a change. Furthermore it should also be noted that by having a wider statutory voltage limit, doesn't force all voltage levels to be reduced to operate at a minimum level. The same mode of operating the network, as is done today will still be applied, but it provides parties with opportunities to further reduce the voltage when required either tactically or as an enduring solution.

WPD promoted the issue of adopting EU voltage limits in its presentation to the Ofgem Expert Panel in October 2010, but did not factor in an level of benefits to the Project, as it would not be within WPD's power to implement it. There has also recently been wider recognition of the potential for temporary voltage reduction (e.g. Electricity North West Tier 2 LCNF CLASS Project). Consequently from the analysis undertaken as part of the Stresses Report, it is strongly believed that there is now a case for initiating wider debate to test benefits and constraints with a view to DECC issuing a public consultation. Given the range of stakeholders potentially involved, initial discussion might be facilitated by the Energy Networks Association, or by Ofgem.

PERFORMANCE COMPARED TO THE ORIGINAL PROJECT AIMS, OBJECTIVES AND SUCCESS CRITERIA

Details of whether and how the Project helped solve the distribution issue described in the First Tier LCN Project Registration Pro-forma.

There were 4 core aims and objectives that LV Network Templates intended to originally address. WPD has since being awarded funding achieved and exceeded the original core objectives, as well as successfully delivering invaluable additional outputs, via further DNO validation and a ready to use classification tool. An overview of performance is provided in the table 14 below, with additional performance related outputs identified in the 'outputs' section of this report. Finally it's important to note, that all successful delivery reward criteria were met and achieved within +/- 10 per cent of the original budget.

Objective	Purpose	Comment	Objective Achieved
Core Objectives			
The ability to identify low carbon stresses through templates and the associated voltage profiles	With greater visibility of temporal variations, UK LV network planners would be able to more effectively identify headroom constraints and opportunities via the application of templates.	Impact assessments regarding the application of low carbon generation and technologies have been completed for each of the templates. This analysis has utilised data from multiple sources: • Internal Project monitoring; and • externally from the £30m ARBED scheme	☑
A greater understanding of the actual difference between stressed and non-stressed parts of the network, due to either the connection or not, of low carbon technologies to the network (e.g. Heat Pumps, PV, Electric Vehicles)	Having greater understanding of the stresses on the network, will aid planners in identifying parts of the network which are better suited to accommodating low carbon technologies and generation. Additional information can also be provided to National Grid aiding them with short to long term forecasting activities.	There was no marked difference between substations associated with high level of PV installations. However there was some evidence of stresses associated with heat pumps.	☑
The statistical case for using a limited number of PV feed-in tariffs (meter readings to reflect the aggregate output of others).	If proven, proxy FiT monitoring would provide a lower cost solution in understanding network demand and generation.	High levels of accuracy were achieved in predicting PV outputs within postcode areas based on knowledge of the installations e.g. capacity, inclination and bearing.	☑

The degree of headroom and actual voltage levels measured across wide parts of the LV system (topology and customer mixes)	To demonstrate that statutory voltage limits were complied with, and to understand if there was a valid case in being able to operate the network at wider EU voltage limits.	Extensive analyses of voltages identified that levels were at the higher end of the permitted scale, indicating that existing levels could be reduced enabling more headroom for future generation to be accommodated.	☑
Additional Objectives			
DNO Template Validation	**To further validate that Templates would be applicable across 50% of the GB Network**	**In addition to the WPD monitored substations, data was supplied from five DNOs for 284 substations. Following the templates methodology, substations were classified into templates, and where data was available, estimated demands were compared with measured values. Accuracy was found to be very high at between 80 and 90% for each of the DNOs (accuracy being defined as the total error within a day being less than 20% of the transformer rating).**	☑
Classification Tool	**To allow planners a visual representation of the indicative load and voltage flows on any given LV substation**	**Provides a standalone planning tool that is ready to use today. Behind a user-friendly input screen, the statistical modelling required for the templates methodology is utilised to produce graphical output of predicted load demands. Options are available for output by day and season.**	☑

Table 14, Performance compared to the original Project aims, objectives and success criteria Overview

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

The DNO should state any changes to its planned methodology and describe why the planned approach proved to be inappropriate.

The Project continually sought to embed the lessons learnt, whilst adapting and addressing the challenges that occurred when delivering a complex Project like LV Network Templates. As a result of this, additional modifications to the planned approach were identified, as illustrated in Table 15, below. A brief summary of these modifications will be provided below, for further information please refer to the 'details of work carried out section'.

Item#	Change	Impact/Outcome to Project	Change to Project costs
CCR001	Reduction in the number of Voltage Monitors	**Neutral** • No impact on the credibility or outcome of the templates (confirmed retrospectively following data collection and analysis by the University of Bath) • Unused voltage monitors are being redeployed by WPD resulting in a Project "refund" of £350k to customers	Yes
CCR002	An alternative to customer premises monitor installation	**Positive** • Additional solutions were deployed to ensure sufficient feeder-ends are monitored without disrupting customers	No

CCR003	DNO Validation Analysis	**Positive** • Further validation work was undertaken by comparing other DNO network data enabling actual versus estimate analysis to be undertaken. This work adds further value to the Project by reinforcing the findings and templates overall suitability for wider GB application • This change was suggested by industry stakeholders when CCR001 was consulted upon	No
CCR004	Classification Tool Development	**Positive** • Provides DNOs with a tool that can be immediately applied into their businesses • Tool provides a visual view of the scaled or un-scaled load and voltage flows at a given substation allowing a greater understanding of the impact that various Low Carbon Technologies have	No

Table 15, Change Request Overview

CCR001: Reduction in the number of voltage monitors installed

The number of feeder-ends being monitored in the customers premise was lower than initially anticipated. This was due to the customer recruitment and installation proving more difficult and time consuming than originally estimated. Within the original submission it was anticipated that over 7,000 voltage monitors would be installed in domestic properties, located at selected phase ends of the LV feeders from the 1036 substations in the trial area.

When installing the voltage monitors, the initial customer response rate was not very high, due in part to the format of the letter, the time of the year, and unwillingness to have a 30-minute power outage to fit the voltage monitor. Additionally in some installation visits, space restrictions close to the existing household meter position meant that the fitting of a voltage monitor was not possible ('meter abort'). This resulted in a further reduction of the number of installations already restricted by limited consent (See Figure 61, Example Abort Photo).

Figure 61, installation aborted (restricted space photographic evidence)

Steps were taken in late 2011 to improve the letter, including offering an incentive, which marginally increased the response rate. Never the less, the low customer response rate had significantly affected the installations of single-phase monitoring in customers' homes, to the extent that alternative methods of obtaining voltage readings were being pursued. Such as installing monitors in street furniture such as road-side pillars and in enclosures up poles (see CCR002). These alternative methods would ensure that sufficient data was being collected, allowing for credible and representative Project outputs to be concluded.

Single-phase monitor installations in customer's houses were due to finish at the end of May 2012, but continued until the end of November 2012. Three-phase installations in businesses also continued until the end of November 2012 The final number of feeder end monitors successfully installed was in excess of 3600.

Finally it should be noted that when it became clear that to achieve the original 7000 target considerably more time and expense would be required, The University of Bath were asked to assess the impact on the Project. This concluded that it would have little impact on the National applicability of the Templates. Their letter of support is provided in Appendix B.

The unused monitors will be used by WPD's Smart Metering department and the cost savings of £314,200 will be returned to customers upon Project closedown through DUOS. The above changes were presented to Ofgem along with the lessons learnt through customer engagement in March 2013, and a copy of the report including our six monthly progress reports can be found at www.westernpowerinnovation.co.uk.

CCR002: Alternative Monitoring Methods
As CCR001 identified, it was necessary to deploy alternative methods of recording voltage at the feeder-ends of the monitored substations. As such in addition to a fixed voltage being installed in a customer's premise, the following alternative methods were developed and deployed:

- Ground monitoring (Haldo Pillar street furniture)
- Pole monitoring (street furniture)
- Plug in voltage monitor

The network services team installed over 135 ground and 30 pole-mounted 3 phase monitors at short notice. In deploying these two methods additional work was required from designing and buying of monitoring enclosures to the identification of the best locations of the network for monitoring to occur [38]. Sites were then chosen that were closest to the end of the feeders, and where there was no or minimal monitoring taking place at that given point in time. The key benefit of this approach is that no customer consent was required and an installation plan could be followed that didn't require the customer to be at home during their deployment. Finally, ground and pole mounted installations were completed at the end of June, at a cost of approximately £1500 each, costing in the region of £250000 in total.

In addition to the ground and pole mounted monitoring methods, a more affordable and flexible solution was developed. A plug in type voltage monitor was designed, that could be plugged into a customer's wall socket without the need for an interruption of supply. 250 were developed, all of which were installed at a cost of £51.92 each, costing in the region of £12980.

The costs of both of these alternative methods are to be allocated to the contingency budget and as such will not impact on the overall cost of the Project. Each of the above alternative solutions have been discussed in greater detail in the works carried out section of the report, for further information please refer there or get into contact with wpdinnovation@westernpower.co.uk.

[38] Other activities: Surveying the suitability for street furniture erection, installing the required cabinet, excavating the footpath/road to gain access to the cable, jointing a new 3phase service onto the main and terminating it in the new cabinet.

CCR003: DNO Data Validation Analysis

The original Project proposal was based on the final Templates being applicable to 50% of GB Networks. This was an assumption, based on the varied topography of the Project area, rural, urban and suburban, with a good mixture of customer types (Elexon profiles 1-8). In addition to this WPD's networks are designed as part of the historic national system, and their planning and design tools are common to most other DNO's.

Rather than carry on with this assumption, WPD held a DNO/Ofgem learning and consultation workshop in Bath on 14th May 2013, and suggested that using DNO monitored and fixed data to validate the templates and tools would reinforce the Projects findings.

At the time, all the DNOs agreed to provide WPD with this data, as they saw the real value and relevance/ timing for further validation work to be undertaken. The data received from the DNOs was analysed by The University of Bath for its ability to cluster into the appropriate template. The findings of this are discussed in the outcomes section of this report.

The costs of extending the analysis with the University of Bath will be £61,509. This will also cover CCR004, the development and creation of the classification tool. Both changes will be allocated to the contingency budget, and therefore does not require additional funding.

CCR004: Classification Tool Development

In order to help the other DNOs, in potentially being able to immediately embed the LV Network Templates into their business as usual planning activities, a common classification tool was developed. Whilst this work was not in scope of the Project, it was deemed as being both relevant and timely to do so. And would minimise the additional work, cost and time that other DNOs would need to spend in order replicate the steps needed in order to embed it into their business.

For the Templates to be of real use to all DNO's there needs to be a relatively simple method of feeding in network data to produce the required output. Having a Classification Tool would provide a visual view of the scaled or un-scaled load and voltage flows at a given substation. Allowing the user to have greater understanding of the impact that various Low Carbon Technologies will have at that given substation, during weekday, weekend and or various season. The tool has been made available to all interested parties on Project closedown, allowing the benefits of the templates to be immediately applied by other DNO planners. It should be noted that without having this tool, a DNO would need to analyse their network themselves in relation to the Templates. For further information surrounding the classification tool, please refer to the 'works carried out' section of the report.

SIGNIFICANT VARIANCE IN EXPECTED COSTS AND BENEFITS

The DNO should describe if any parts of the Project ended up costing more or less than expected (+/- 10 per cent). In relevant cases, the DNO can link the cost changes to the section on required modifications to the planned approach.
If costs were different to what the DNO expected, the DNO should provide details of why this was the case.

The DNO should discuss whether the benefits of the Project matched the DNO's expectations. This should include any changes to incentive payments and any changes to expected savings in revenue allowed for in the DPCR5 settlement.

As table 16 below highlights, no part of the Project ended up costing more or less than expected (+/-10percent),as such the final costs of the Project were not different to what was expected. When making a comparison of the potential benefits that have been realised as a result of this Project to it costs, distribution customers have made a significant return of investment from this Project. These benefit estimations are as discussed in the outcomes section of the report, based on conservative calculations and do not take into account benefits derived from the qualitative outcomes or lessons learnt along the way for future Projects.

Budget identifier	Item	Total budget	Expected spend to date	Total Expenditure	Variance %
	Box 6 (Employment costs)	£1,347,000	£1,347,000	£1,340,495	-0.5%
6.1	Substation monitor fitters	£414,000	£414,000	£434,030	4.8%
6.2	Planning Manager	£187,000	£187,000	£177,856	-4.9%
6.3	B2B External Relation Manager	£112,000	£112,000	£113,933	1.7%
6.4	B2B Manager	£112,000	£112,000	£109,052	-2.6%
6.5	Project Manager	£187,000	£187,000	£171,339	-8.4%
6.6	Project Management Team (3 staff)	£300,000	£300,000	£299,059	-0.3%
6.7	Call centre staff	£35,000	£35,000	£35,227	0.6%

	Box 7 (Equipment costs)	£5,301,000	£5,301,000	£5,787,453	9.2%
7.1	Data concentrator at substation	£200,000	£200,000	£218,816	9.4%
7.2	ENMAC updates	£100,000	£100,000	£109,408	9.4%
7.3	Message switching/hub software	£150,000	£150,000	£164,112	9.4%
7.4	Enhanced FEP software	£95,000	£95,000	£103,937	9.4%
7.5	Data concentrator/ substation monitoring	£1,190,000	£1,190,000	£1,301,955	9.4%
7.6	Data comms hub	£150,000	£150,000	£164,112	9.4%
7.7	Data comms using meshed radio type technology	£735,000	£735,000	£800,505	8.9%
7.8	Data comms using PLC technology	£867,000	£867,000	£948,567	9.4%
7.9	LV end voltage monitors	£1,765,000	£1,765,000	£1,922,432	8.9%
7.11	LV FIT meter installs	£49,000	£49,000	£53,610	9.4%
	Box 8 (Contractor costs)	£1,293,000	£1,293,000	£1,302,590	0.7%
8.1	Monitor fitter contractors / appointment booking contractors	£727,000	£727,000	£747,286	2.8%
8.2	Project management / consultancy	£160,000	£160,000	£163,531	2.2%
8.3	Bath University analysis	£306,000	£306,000	£282,414	-7.7%
8.4	Radio site survey contractors	£80,000	£80,000	£87,488	9.4%
8.5	System testing / analysis contractors (SCADA)	£20,000	£20,000	£21,872	9.4%
	Box 10 (Other costs)	£1,074,000	£1,074,000	£1,140,857	6.2%

10.1	IT costs	£106,000	£106,000	£109,534	3.3%
10.2	Contingency	£820,000	£820,000	£882,894	7.7%
10.3	Public engagement/ learning dissemination	£148,000	£148,000	£148,429	0.3%
		£9,015,000	£9,015,000	£9,571,395	6.2%

Table 16, Project Costings

Finally, it should be noted that £350,000 remains in the Project Bank Account. This is equivalent to the cost of the unused voltage monitors previously agreed. In line with LCNF governance this money will be returned to GB customer via DuoS, following Project close down. The final Project spend in each box will not exceed the 110% limit set in section 6 of the Project Direction.

LESSONS LEARNT FOR FUTURE PROJECTS

Recommendations on how the outcome of the Project could be exploited further. This may include recommendations of what form of trialling will be required to move the Method to the next TRL. The DNO should also state if the Project discovered significant problems with the trialled Methods. The DNO should comment on the likelihood that the Method will be deployed on a large scale in future. The DNO should discuss the effectiveness of any contractual Methods that formed part of the Project.

In this section of the report specific focus is given to lessons that have been learned along the way, whilst delivering the Project. To better understand how the Project objectives (core and additional) and their outcomes are exploited further, please refer to the Planned Implementation section of this report. These two outcomes have been separated; in order to clearly make a distinction between 'delivery lessons learnt' that can be applied to future LCN funded Projects; and the outcomes associated to the key Project objectives being embedded into DNOs and the wider industry. As the Project was challenging and complex, valuable delivery lessons were learnt along the way that were either anticipated or unforeseen during the Projects proposal to Ofgem. These delivery lessons have been captured by the University of Bath, in their capacity as knowledge brokers.

Through the knowledge capturing methodology and tools applied, many successful practices which can be replicated in future Projects have been identified. An overview of some of the lessons learnt and the area for future application is illustrated in Table 17 below. The knowledge management report (Appendix A) presents a more exhaustive list of the 86 concrete lessons learnt and where they could be exploited further. As lessons were learnt throughout the Project lifecycle, internal and external dissemination events have allowed other parties to embed relevant learning's for their Project.

In addition to sharing the lessons learnt via dissemination events, WPD and its Project Partners are also developing a LCN bidder's guide. This guide will distinguish between the type of Project (e.g. research, engineering, mixture) being proposed and some of the opportunities or pitfalls to be aware of when eventually delivering it. This guide is timely and relevant to the industry, especially as the Network Innovation Fund and Network Innovation Allowance have opened up to the gas and transmission markets.

		Customer Communication	Engineering Process	Project Management	Engineering Practice	Bidding	Telecommunication	Collaboration	Ofgem	Knowledge management
L3	It might be useful to use higher Technology Readiness Level (TRL) thresholds for the volume/cost elements of Tier 2 schemes which are not the primary focus of the Project.								■	
L4	Technology readiness levels can prove different to what they initially appear, and having sufficient flexibility in a Project to allow for this is valuable.				■	■			■	
L6	Whilst DNOs have addresses and MPANs, they might have difficulty accessing up-to-date customer contact details as they do not routinely contact householders. Having up-to-date customer information available is critical for any Project seeking customer consent.	■								
L7	It is useful when customer interaction across a Project is viewed as one activity. Where there might be several steps involved, ensure opportunities to minimise disruption and visits to customer premises are exploited where possible.	■								
L16	Contacting customers at an appropriate time leads to a better success rate. In this Project it was useful to contact householders after 1800 and businesses between the hours of 1000 and 1400.	■								
L17	It is valuable to consider in advance the types of questions that customers might ask and to ensure that everybody on the Project is able to answer these effectively and consistently.	■								
L18	Attempts should be made to inform the customer in advance of any visit (e.g. letters, telephone calls, local media etc.). Additionally it is also important to ensure all relevant authorities (and customer-facing teams in your business) are aware of the Project so they can provide consistent, high-quality advice.	■								

L20	Plug-in voltage monitors have many advantages over hard-wired meters, including greater customer appeal and quicker, easier installation. However, there is a risk customers could unplug them.
L21	When planning or sourcing equipment, consider some of the following: • Are aesthetics of a solution important? • How can technology be used to reduce disruption?
L22	Customers' ability to house monitoring equipment varies a great deal, and sufficient time needs to be allowed for when installing any form of monitoring.
L23	The way installers are remunerated could affect the overall customer experience, sign-up rates and installation speed.
L26	Householders are more reluctant to tolerate an interruption to their energy supply in winter.
L31	If equipment is to be installed in rented properties, time must be budgeted to seek permission from both the tenant and landlord.
L34	When working with contractors, it is useful to have a back-up plan in place to allow the Project to progress smoothly if they become unavailable or fail to meet their targets.
L35	Where hardware is not available off the shelf, seek that the proposed design is explored thoroughly at bid stage and/or ensure sufficient contingency is built into a design phase.
L37	A full substation survey prior to equipment being installed can highlight potentially difficult to install sites.
L39	For unavoidable supply interruptions, out-of-hours working further minimises the impact to customers, although the resource implications of significant out-of-hours' work must be considered.
L41	There is great value in planning, at an early stage, to use recognized International standards wherever possible – specifically for IT, data storage and communications.

L47	When technical documents or ideas need to be translated for wider audiences, a person with specific communication or marketing skills can work with the domain experts to improve communication.
L49	The use of tools and techniques not commonly employed in the electricity industry may give rise to useful domain-specific learning, such as the fastest clustering methods for data gathered from voltage monitoring.
L51	Support from the Project manager is vital for ensuring knowledge capture occurs easily. Knowledge managers and Project managers can lead by example to highlight the value of knowledge capture.
L52	Regular meetings in which information is shared across DNOs could allow knowledge managers to better embed best practices, lessons learnt and avoid duplication of effort.
L56	It could be useful to explore ways to routinely store key emails as a way of capturing informal thoughts and decision processes.
L59	Dissemination events are excellent for sharing knowledge with the industry, although there may be a benefit if these are collaboratively coordinated to reduce overlap and conference fatigue.
L61	Dissemination events worked best and proved popular when the audience were required to provide feedback and proactively participate in the discussions.
L62	Communicating back to the wider industry the feedback from dissemination events, will help to continually improve future events.
L63	Providing a centralised website helped interested parties explore and understand the LCNF Projects. Visitors who found the website through one Project may benefit from learning about the others.
L64	More traditional methods of internal document dissemination – including email and the publishing of reports on websites – have worked well and should continue to be adopted for further Projects.

L67	The guidance and governance criteria set by Ofgem is extremely helpful during the bidding and delivery stage. Further guidance could be useful on whether Ofgem values technological novelty (with the possible complications this brings to Projects) or whether they would prefer Projects whose main purpose is to answer engineering questions.
L71	DNOs making data requests to other DNOs need to be aware that other DNOs may use different internal processes, meaning it may be harder for them to gather the data than might be assumed.
L73	Online tools have much to offer for facilitating collaboration between distributed Project teams and their greater use should be seriously considered for future Projects. If online tools are not to be used, Projects might be lengthened, or their aims reduced, to allow for the additional demands of analogue working.
L74	It is useful if explicit consideration is given to the relationship between a DNO and each of its LCNF collaborators. Is the relationship a straightforward supply of goods or services, or is it a partnership arrangement? Different practices and demands apply to each.
L76	LCNF Projects are very different from the core activities of a DNO. Expectations should be set accordingly, and practices need to be sufficiently flexible to acknowledge the difference.
L78	A technique which might prove useful for capturing informal knowledge and experiences in the future is for the knowledge capture team to call members of the Project from time to time and take a brief ‘snapshot’ of their recent experiences and thoughts.
L79	Contingency in a Project’s schedule is valuable to allow for unexpected events and developments, but also – in later stages – allowing reflection on the Project’s outputs and what these mean.
L80	Where a Project involves an activity outside usual DNO business, it is usually better to engage an outside expert rather than seek in-house skills. Outsourcing also reduces demands on key DNO people.

L81	Having a co-manager clearly made the Project run more efficiently and might be considered for standard practice in the future.
L84	It can be useful to have cross-over between Project personnel to help disseminate the learning.

Key
Customer Communication: how DNOs might deal with the public effectively
Engineering Process: how to plan and run the engineering components of a research Project
Project Management: how best to run an LCNF Project
Engineering Practice: concrete engineering principles
Bidding: planning and writing LCNF bids
Telecommunication: the telecommunication aspects of LCNF Projects
Collaboration: interaction between multiple organizations in a research Project
Ofgem: LNCF issues that Ofgem might consider
Knowledge Management: capturing and sharing information about research Project

Table 17, Delivery Lessons Learnt

Finally, Tier 2 LCNF Projects present a number of contractual challenges that are not present in normal contracts:

A) There is a significantly longer timescale between seeking competitive tenders for the final submission and award of contract after award notification (about 3-4 months) than normal tender validity periods. This can impact on potential suppliers view of risk associated with their bid and management of their forecast order book
B) Publication of detailed cost breakdowns in the submission may influence suppliers bids
C) The period between ISP and final submission, together with containing cost, mitigate against undertaking detailed ICT architecture studies with any given supplier

PROJECT REPLICATION

List all physical components and knowledge required to replicate the coutcomes of this Project, also showing how the required IP can be accessed by other GB DNOs

In order to replicate the LV Network Templates Project, both physical components (Table 18) and the knowledge (Table 19) provided in the tables below are required. Please contact WPD and the University of Bath for further detail relating to any physical component or knowledge requirements wpdinnovation@westernpower.co.uk.

Physical Compo-nent	Specifications	Products used in Project
	Substation Monitoring	
Substation Monitor	The device must provide the equivalent functionality of a multifunction, UK certified, poly phase electronic meter to the same accuracy and must be suitable for both commercial and industrial applications. The device must be provided with two alternate addressable communications ports each being capable of supporting power line carrier or UHF radio communications links. Each port must be capable of operating simultaneously and independently. As a minimum, the Smart Grid Sensor must provide facilities to measure the following information: • Separately, both Instantaneous and Time Related Active and Reactive Imported and Exported Power Throughput. It is anticipated that the time band will initially be 30 minutes though this should be capable of being changed in 5 minute increments from 5 minutes to 60 minutes inclusive.[This is similar to the collection of Settlements Data as practised throughout the ESI at present] • Instantaneous Current and Voltage over each of the phases It must be possible to establish, remotely or locally, bandwidths of absolute values that will prevent unnecessary value transmissions over the communications network e.g. say a value of =/- 10% is established with a measured voltage of 230v, no values would be transmitted if they sat between 217v and 253v respectively. AC power data associated with maximum current, minimum voltage and power factor for each half hour of the day (i.e., 144 analogues per day) Real time data showing loss of supply, current and voltage irregularities Real time polling for any of the data types above. In addition, the device should be capable of also providing the following ancillary facilities: • Phase Sequence • Phase Voltage phase angles • Phase Current phase angles • Neutral Current • Power – active, per phase • Power – reactive, per phase • Apparent power (kVA) per phase • Displacement power Factor • Voltage Sags and swells • Outage Counter • Date and Time Of Last outage • Cumulative Power outage Time • Harmonic Distortion per voltage and per current phase • Total Demand distortion per phase	GE KV2C Meter GE SD4 Radio GE Data concentrator

	It should be possible to implement a minimum of 7 of these additional elements at any time by means of remote configuration. The accuracy of the data produced by the measuring device must be collected to IEC 62053, Class 0.5 S accuracy. If a meter is used as this device it must be certified for use in the United Kingdom. Preference will be given to installations where modems can be hot swapped to support Power Line Carrier and Mesh Radio connections.	
Housing of Substation Monitor	Must be a secure and, as a minimum, a polycarbonate, cabinet designed to IP67 It must be capable of accommodating effectively all of the various elements proposed to meet the specification. It must be possible to securely close the housing using a standard locking mechanism. The polycarbonate (or equivalent) housing must be self-extinguishable and must be capable of being recycled. The housing must also be capable of accommodating additional equipment with an overall size of 37 cm * 20 cm * 10 cm that may be included at the site in future. The housing should be capable of accepting external temperatures between -20° Centigrade and +40° Centigrade. Equipment contained within the housing must operate between the temperature limits of -30° Centigrade and +60° Centigrade. This can be accommodated by introducing elements of ventilation/heating into the box construction. Provision must be made to enable the housing to be mounted either on a pole, alongside or on the LV cabinet of a ground mounted transformer. A typical example is shown below:  The design and size of the cabinets must be such that access and clearances to existing substation equipment can be maintained at all times. The cabinet must be provided with appropriate heaters and / or hydrostats to maintain the environmental temperatures specified inside the cabinet.	IP 67 Poly carbonate cabinet

	The design of the installation must allow the cabinets to be accessed for work within on the measuring device whilst the L.V. Network is kept ALIVE. The housing will also make provision to accommodate any modems and antennae required to provide communications. It must also be possible to mount an external antenna to be used where the 'internal' antenna cannot be used. The connection port to an external antenna must be present inside the housing. Any mounting foot for the cabinet must be designed to allow direct fixing to a pole and any other surface such as a wall or other cabinet.	
Current transform-er (compat-ible with monitor)	The CTs must be class 0.5S and can either be enclosed in the housing above, or can be weather-proof and outside of the housing where they are to be used in pole mounted installations. If the weatherproof CTs are proposed, they must IP68 compliant. Strain relief or a sheath will be provided where cables enter a CT encapsulation to prevent damage during installation. A torroid aperture of 1" for 400 amp and 3" for 1600 amp with suitable sleeving will be provided.	D.K Moriarty Ltd 1600/5, 800/5, & 400/5. BS EN60044-1 class 0.5S. 50mm Int Dia. 100mm Ext Dia.
	Feeder-End Monitoring	
Voltage Monitor	The voltage monitor installed in consumer premises must provide the equivalent functionality of a multi-function, UK certified, single phase electronic meter to metering accuracy standards. Voltage monitors used in domestic premises will be either capable of housing a power line carrier, GPRS or radio modem within their casing OR be capable of being installed INSIDE a power line carrier, GPRS or radio modem casing. There is no requirement for the domestic voltage monitor to have a visual read out facility The domestic voltage monitor must be capable of recording the following information: • The voltage monitor will only be required to record Instantaneous voltage : • The accuracy of the data produced by the measuring device must be collected to IEC 62053, Class 0.5 S accuracy. Samples will be taken at 10 second intervals • If a meter is used as this device it must be certified for use in the United Kingdom	EDMI Mk 7c & Mk10A GPRS Meter (domestic & Street furniture) GE SM110 Meter (PLC) GK PLC-S8-P(V1) Node
Street Furniture	A standard street furniture cabinet, housing BS88 cutout and EDMI Mk7c GPRS Meter. Overhead system. An IP67 Polycarbonate cabinet, pole mounted housing an EDMI Mk7c GPRS meter	EDMI Mk7c GPRS Meter IP67 BOX Polycarbonate cabinet

Plug-in Monitor	An IP67 polycarbonate box with flexible lead with standard 230v 3 pin plug connected to EDMI Mk7c GPRS Meter	EDMI Mk7c GPRS Meter IP67 Box
		
PV FiT Monitoring		
PV Monitor	PV monitors were fitted in series with customers FiT meters , Capturing Current (generation) and Voltage	EDMI Mk7c GPRS Meter
ICT and Communications		

Data Process-ing	The computer operating system for all of the various components of the Project should be either Linux or Windows. Full Development Tools must be recommended and/or provided to allow future work to be undertaken by WPD staff. Each Feeder-End, PV and Substation Monitor connected to the LV network will be provided with a unique identifier that will be used to 'tag' collected data so that it can be managed and monitored at any time. The preferred format of the identifier will be a simple number in the range 00000 to 99999 inclusive though any properly defined format will be acceptable. The identifier must be anonymised i.e. it must not be possible to identify a physical address from the identifier. At each of the substations there will be a Smart Grid Sensor as defined previously monitoring data associated with the substation. In addition, at a number (or all) of the substations it will be necessary to establish a Substation Concentrator that will communicate with the associated Smart Grid Sensors. In addition, the Substation Concentrator will accommodate the storage and onward transmittal of the data to: • WPD's ENMAC/PowerOnFusion © installation and, • A data concentrator where it can be stored for analysis by Bath University The Substation Concentrator will also have the ability to forward data to WPD's ENMAC/PowerOnFusion © installation on demand. The information can take the form of a request for loads or a simple ping of the installation to see if supplies are available to the customer, a request for substation loads etc. – either in real time of for the half hourly demands. The substation data concentrator will hold up to 144 half hourly demands for onward transmission to the main concentrator on demand, or as a programmed weekly task.	GE PowerOn Fusion GE SMOS server GE STIP server Bath University Server GE Data concentrator GK PLC Node FTP server Operating system: Microsoft Windows Server 2003 Standard Edition (32bit) SP1 Hardware: Intel: Genuine Intel x86_64 (VM Version 7)

Data Processing (continued)

When the data has been received at the main concentrator, it will be removed from the Substation Concentrator.

The main Regional Concentrator will act as a 'message switch' between the WPD ENMAC/PowerOnFusion System, the Substation Concentrator and the Bath University system

The Regional Concentrator will have the following functionality:

- Continuously poll the Substation Concentrators to obtain data associated with the Project. It will act as a storage location for all of the data required for the development of the LV Templates and will also forward data to WPD's ENMAC/PowerOnFusion System associated with half hourly demands.
- To poll the Substation Concentrators at 5 minute intervals to obtain 'real time' loading information to be used in the Control Room through WPD's ENMAC/PowerOnFusion System
- Interpret customer outage data received from the substation data concentrator to indicate the existence of LV fault. In order to achieve this, it will be necessary for the main concentrator to hold a database of LV feeder information against customers. Processing will be carried out the interpret customer outages as single customer, phase, feeder or substation outages. It must also be able to interpret outages from a variety of Substation Concentrators as widespread HV faults
- In all cases appropriate Alarm Log entries will be made in WPD's ENMAC/PowerOnFusion System
- Receive requests from WPD's ENMAC/PowerOnFusion System for information either in real time, or as programmed actions for the following data:
  - Voltage
  - Current
  - Quality of supply
  - Customer on or off supply

STIP server

Operating system: Red Hat Enterprise Linux Server release 5.3 (Tikanga) 2.6.18 128.el5 (64-bit)

Hardware: Intel: Genuine Intel x86_64 (VMWare Version 7)

Database: Oracle Database 11g 11.1.0.7.0 Standard Edition.

LCNDATA server

Operating system: AIX 6.1.0.0 6100-06 (64-bit)

Hardware: IBM Corporation

Database: Oracle Database 11g 11.2.0.1.0

Data Process-ing (continued)	The mechanics of the transfer of data from the Regional Concentrator to Bath University will be by SFTP at regular intervals. When the data is transferred to Bath University it will comprise the site identifier, the time stamped data types and values being transferred. Under normal circumstances, every day the previous day's data will be transferred to Bath. Bath University's system will carry out the interpretation of the identifier into customer related information.	
Communi-cations	It is expected that the communications between customer's voltage monitor and GE'S data concentrator (SMOS) will normally be via GPRS .The Substation Concentrator will normally communicate by meshed radio. A small number of voltage monitors will use Power Line Carrier communication protocols. All communications must use nationally agreed standard protocols e.g. DNP3, IEC870 etc. and must support full encryption through all the stages of data transmission. Where meters are involved, the communications protocols utilised must either be one that is currently approved for use in the UK or one that is available internationally. Communications speeds should be a minimum of 9,600 bits per second between the Substation Concentrator and the domestic voltage monitors and between the Substation Concentrator and the Regional Data Concentrator. The communications speed between the Regional Centre should be a minimum of 19,200 bits per second, though if the processor is installed in the existing computer room it will be a standard Ethernet connection onto WPD's corporate LAN. Data encryption will be unnecessary for this link. Communications between the Substation Concentrators and the main Regional Centre can take numerous forms though preference for LV Network Templates was Ultra High Frequency (UHF) Radio. Bath University:- To assist with the data transfer, a SFTP server was configured on a Linux server within the Department of Mathematical Sciences, allowing restricted access to a secured storage area. The University firewall was opened up to allow traffic on port 22 to be forwarded from WPDs network to this host. Shared keys were used to allow passwordless file transfers to occur automatically without the need for continual user interaction.	GE SD4 Radio Vodafone M2M platform 3G Sims GK PLC NODE SFTP Server Linux server

Table 18 Physical Components

Knowledge (Subject)	Application	Methodology
	LV Network Templates	
IT, Linux, SFTP	Data delivery	Set up secure link for regular data transfer
Power engineering, data analysis	Data Sense-Checking	Routine checking of data quality: summaries, consistency between fixed and variable data
Statistical clustering (postgraduate statistician level), statistical programming language R (open source)	Clustering	Hierarchical clustering
Statistical modelling (postgraduate statistician level), statistical programming language R	Classification	Multinomial logistic regression
Statistical modelling (postgraduate statistician level), statistical programming language R. Power engineering.	Scaling	Constrained non-linear regression
Power engineering, data analysis	Quality Assurance: Outlier Analysis	Checking accuracy of estimates versus actual measurements, relating to fixed data
Statistical techniques (postgraduate level) as in Clustering, Classification and Scaling above	Additional DNO Data Validation	As in Clustering, Classification and Scaling above.
Interface between output from statistical package R and Excel. Expertise in Excel (intermediate).	Classification Tool Development	Embedding coefficients and results from classification and scaling models into Excel workbook. Data entry is via Excel worksheet that calls appropriate values and performs calculations. Results and graphs presented in Excel sheet.
	Low Carbon Technology Stress Report	
IT, Linux, SFTP	Data delivery	Set up secure link for regular data transfer
Power engineering, data analysis	Data Sense-Checking	Routine checking of data quality
Database management	Matching feeder end voltage monitors to substations and templates	Comparing voltage profiles at feeder ends with corresponding demand profiles for substations
Data analysis, power engineering	Stress Analysis	Identifying potential stresses though comparison of actual measurements with limits
	PV FiT Proxy Analysis	
Power engineering, data analysis	Data Sense-Checking	Routine checking of data quality
Statistical modelling (postgraduate statistician level), statistical programming language R	Modelling underlying patterns in PV outputs in relation to fixed data	Spatial-temporal regression modelling
Statistical modelling (postgraduate statistician level), statistical programming language R	Prediction of PV outputs using fixed data	Regression modelling
Power engineering, statistics	Assessment of use of proxy meters	Estimating biases from prediction models

Tabel 19, Knowledge Components

PLANNED IMPLEMENTATION

Details on whether and how the DNO plans to modify its Distribution System based on learning from the Project. If the Method is not ready to be implemented, the DNO should explain what needs to happen before the Method can be implemented. The DNO can break down the requirements into actions required by DNOs and actions required by non-DNO parties.

Western Power Distribution commissioned Accenture to undertake an assurance review of all of outcomes as a result of the core and additional objectives the Project set out to achieve. The purpose of this review was to, at a high level, understand the key opportunities that the outcomes could present to WPD and the wider Industry; followed on by the development of an 'implementation roadmap'. A template approach was taken, as identified in the tables below that capture a range of information from a number of internal workshops and interviews held. These workshops and interviews were supplemented by Accenture's experience, allowing for a number of outcomes to have already been 'deployed', and the remaining 8 outcomes to be classified as either 'planned' or 'requiring further work'. It is important to recognise that for those outcomes having a status of 'planned' or 'requiring further work', there may be the requirement to do further analysis, to ensure they are suitable for deployment into business as usual.

OUTPUT ANALYSIS AND PLANNED IMPLEMENTATION

Output Overview versus Planned Implementation

Area	Key Project outputs	Dependencies: Output Inter-dependencies	Dependencies: Actions required by non-DNO parties	Current As-Is	Future To-Be (Potential)	Output Status (Deployed, planned, requires further work)	Length of benefits & expected delivery time-frame (Short, Medium, Long-Term)
LV& HV	**Voltage Reduction (+10%/-6%) (South Wales Selective Voltage Reduction Programme):** The findings of the Project have identified the opportunity of WPD being able to reduce the voltage level on certain parts of the WPD network whilst remaining within statutory limits.	None	None	Voltage levels are automatically controlled through tap-changers at the primary substation, tapping up or down to ensure that voltage levels remain within statutory limits (ESQCR). Only in the event of an "OC6" request from National Grid will a signal be sent to forcing the tap changers at the selected 33/11kV substation to cause a reduction in demand for a given period of time.	Selected HV networks will have their voltage and thereby HV & LV demand levels reduced by the lowering of the normal tap changer setting. Even with the lowering of the voltage levels, WPD will remain within statutory limits (ESQCR) and be able to respond to "OC6". The outcome of this change as a business as usual operation would result in both carbon and financial savings to customers.	**Deployed**	Long term benefit delivered quickly (2013-2016) The expected delivery time of the tactical drop in voltage levels at selected substations will be rolled out in stages across the next 3 years.
	Voltage Reduction (+10%/-10%): The findings in the Project highlight the opportunity of changing the statutory voltage limits (+10%/-6% to +10%/-10%). Adoption of the EU levels, coupled with lowering target HV system voltages would provide multiple benefits to UK capacity margin, CO2 emissions, reduced customer bills, deferred reinforcement and increased network capacity to absorb new low carbon stresses such as PV, EV charging etc.	None	Ofgem & DECC	The current statutory voltage limits are to operate the distribution network at +10%/-6%. The voltage levels are automatically maintained through adjusting tap-changers at the primary substation. Only in the event of an "OC6" request from National Grid will a signal be sent to forcing the tap changers at the selected 33/11kV substation to cause a reduction in demand for a defined period of time.	The majority of the WPD HV & LV network can operate at a lower voltage level by reducing demand through the lowering of the tap position within the primary substations. WPD will still be able to respond to OC6 albeit whilst at a lower voltage level.	**Requires further work**	Long term benefit delivered in the long term (2013-TBC) The expected delivery time is likely to be in the long term as it will require industry consultation (ESQCR change).
	LV Network Templates: Templates can be applied to check and modify the standard customer profiles (or after diversity maximum demand values) used within our LV Design Software	None	None	Currently LV Planners use the Elexon customer profiles to make informed decisions.	Templates to be embedded within existing planning tools	**Planned**	Medium term, benefit delivered in the short term (2013-2014)

Scaling and MDI Modelling: Templates could be used to enhance modelling of maximum demand values and load factors. Whilst ground mounted substations have been equipped with Maximum Demand Indicators that show peak since they were last manually reset, the same is not the case for pole mounted units. Neither have measured load factor data at each substation	Dependent on classification tool	None	In the majority of DNOs, maximum demand indictors were traditionally installed at the substation to provide an indication of headroom for planning purposes. The traditional method of collecting demand values required manual readings to be taken by field staff.	Development of an automated screening tool to better identify overloaded transformers.	**Requires further work**	Long term benefit delivered in the short term (2013-2014)
Transformer Losses: Estimate the load profiles on distribution transformers to provide targeted candidates for early change out on the basis of saving in transformer losses	Scaling and MDI modelling	None	Currently there is no mechanism to calculate losses on individual substations.	Accurate identification of both peak demand and load factor is required to determine cost benefit of early change out.to save losses (transformer)	**Requires further work**	Long term benefit delivered in the long term (2013-TBC)
Transformer Ageing: Estimations can be potentially made on the age of the transformer by knowing the load profile which in-turn can inform you about the load loss factors and the resulting age of the transformer	Scaling and MDI modelling	None	Transformer ageing is in part based on the maintenance cycles and the condition of those substations.	Need load factor which you can get from the template profile. Which you then turn into the load loss factor in order to calculate the transformers age.	**Requires further work**	Long term benefit delivered in long term (2013-TBC)
Classification Tool (Version 2): as an additional tool that is used alongside existing planning activities to understand weekly and seasonal changes of load/ voltage on a given part of the network using fixed data only	LV Network Templates	None	Currently there are three methods that WPD deploys to understand the weekly, seasonal changes of load on a given part of the network, these are: Preferred Method: Enter estimated actual consumption into WinDebut Sum after diversity maximum demand (ADMD) of a connection Actual monitoring at a primary substation There are a number of limitations in the current as-is approach.	The developed classification tool will be embedded into existing planning tools WinDebut. This will become the second version of the classification tool.	**Requires further work**	Medium term benefit, delivered in the short to medium term

PV Diversity Factors 1: Update the rating / diversity factors of installed PV, allowing the planners to estimate more accurately the impact of existing installed PV (Domestic)	None	None	The PV diversity factors within WinDebut are updated to reflect the findings of the Project.		**Deployed**	Long term benefit, delivered in the short term
National Grid ICCP (Operation Status Information around boundaries) The Project has demonstrated the statistical accuracy of use of local "Proxy" PV FIT meters to reflect the real time output of others in the locality This, coupled with WPD/ NG Tier 1 LCNF Project to link WPD and NG SCADA systems, provides for a capability of NG having real time visibility of "hidden" PV generation, presently of some 1200MW UK installed capacity. Such link would assist NG in their day ahead demand forecasting and generation scheduling.	None	National Grid	Currently Grid has no view of the "hidden generation" on the distribution network. This hampers their ability to be more cost and carbon effective in activities such as next day forecasting and the management of spinning reserves. There AS-IS forecasting methods rely on registered FiT and RO data.	Potential solutions being discussed is to provide at the Grid Supply Point, real-time PV output readings. This data would be provided through an existing ICCP link.	**Requires further work**	Long term benefit, delivered in the medium to long-term
PV Ratings The Project has demonstrated that installers of LV PV have adopted varying approaches to determining the peak ratings included in their (retrospective) connection notice. The consequence has been that the PV capacity has until now generally been-overstated. It is thus beneficial to explore this finding with the solar industry and see if improvements can be made to the determination of declared ratings to the benefit of all.	None	Solar Industry (e.g. DG installers, Distribution Code Review Panel), Ofgem, DECC, DNOs, BRE	Within WPD currently the peak PV ratings are registered based on the information provided by the installers. Some may provide inverter others panel capacity ratings.	Industry standard method of determining peak rating in a PVs connection.	**Planned (Anticipated in the next coming years)**	Short Term

Table 20, Output Overview versus Planned Implementation

DEPLOYED OUTPUT TO BE EMBEDDED

Project Output	Deployment Method	Deployment Cost (1= £0 to £10k) (2 = £10k to £100K) (3= +£100K)	Analysis of Business Impact (Processes, Systems and People) — Business impact key: ○ no impact, ◔ minimal impact, ◑ medium impact, ◕ strong impact, ● extensive impact					
			Component	Operations & Control	ICT Tech	Customer (including Connections)	Policies & Standards	Design
Voltage Reduction (+10%/-6%) (South Wales Selective Voltage Reduction Programme): The findings of the Project have identified the opportunity of WPD being able to reduce the voltage level in the South Wales area parts of the WPD network whilst remaining within statutory limits.	Existing tap changers within the primary substations	2~ cost of installers to change configurations and settings of tap changers and relays.	◔ As voltage levels are reduced, assets life is extended as a result	◔ Selected networks would operate at lower voltage levels than normal, tap changers will continue to operate automatically	◔ Impact on the network will be assessed using existing feeder end monitoring	◔ Customers should potentially realise lower bills as voltage and demand is reduced. Additional distributed generation could be connected as a result	◑ A number of policy and standard documents will need to be modified.	○ No impact
PV Diversity Factors 1: Update the rating / diversity factors of installed PV, allowing the planners to estimate more accurately the impact of existing installed PV (Domestic)	Windebut profile updated, implemented as part of release update	N/A	○ No impact	○ No impact	◔ There will be some minor updates to WinDebut PV profiles	◔ With more accurate PV diversity factors planners can better assess the connection of other distributed generation to the network.	○ No impact	◔ There will be some minor changes to network design as a result of the WinDebut PV profiles

Table 21, Deployed Output to be Embedded

PLANNED OUTPUT TO BE EMBEDDED									
Project Output	**Future Planned Activities**	**Planned deployment method (Potential)**	**Planned deployment costs** (1= £0 to £10k) (2 = £10k to £100K) (3= +£100K)	**Analysis of Business Imapct (Processes, Systems and People)** Business impact key: ○ **no** impact; ◔ **minimal** impact; ◑ **medium** impact; ◕ **strong** impact; ● **extensive** impact					
			(1= £0 to £10k)	Components	Operations and construction	ICT & Tech	Customer (inc Connec-tions)	Policies & Standards	Design
LV Templates: Templates can be applied to check and modify the standard customer profiles (or after diversity maximum demand values) used within our LV Design Software	Comparison analysis of substations versus tem-plates with respect to WinDebut profiles (esti-mates versus actuals)	Inclusion in planning and design policy	1 ~ Costs associated to changes to WinDebut Profiles	○ No impact	○ No impact	◔ Some changes required to WinDebut and other planning tools	◔ Improve connection time to the network	◔ Planning tool operating manuals will need to be updated	◔ Increase visibility of the LV network improving planning accuracy
PV Ratings: The Project has demonstrated that installers of LV PV have adopted varying approaches to determining the peak ratings included in their (retrospec-tive) connection notice. The consequence has been that the PV capacity has until now generally been- over-stated. It is thus beneficial to explore this finding with the solar industry and see if improvements can be made to the determination of declared ratings to the benefit of all	WPD will inform the industry of the Projects findings and organise discussions between Ofgem, DECC, National Grid, DNOs and the Solar Industry about best practice standards	Mixture of one-to-one discussions, and wider dissemi-nation events	1~ attendance and potential responses to wider industry consultations	○ No impact	○ No impact	◑ Initial changes required to update PV registered database	◑ Potential impact in customer uptake of PV	◑ There will be a defined common standard approach for PV ratings impacting policies and standards for PV registra-tion to DNOs.	◑ If changes are made to the future way in which installers calculate ratings, DNOs will have to differentiate between "old" and "new" installations w.r.t. ratings

Table 22, Planned Output to be Embedded

REQUIRES FURTHER WORK

Business impact key: ○ no impact; ◔ minimal impact; ◑ medium impact; ◕ strong impact; ● extensive impact

Project output	What required further work is needed	Required further work cost (1= £0 to £10k) (2 = £10k to £100K)	Availability: Dependence on partners & external	Availability: Dependence on internal resource	Impact Analysis: Component	Impact Analysis: Operations & Control	Impact Analysis: ICT Tech	Impact Analysis: Customer (including Connections)	Impact Analysis: Policies & Standards	Impact Analysis: Design
Voltage Reduction (+10%/-10%): The findings in the Project highlight the opportunity of changing the statutory voltage limits (+10%/-6% to +10%/-10%). Adoption of the EU levels, coupled with lowering target HV system voltages would provide multiple benefits to UK capacity margin, CO2 emissions, reduced customer bills, deferred reinforcement and increased network capacity to absorb new low carbon stresses such as PV, EV charging etc.	Changes required to existing tap changers within the primary substations	2~ cost of installers to change configurations and settings of tap changers and relays.	DECC & OFGEM	Internal installers and network services	(minimal impact) As voltage levels are reduced, assets life is extended as a result	(minimal impact) Selected networks would operate at lower voltage levels than normal, tap changers will continue to operate automatically	(minimal impact) Impact on the network will be assessed using existing feeder end monitoring	(minimal impact) Customers should potentially realise lower bills as voltage and demand is reduced. Additional distributed generation could be connected as a result	(medium impact) A number of policy and standard documents will need to be modified.	(no impact) No impact
Scaling and MDI Modelling: Templates could be used to enhance modelling of maximum demand values and load factors. Whilst ground mounted substations have been equipped with Maximum Demand Indicators that show peak since they were last manually reset, the same is not the case for pole mounted units. Neither have measured load factor data at each substation	Updating Crown with the required data for each individual substation	2 ~ Costs of developing IT systems and inputting of required data	None	Crown team and ICT delivery team	(no impact) No impact	(no impact) No impact	(extensive impact) Extensive ICT input required	(minimal impact) Improved assessment of the network leading to quicker connection times.	(minimal impact) Minor changes required to some policies and standards	(medium impact) Additional design tool to facilitate more accurate and speedier quotations.

Transformer Losses: Estimate the load profiles on distribution transformers to provide targeted candidates for early change out on the basis of saving in transformer losses	A process needs to be developed to apply the load factor from the classifica-tion tool	1~ Analysis work to be undertaken	None	ICT and Crown delivery team	◑ Potential early replacement	○ No impact	◑ Incorporat-ing classif-cation tool load factor into Crown	◔ Lower losses likely to result in lower bills	◔ Minor impact to policies and standards	◑ Visibility of high loss transformer may influence planning decisions
Transformer Ageing: Estima-tions can be potentially made on the age of the transformer by knowing the load profile which in-turn can inform you about the load loss factors and the resulting age of the transformer	A process needs to be developed to apply the load factor from the classifica-tion tool	1~ Analysis work to be undertaken	None	ICT and Crown delivery team	◑ Potential early replacement	◑ Early identification of prema-turely aged transformers will reduce network faults	◑ Incorporat-ing classif-cation tool load factor into Crown	◔ Early idenfication of aged assets, more reliable network, reducing potential faults / CML.	◔ Minor impact to policies and standards	◑ Visibility of aged transformers may influence planning decisions
Classification Tool (Version 2): as an additional tool that is used alongside existing planning activities to under-stand weekly and seasonal changes of load/voltage on a given part of the network using fixed data only.	Further develop-ment of the existing classifica-tion tool required in order to automate the fixed data input process	2~ External support costs and internal develop-ment	Specialist support in statistical and power engineering	Crown, ICT and planning design delivery teams	○ No impact	○ No impact	● Extensive ICT and Data Analytics required	○ No impact	◔ Minor impact to policies and standards	◑ Process and people change manage-ment

National Grid ICCP (Operation Status Information around boundaries) The Project has demonstrated the statistical accuracy of use of local "Proxy" PV FIT meters to reflect the real time output of others in the localityThis, coupled with WPD/NG Tier 1 LCNF Project to link WPD and NG SCADA systems, provides for a capability of NG having real time visibility of "hidden" PV generation, presently of some 1200MW UK installed capacity. Such link would assist NG in their day ahead demand forecasting and generation scheduling.	Further development of the existing ICCP link is needed with National Grid. Potential opportunities for further discussions with other DNOs in establishing a standard industry design could prove valuable	TBC ~ depends on functionality of ICCP link and the solution of providing proxy FiT generation data.	National Grid	Internal ICT, Security Specialists, ENMAC/ SCADA delivery teams	● ~ Depends on the final solution of providing Proxy FiT data	● ~ Depends on the final solution of providing Proxy FiT data	● ~ Depends on the final solution of providing Proxy FiT data	○ No impact	● ~ Depends on the final solution of providing Proxy FiT data e.g (data privacy, security protocols etc)	◔ More accurate information around actual PV generation output

Table 23, Output requiring further analysis overview

NOTES

WESTERN POWER DISTRIBUTION

NETWORK TEMPLATES

LCN Fund Low Carbon Networks

Llywodraeth Cymru Welsh Government

npower

UNIVERSITY OF BATH

imagination at work

passivenergy