SoLa Bristol

SDRC 9.8 Final Report

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SOLA BRISTOL

Contents

Acknowledgements:

SoLa Bristol was a team effort and we would like to thank the following for their significant contribution throughout the project and in compiling this report:

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Mr Andrew Smyth, Mr Ivan Hewlett (Siemens).

Executive Summary

The aims of the SoLa Bristol project were to try and address the technical constraints that DNOs expect to arise on LV Networks as a result of the adoption of solar PV. In order to achieve this SoLa Bristol trialled in-home battery storage devices to provide benefits to consumers, and moreover aid the DNO with network management devices, this was achieved through the use of DNO to storage device communications to facilitate the charge and discharge of the devices directly.

The project had a series of key milestones and SDRCs around the communication of key learning and as such a number of reports have been disseminated throughout the project lifecycle to demonstrate the achievement of key stated project aims and objectives. This final report is the last part of this process and includes the achievement of the final SDRCs as part of the report.

The learning from SoLa Bristol falls into three distinct categories:

- Smart tariff- there are positives and negatives to tariffing we found. There are some customers for whom it is very clearly a benefit, whilst we found for other customers that perhaps more active forms of engagement might be required if we are to influence behaviour.
- DC Network- For the domestic homes this consisted of all fixed lighting points being converted to LED's and several USB device charging points. Views on the lighting varied considerably, but most homes were positive about the usb points. For commercial properties this consisted of a DC solution for IT equipment and the conversion of the lighting system to LED's in the IT suite. There were no significant issues found from these changes.
- Storage- whilst the devices worked and worked broadly in line with expectation we feel that there is some work to do to make this kind of mode of market operation successful and attractive to DNOs.
- Customer feedback – whilst generally positive we believe that there are some significant lessons that the industry as a whole can learn from engaging with the local community around energy matters. It is often more time consuming than one first imagines and moreover there are some invaluable insights into making sure that you get the message across succinctly. Maintaining customer engagement throughout though is absolutely vital.
- Network Benefits- there are some observed benefits that we have seen from the project. Further work, as detailed later within Section 11 is required, however indications are that although the penetration of battery and PV was relatively low in the trial network and there was some demand uncertainty, the network demand change was not be reflected in the measured data and therefore corresponding

network investment deferral was small. When the penetration increases, the network investment deferral is increased to thousands of pounds. It is our view that more work is needed.

The report will provide more information and analysis throughout and starts with a description of the project, its timeline and then details the system design and approvals process. We then discuss the domestic and commercial customer elements of the project as well as, benefits for DNO's and then learning and next steps.

Throughout the document there will be a series of learning points which are shown as below:

Lx	Description of the learning

SECTION 1

Project Background

1.1 Summary

This section provides a summary of the project with particular reference to the case made within the Final Submission Proforma.

1.1.1 The problem

SoLa Bristol sought to find an alternative method to enable high density photovoltaic solar generation to connect to the Low Voltage network more efficiently through using an in-home battery and variable tariffs. The project aim was to address the technical constraints that DNOs expect to arise on Low Voltage networks as a result of the adoption of solar PV. The trial used in-home battery storage to provide benefits to customers and aid the DNO with network management. Twenty six houses, five schools and an office were commissioned, with solar PV and a battery installed. Within the domestic properties, the solar PV was connected directly to the battery using a DC/DC converter.

The AC lighting circuits in all the premises were converted to DC, and a set of DC outlets were installed to enable customers to run small USB connected appliances directly from the PV/battery. The battery was "shared" between the customer and the DNO. The customer was provided with a pseudo variable tariff to encourage electricity use at times of high PV generation and to use electricity stored by the battery when the network is heavily loaded. The DNO was able to communicate with the battery to charge and discharge it to help with network management.

The project aimed to:

● solve the network problems that arise when a number of customers in a local area connect PV solar panels to their house

● investigate how a battery installed in a property can help customers to manage their energy usage and save money on their bills

● test how customers respond when offered different electricity tariffs throughout the day

● explore the benefits of utilising direct current (DC) in the home, rather than the traditional alternating current (AC).

The project was managed using WPD mandatory project management governance arrangements. As part of this process learning is captured from the outset and therefore we have provided some learning on the project management aspects of the project within this section.

We also will provide some learning on the technology and customers further on within this report, this we think will be useful for those who do not wish to delve into the detail of the report and are looking for some early indicators of how successful the project was from a technical point of view.

1.1.2 The trials

In order to further explain the project, we feel it important to describe in a little more detail what the trial looked like.

Bristol was an ideal location for this trial for a number of key reasons. The housing occupant compositions are roughly in line with national averages based on Communities and Local Government 2008-based household projections. There is a large base of socially rented and council owned houses that are typical of other common UK property construction types. To ensure the right location was chosen, we worked with Bristol City Council to identify a representative area with typical 3 bedroom semi-detached housing. The selected area also required a dense rollout of PV panels to ensure maximum opportunity to acquire the necessary learning. The trial was envisaged to last for 18 months to ensure at least one winter and summer period with an additional six month overlap to aide verification of findings. This was also seen as a suitable period to learn how effective the technical solutions were and quantify any behavioural changes. Initial power analysis showed that thirty households will provide sufficient information for aggregate changes in behaviour to be reliably measured.

Of course a number of things were amended during the lifecycle of the project and we will cover this in more detail in this report.

1.1.3 Reliability of data

The key to SoLa Bristol was of course the acquisition and analysis of meaningful data.

To achieve this a combination on quantitative and qualitative measures were proposed. For example, for assessing behaviour (e.g., energy consumption), we wanted to utilise direct measurements through an LV Connection Manager. This is in contrast with relying on customers to self report results, thereby reducing possible biases from social desirability.

Network data generated from the LV Connection Manager and LV Network Manager was to be recorded and stored in a data archiving PC located in a distribution substation. The raw data would be analysed to generate the DNO network learning. Less tangible data such as attitudes, which cannot be measured physically, would be studied using existing, validated scales. Where more subjective measures were inevitable, reliability and validity would be explicitly considered and measured.

Our approach thereby sought to obtain high quality, often numerical, data which minimised the likelihood of measurement error. We also considered it important to supplement this quantitative work with more open, qualitative work to provide more in-depth understanding of the participants' experiences and feelings about energy use and the LV technologies being employed. As such, interviews and focus groups would form part of the project. In order that the data arising from these are explored carefully, we sought to use appropriate existing analysis methodologies.

Based on this, it is our belief that SoLa Bristol has been unquestionably valuable. The project has, we believe, achieved a great deal and obtained some great insights that we feel can be and should be further explored.

SECTION 2

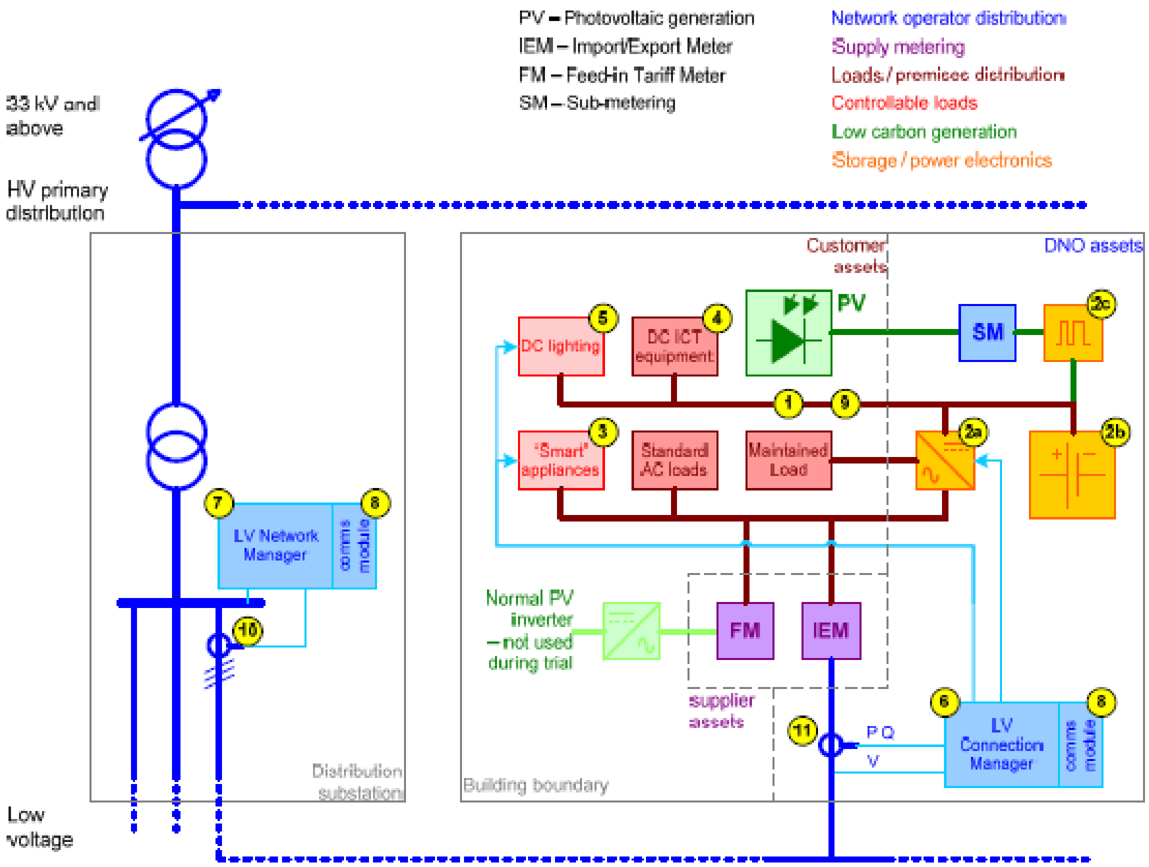
System Design & Approvals

2.1 System Design

This section deals with the overall system design for the project and covers in some detail the proving of the solution through testing. This was an important aspect of ensuring delivery given the end user focus of the project.

Figure 1 below shows the overall solution.

Figure 1: Technical Solution



Source: Project Team

The solution had two main aspects within premises equipment and substation equipment, these are described below:

2.1.1 Within Premises Equipment

The normal electrical distribution arrangements for premises connected at low voltage (LV) are as follows:

- The electrical supply is delivered by the network operator to the point of connection where it is metered.

- For feed-in tariff purposes this is an import/export meter (IEM in Figure 10).
- Photovoltaic (PV) generation is normally connected to the premises AC distribution through an inverter and feed-in tariff meter (FM).
- Appliances within the premises are supplied by AC distribution.

The SoLa BRISTOL project design, developed by Siemens, proposed to modify this arrangement as follows:

- On the network side of the import/export meter (IEM) sensing equipment (11) was connected which provided measurements of voltage and power to the LV Connection Manager (6).
- An inverter (2a) connected a battery bank (2b) to the premises AC distribution.
- The battery bank also fed a DC distribution system (1) which supplied DC loads such as IT equipment (4) and lighting (5).
- The PV generation, rather than feeding the AC distribution through its inverter, delivered its power to the battery bank and DC distribution system through a charge controller (2c).
- The LV Connection Manager was connected to control/influence the operating mode (charge/discharge) of the battery inverter (2a) and any loads which it could, including smart appliances (3), controllable AC loads such as immersion heaters, and any controllable DC lighting.
- The LV Connection Manager communicated with the LV Network Manager (7) in the distribution substation using attached communication modules (8).

2.1.2 Substation Equipment

For the SoLa BRISTOL project equipment fitted at the distribution transformer/substation was as follows:

- Sensing equipment (10) at the distribution transformer/substation was connected which provided measurements of voltage and power to the LV Network Manager (7).
- The LV Network Manager monitored the local measurements it receives, and those received from LV Connection Managers at premises on the LV network, to identify when the LV network reached constraint points. These were voltage and/or thermal constraints, and may have been caused by an excess of load or an excess of generation. Requests are then made from the substation to associated properties which are electrically connected to request an intervention, either load increase or decrease from a network perspective.

2.1.3 System Testing

To ensure that the systems operated in accordance with the design, Siemens, WPD and University of Bath attended a Factory Acceptance Test (FAT) of the equipment. The FAT was a critical stage in the delivery of the project and systems and was a stage-gate for progression to the installation of the systems within the field.

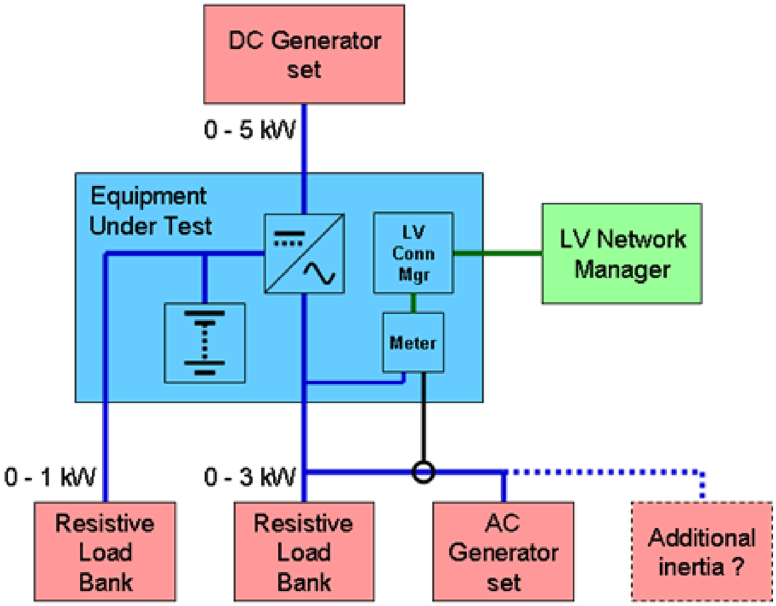
Two separate FAT's were scheduled, one for the domestic system and one for the commercial system. The rationale behind this approach was the requirement for the initial installation of a single domestic system within Bristol City Council's 'EcoHome'. This was being used as a demonstrator to both up-skill the installation teams on the process to retro-fit the equipment to an existing site, and also demonstrate the capability of the system to perform to the design requirements in situ. Thereafter the commercial builds progressed and a further FAT was completed to verify the operational capacity of these systems.

The FAT employed the set-up shown in Figure 2 below, the set-up was designed to provide variable conditions which would replicate the real-world application of the system in-line with the following requirements;

1. The AC Generator should set to regulate frequency and voltage to 50 Hz and 230 VAC.
2. The following quantities shall be variable according to the test requirements:
   - DC load
   - AC load
   - DC (PV) generation
   - Demand Response requests from LV Network Manager
3. The DC Generator set provided the PV simulation with varying levels of DC input voltage.

A DC Resistive Load Bank was used to simulate further system load, this could be adjusted through to 10A DC. Similarly the AC Resistive Load Bank was applied to demonstrate the 'Grid' demand response / export requirements of the system. The AC Generator Set provided the grid side of the interface during import periods.

Figure 2: FAT system set-up



Source: Project Team

Several test cases were drawn up, Table 1 shows the individual test cases and test aims below.

Test Case	Test Aim
Charging the battery	Demonstrate that the system will charge the battery to its required state of charge (SOC), making use of surplus PV and grid
Supply of AC and DC load	Demonstrate that the system will supply AC and DC loads from a combination of PV, battery and grid
Export of surplus energy to the grid	Demonstrate that the system will use surplus PV to charge the battery to its required SOC and export to the grid when the tariff price is high but continue charging the battery when it is low
Maintaining the battery SOC	Demonstrate that the system will charge and discharge the battery as required to maintain the SOC at the appropriate level
Responding to network requests	Demonstrate that the system will respond to requests from the LV network manager
	Ensure the G59 relay completes the 90 second reset, allowing the switching of the Studer transfer relay post firmware upgrade
End to end data communications	Demonstrate that the system can send accurate time tagged data from end nodes to the DC and process that data as required.
Testing of the LVD and thermal cut-	Demonstrate that the system will respond to a low voltage on

Test Case	Test Aim
out	the battery and disconnect the load; this should also re-connect the load once the applicable conditions are met.
	If possible, raise and lower the battery (or temperature probe) to activate the thermal cut out, then reducing the temperature to ensure complete operation.
Domestic property 4 fault creation	If possible, try to recreate the fault conditions found at property four based around the tripping of AC MCB's fed from external devices to the SoLa BRISTOL system.
Loss of power to the communications equipment	Complete a powerloss to the translation unit, confirm the unit is still operational once power is returned and operates correctly with the Studer unit.

Table 1- Individual test cases & aims

Once the FAT was approved by the customer, the system build progressed in earnest. Thereafter delivery of the units was coordinated with the various partners and suppliers to allow the installation of the equipment within their trial locations. The installation and commissioning works were then completed by other service providers within the project.

System Design Considerations/ Lessons Learned

The delivery process (specifically the design reviews employed) within the project provided opportunities to improve the system design, as applicable, based on both factory and real-world operational results.

Rigorous factory testing enabled the system design and parameterisation to be adapted for improved operation – however when we installed the first three trial properties and evaluated their operation as part of the Ofgem early learning report, some limitations of the system were then acknowledged. These are discussed below:

The **DC/DC converter**, a unit designed to regulate the variable output voltage from the PV (circa 150-240vDC) to the 24vDC nominal internal system bus voltage- at the time of design no individual unit existed which supported the wide input voltage therefore if standard products were to be applied the PV array would need to be adapted. There was a desire within the project team to maintain a 'typical' PV installation which would increase the scalability of the system post-trial should it be successful. The DC/DC unit was designed and supplied by PE Systems.

During testing it was noted that the DC/DC converter did not display the characteristics of MPPT (Maximum Power Point Tracking). MPPT is a requirement of all 'typical' solar PV inverters – providing an electronic method of 'matching' the solar PV generation with the requirements of the in-building system. Without this functionality the output voltage of the DC/DC unit could collapse if load requirements were too great within the in-building system, therefore a retro-fit modification to the control system was required to stabilise the output and maximise the solar energy harvest into the system.

In order to confirm applicability for sale within the UK, the DC/DC converter also needed to be CE marked (alongside all of the other equipment applied within the SoLa Bristol project). The CE marking process required robust EMC testing of the DC/DC units to confirm their safety and compatibility against 2006/95/EC (The Low Voltage Directive) and also 2004/108/EC (The Electromagnetic Compatibility Directive).

The DC/DC was therefore tested for conformity against EN61204-3-200 (Low Voltage Power Supplies, D.C. Output – Part 3 Electromagnetic Compatibility), EN55022:1998 (Reference Standard for Class B limits for Conducted and Radiated Emissions) and also IEC/ EN 60950-1 (LVD Testing Information Technology Equipment – Safety).

The introduction of a **Low Volts Disconnect (LVD)** – this was a mechanical device which isolated the DC load if the measured battery voltage dropped below 19.8vDC (this was programmable) – this component ensured that the battery would not fully-discharge

To compensate for this potential loss of DC supply for the in-building load (lighting/ ICT) a software algorithm was included to **'force charge'** the energy storage. This acted as an override (therefore did not consider the current tariff) which again was triggered when the measured battery voltage reached a voltage decreed to be too low – in this case 22vDC. Again this was programmable and the override was disabled once measured voltage reached 24vDC.

Finally, to mitigate the risk of low-quality state of charge measurements the EMS would charge the EES, at times of low tariff, to circa 100% on a two week cycle.

These changes were required as the initial design, which used internal inverter control to tighten restrictions/ reduce system output under high load/ low SoC conditions. The SoC proved to be an unreliable measured value, limiting the effectiveness of this control.

L28	Extensive testing was undertaken to ensure systems complied with regulations. This testing phase also allowed tweaks and improvements to be made to the system.

2.2 Domestic Overview of BMS and logic algorithms

2.2.1 Design principles of the Battery Management System (BMS) logic

The principles behind the development of the domestic logic for the SoLa BRISTOL project were based on four primary objectives, as follows:

- Capture all available PV output – to the capacity of the batteries
- Avoid energy purchase from grid outside low tariff periods where possible
- Provide capacity in reserve to support push/pull requests from WPD
- Ensure that the system could always provide power for lighting

The logic considered the storage battery to have two end points inherent in its nature, these were:

- 0% capacity (empty)
- 100% capacity (full)

Additional to these absolute limits, three further set points were included in the logic design:

- Minimum state of charge (This sets the lower limit of battery operation)
- Target state of charge (This sets the optimum battery charge over time)
- Maximum state of charge (This sets the upper limit for domestic operation)

2.2.2 Operation

The system assumed that during daylight hours there would be PV generation from the roof mounted panels, hence the target state of charge was generally low in the morning to allow as much ‘headroom’ as possible for PV generation capture during the day.

Should PV generation take the batteries to the maximum state of charge value then the excess was exported to the grid to maintain this level. This ensured that should WPD require to ‘push’ excess power from the system there would be a percentage of capacity available to accept this.

The logic was designed to push power out to the grid overnight, when PV was not available to reduce energy purchase from the grid, as well as preparing the batteries for collection of PV generation the following day.

The batteries could continue to discharge down to the minimum state of charge value, in the absence of PV generation, should the tariff remain above the lowest rate. The discharge would end and the batteries start to take charge again either when the tariff reduced to the low rate or the batteries reached the minimum state of charge level. In the event of the second condition being met then the logic would enter and import-export cycle to maintain the minimum state of charge level until conditions changed.

The ability of the system to support a ‘pull’ request from WPD was dependent on the batteries having spare capacity above the minimum state of charge level to support this request.

Ultimately the system would attempt to track the target state of charge unless other conditions, e.g. PV generation levels or time of day tariffs, precluded this within the design rules.

Some information worthy of mention is as follows:

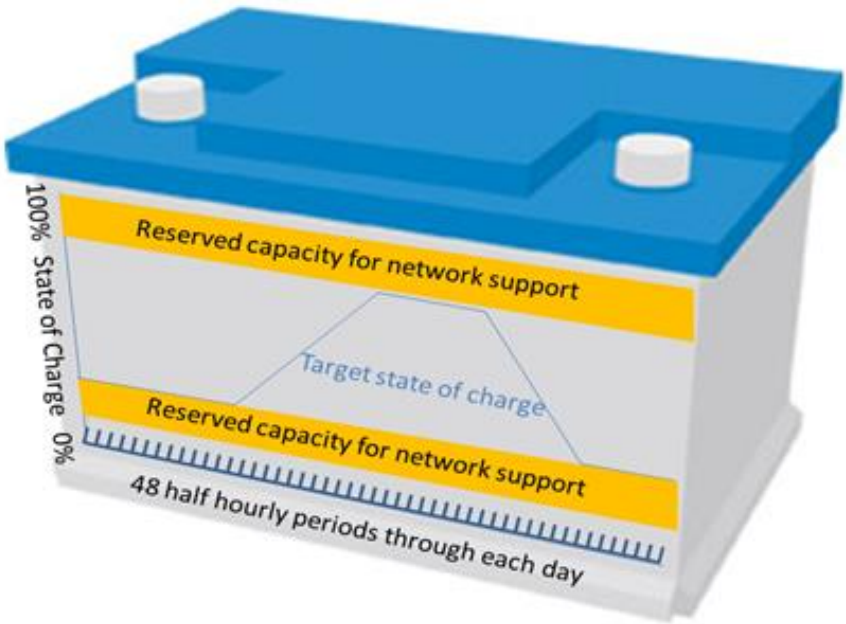
- The capacity between maximum state of charge and 100% capacity was reserved by the logic for WPD use
- The logic operation when maximum state of charge is reached was to push power out to grid to match the current AC domestic load. The purpose of this was to permit tracking towards the target state of charge. Adjusting this logic decision point would

result in the system remaining at maximum state of charge, potentially overnight, and hence reduce its capacity to capture available PV generation the following day.

- The minimum state of charge level has a slightly different role to play in the system than its counterpart, maximum state of charge. While maximum state of charge reserves working capacity up to the 100% capacity of the battery for WPD support purposes, the area below minimum state of charge down to 0% capacity is less predictable.
- Based on the statement in note 3, above, the logic does not permit the system to support a 'pull' request from WPD unless the state of charge is above minimum; this avoids system operation in the minimum to 0% region where voltage support may not be achievable.
- It will be apparent from the text herein that all aspects of logic operation are dependent on correct state of charge values being read from the battery storage system. The logic cannot compensate inherently for inaccurate state of charge values. However, as has been demonstrated through the project to date the ability of the system logic to accept dynamic changes to operating values can help overcome other system element shortcomings.

The following illustration (Fig.3) represents graphically how the set-points relate to battery capacity.

Figure 3: graphical representation of the EMS operation



Source: Project Team

2.3 Hardware

2.3.1 Factory Acceptance Testing details

2.3.1.1 Background & Approach to the tests

The SoLa BRISTOL system was a geographically dispersed yet interconnected system, located between various location types such as end user premises, commercial premises, associated sub-stations premises, University of Bath data repository and our Bristol office.

In view of lack of approved or recommended 'standards-based' system-wide end to end test methodologies in 2012, a custom acceptance test regime had to be devised. These FAT scenarios were location dependent.

A two stage testing strategy was deployed for the FAT tests. As neither Siemen's nor University of Bath's labs were certified installation sites for export of energy to the Grid, a specialist test facility was sought at the National Renewable Energy Centre (NaREC) over two visits between 16th-17th Jul 2013 NaREC (I) & 14th-15th Jan 2014 NaREC (II).

NaREC facilities are described in this section. In the first stage of acceptance testing a standalone version of the system was tested as at that stage a complete system replication at the test site was not feasible. With this additional constraint, a modular system acceptance approach was adopted. The tests performed were 'witnessed-for-acceptance' type of tests. Based on various system configurations, a 'Factory Acceptance Test procedure' document was generated.

Text below provides some details of SoLa Bristol's typical domestic installation's major components:

- PV Panels-During FAT, simulated using PV Sim supply
- DC-DC charge controller-In system device
- Battery sub system- In system device
- DC loads-During FAT, LED & USB, Simulated using loads
- Bidirectional inverter-charger-In system device
- Grid-side protection-In system device
- internal inter-equipment communication elements-In system devices
- External communications equipment-On & Off site service
- External communication's data encryption and Wireless Service
- External access control-IP path access

The User premises equipment, in purely functional terms, can be seen to have two major functional blocks, 'The Power Side' and 'The Control and Communication Side' block.

'The Power Side' of the system acceptance was the objective of NaREC (I) testing which was based on the selected test cases, as described further in this section. The power side of the system covers the Bidirectional-Inverter-Charger 'the Xtender', its associated equipment including the battery sub-system.

'The Communication Side' of the system testing was performed during NaREC (II) is also briefly described within this section NaREC II testing setup also included enhancement to the system along with Sub-Station equipment. In-depth operational or configurational details of the communications side are not covered in this section.

The prime objective of the NaREC Factory Acceptance Test NaREC (I) was to observe a typical domestic installation's 'Power Side' functionality and it's response to external commands received via 'Control & Communication Side' either through simulation or where practical real external commands.

The prime objective of the NaREC Factory Acceptance Test NaREC (II) was to observe whole system performance.

Elements of the FAT

This section describes the various parts of the acceptance testing undertaken, more information can be obtained through WPD.

Power Side Sub-System

The primary pieces of equipment on the 'Power Side' were the bidirectional-inverter-charger which is Grid facing and the DC-DC converter which was PV facing. Both these were connected to the DC Microgrid bus. These were installed at the user premises alongside various other configurable devices, which collectively made up the system.

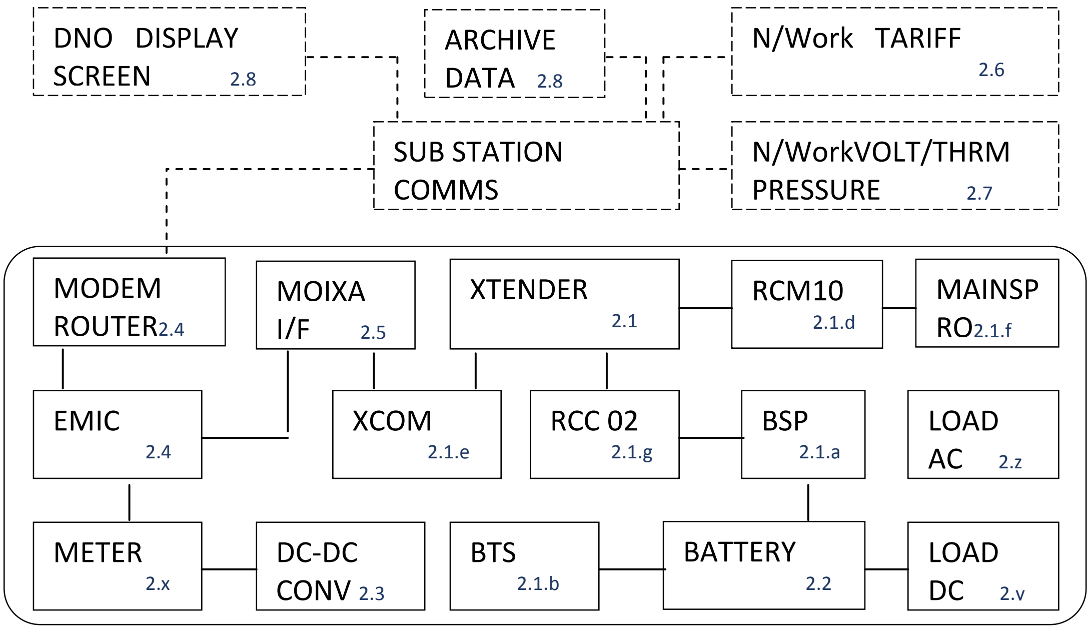
Listed below are some of the devices that were installed at the FAT test site at NaREC (I). Alongside the following were other pieces of NaREC test equipment.

- **Xtender XTM2400 Bidirectional Inverter-Charger**
    - Associated-device BSP Battery Status Processor
    - Associated-device BTS Battery Temperature sensor
    - Associated-device RCC02 Remote Config Console
    - Associated-device RCM10 Remote Control Module
    - Associated-device XCOM232 Xternal Comms RS232
    - Associated-device MainsPro G83/G59 protection relay
- **Battery Sub-System Associated sensors**
- **DC-DC Charge Controller Custom designed charge controller**
- **Modem Router LAN/WAN, Encryption, GSM/GPRS**

- **Moixa Interface Unit Command interface format converter**
- **Other system devices Tariff related request simulator**
- **Other system devices Cable Plant Thermal Pressure simulator**
- **Other system devices Remote real time display consoles**

The following figure(Fig.4) shows two blocks, the NaREC (I) configuration. The dotted line block represents locally generated data traffic. During NaREC (II) testing all data paths to external locations and devices were carrying real-time system generated/received data.

Figure 4: Various NaREC configurations



Source: Project Team

The top block consisting of devices 2.6 and 2.7 were simulated on site and 2.8 were present. The criterion adapted during NaREC (I) was that devices which could pass through the 'operational data' could be considered as functional in their own right.

This criterion did not, however, assume that the device was 'fully-functional' within the overall system context. As stated earlier, during NaREC (II) testing all data path were representative of real implementation, using the equipment intended to be installed at specific sites. Data flows through these devices were observed during NaREC (I) and NaREC (II) testing, and thus were considered to be 'operational' in their own right.

In the bottom block devices 2.4 and 2.5 were considered operational as the test data flows were as expected. During NaREC (II) a live debug screen was attached to the translation unit (2.5) which was a development and debug tool which displayed live data translations and flows.

The DC-DC converter (2.3) was supplied by a PV simulator power supply and could be seen to be operational during NaREC (I) & (II) testing.

Further information on this aspect of the trial can be obtained through WPD.

NaREC System Test Methods

Due to the operational nature of this system, a potentially large number of test case permutations can be perceived just on the ‘Power Side’ alone, so it was agreed, that an acceptable level of prime functional permutations could be demonstrated and other results deduced.

For instance, a message being delivered to the Xtender via XCOM232 communication interface would validate the communication interface’s baud rate, flow control, error checking ability and the integrity of incoming communications data path.

The battery charging and discharging are time consuming processes, for instance, a single charge-discharge cycle of a 200 Ah battery being discharged at 0.1C and then recharged at 0.25C could take well over the test time slot of 48 hours, not including the pre-charging and rest phases, so short period functionality was covered.

In addition, all temperature-related-long-term tests of the battery charging, discharging, capacity and recharging were identified as un-attainable during this test phase and were to be part of data analysis.

With these acceptable observations, five major ‘test-cases’ during NaREC (I) were selected and the agreed procedures were carried out to witness the system behaviour.

The test cases are :

- Test case 1 Charging the Battery
- Test case 2 Supply of AC & DC loads
- Test case 3 Export of surplus energy to Grid
- Test case 4 Maintaining of battery SOC
- Test case 5 Responding to network requests

The tests were carried out using simulated Grid and simulated PV. Grid Simulation was provided for by the NaREC’s setup. PV output was simulated using variable DC power supply unit.

In order to avoid ambiguity of results and ease of performance visualisation, the number of variables were kept low, to an acceptable level, for each test case. For instance, to demonstrate the charging of batteries (Test case 1) the simulated PV was kept constant for test duration and tSOC (Target State Of Charge) levels were varied, to observe the system behaviour.

Similarly, to demonstrate charging from the Grid at low tariff period, the system clock had to be changed and an artificial external tariff request was sent to the system and the charging behaviour change observed.

The protection-relay, performing G83/G59 grid isolation is a pre-approved device and had already been tested and accepted for its intended function by an external MCS approved inspector. A separate report was generated by the inspector confirming the safe system operation using this device with its configurations.

During MCS site certification process, a dedicated installer's-equipment was used by the inspector. This dedicated equipment covers test such as specified dual voltage and frequency limit injection and provides indication of system action and reaction times.

The protection relay had been in operation at an external site for over five months with acceptable results, so during NaREC(I) & (II) testing only the basic function was checked and there was no need to re-demonstrate full functionality at the NaREC.

EMIC performance was monitored using a dedicated PC and the Xtender was monitored using the RCC-02 user console connected to Xtender.

During NaREC (II) testing a further three test cases were introduced as listed below.

- Test case 6 End to End data communications
- Test case 7 Testing of the LVD & Thermal cutout
- Test case 8 P04 site creation

Test case 6 was a comprehensive test and further details of the communications domains are covered in next section.

Test case 7 was introduced to check the operational aspects of additional safety enhancements introduced from the learnings of the field operations the system.

Test case 8 could not be created and the earth fault is still under study.

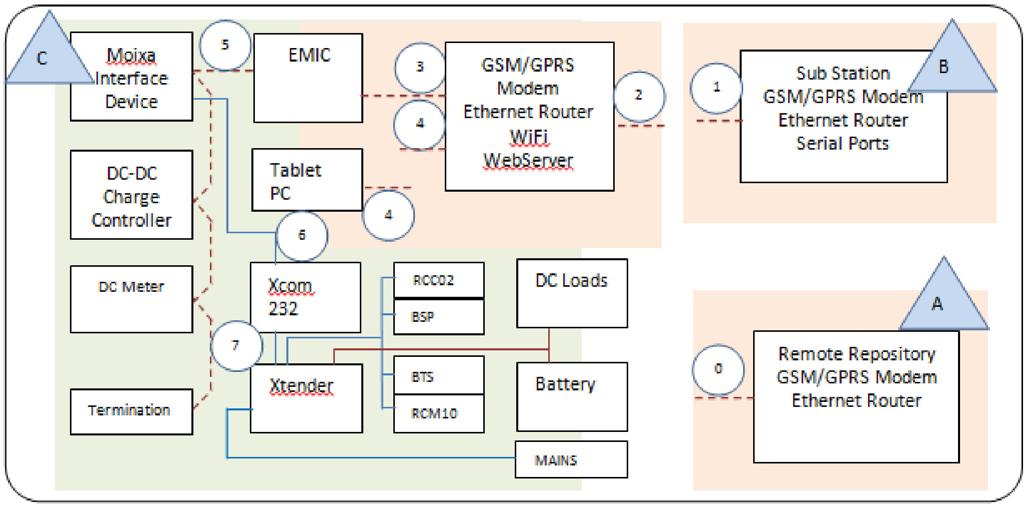
Communication Domains & Structures

As mentioned above, the test cases selected were primarily to demonstrate the systems 'Power Side' functions NaREC (I) in detail and live data flow through the communications side NaREC (II). For completeness of the communications system overview, block diagram below shows the Control and Communication sub-systems.

NaREC (II) system's configuration was much more comprehensive replicating the real live system for end to end data flow testing. The setup consisted of two domestic properties and the University of Bath's data repository, connected to a substation via wireless links with live wide area data paths.

Included in this setup was also the home WI-FI network with embedded web-server conveying system generated real-time information. The hardware and software build of the NaREC (II) system was as follows in Fig 5 below:

Figure 5: End to End SoLa Bristol System



Source: Project Team

There are three physically separate domains, as shown above. Remote Management domain (A), Sub-Station domain (B) & Domestic User domain (C). All inter domain information flows are encrypted with access restrictions as shown by the background colours. Within individual domains both encrypted and plain text/data information exists.

Within these three domains there are identifiable protocols and interface types associated with individual units having their own configuration parameters and procedures.

Within the domestic user domain (C) there are six different communication interfaces which can be identified as shown from (2) through to (7). Communication functions were synthesised for Domains (A) & (B) as identified by (0) & (1) above and within domain (C) the appropriate system response conveyed the integrity of communication paths and contents. These paths and protocols were earlier referred to as the ‘Communication Side’ function of the system. The through-responses of these commands were checked for expected resultant functionality of the ‘Power Side’ of the system.

During NaREC (II) testing, all data paths to external locations and devices were carrying real-time system generated/received data.

NaREC Factory Acceptance Tests (I) & (II) Conclusions

After testing, the system was accepted to be operational. As this system is considered to be evolutionary in nature some changes and further enhancements were expected during the trial period.

2.3.2 CE Marking

Following changes to the DC/DC converter after the EcoHome installation, re-certification was required.

L29	While a working solution may be possible, it may not be approved due to regulations by other boards. It is important to consider external bodies when planning innovative projects.

L30	Early work exploring DC metering suggests that this could be a useful area to explore in the future.

2.3.3 DC Meters

As part of the overall design of the project, the project team wanted to arrange the installation of DC metering at customer premises.

However, this would have required a special dispensation from DECC. Consumers could have used non approved meters to claim FITs, but DECC decided not to support the request, stating that the FIT scheme is not intended to support innovation.

We do think that there could be some further work in this area.

2.3.4 PV connections

Domestic vs commercial Following on from a decision by DECC not to allow the use of an unapproved DC meter for FiT calculations, it was decided that for the project to compensate the commercial participants for loss of this tariff would be too expensive. For this reason the PV connections on the commercial properties were not linked directly to the charging of the battery. For the domestic properties compensation was calculated using historic data and paid to BCC as they requested.

2.4 Software- Energy Management System

2.4.1 Domestic Energy Management System (EMS)

A fundamental part of the SoLa Bristol solution was the implementation of a system to manage the domestic customer solution. Therefore the project had a distinct design phase near the beginning to ensure that there was a clear message and a solution to communicate to the customers.

Essentially the domestic logic implemented within the EMS, as described previously, functioned well in practice although as expected there were challenges through the course of the project that had to be addressed. The challenges stemmed largely from the innovative deployment of energy storage and management in the domestic environment of people's homes, with the variability of usage patterns for electrical loads. Additionally the project provided exposure to limitations in DC power and battery monitoring systems, particularly at the low voltage levels used.

The domestic control logic was entirely dependent on measured state of charge (SOC) values of the batteries derived through a measurement interface associated with the grid inverter system. It is important to recognise that the SoLa BRISTOL project was using batteries in an innovative way within domestic properties to deliver shared benefits of grid support and domestic load reduction in combination with variable tariffs. This application of batteries required them to operate throughout their storage capacity range over time with frequent, variable and partial charging and discharging events. The battery SOC determination was derived from a combination of terminal voltage measurement coupled with a predictive algorithm that provided a reading between 0% and 100% as an estimated SOC.

While this technique undoubtedly works well for battery systems that are subject to more regular and consistent cycling, probably focused around the fully charged state, it proved to be unreliable in the more dynamic application of the project. The effect of this was to deliver an overestimation of SOC which on occasions resulted in an inability of the systems to meet the DC loads.

A number of techniques, used in combination, were deployed through the course of the project to deliver the requirements of project learning while simultaneously maintaining security of supply within the domestic properties.

Logic settings adjustment

The logic implemented within the BMS provided flexibility in adjustment of set points as follows:

- Maximum SOC – This is the upper threshold for domestic purposes
- Minimum SOC – This is the absolute lower threshold for all purposes
- Target SOC – Selectable for individual half hour periods within a day and used to define a target daily profile for the battery system

Through correct setting of these values a proportion of the stored energy is always available for the domestic user while retaining capacity for DNO use in grid support.

However as the project progressed and issues with SOC measurement became apparent it proved possible to alleviate certain problems through re-assignment of the set points to compensate.

Low Voltage Disconnect

Following early problems caused primarily by SOC measurement errors and as a failsafe backstop to avoid battery damage through deep discharge a ‘backstop’ device was installed in the system. This automatic resetting low voltage disconnect device was installed with a threshold voltage of 19.8 Volts; if the battery terminal voltage ever drops to this level then the batteries are disconnected.

A LED installed on the intake cabinet and visible to the householder will extinguish under this circumstance as a visual warning.

The system may either be reset manually through local battery recharging, or in many cases will automatically reset should the terminal voltage recover sufficiently over time.

22 Volt forced charge cycle

The inaccuracy in SOC measurement occurs as a gradually increasing over-estimation of capacity over time. Hence a recharge cycle was built into the system that fully recharges the battery to true maximum capacity on a fortnightly basis, or if the battery system drops below 22 Volts at any time. This has the effect of re-establishing a reliable SOC reading.

L31	Using the batteries in a non-traditional way led an overestimation of the state of charge

L32	Battery problems could sometimes be alleviated through re-assignment of the set points to compensate

L33	A 'backstop' device was produced to automatically disconnect the battery if the voltage dropped below a certain level

L34	Introduction of a recharge cycle into the system resulted in a reliable state of charge measure.

2.4.2 Commercial design principles of the Battery Management System (BMS) logic

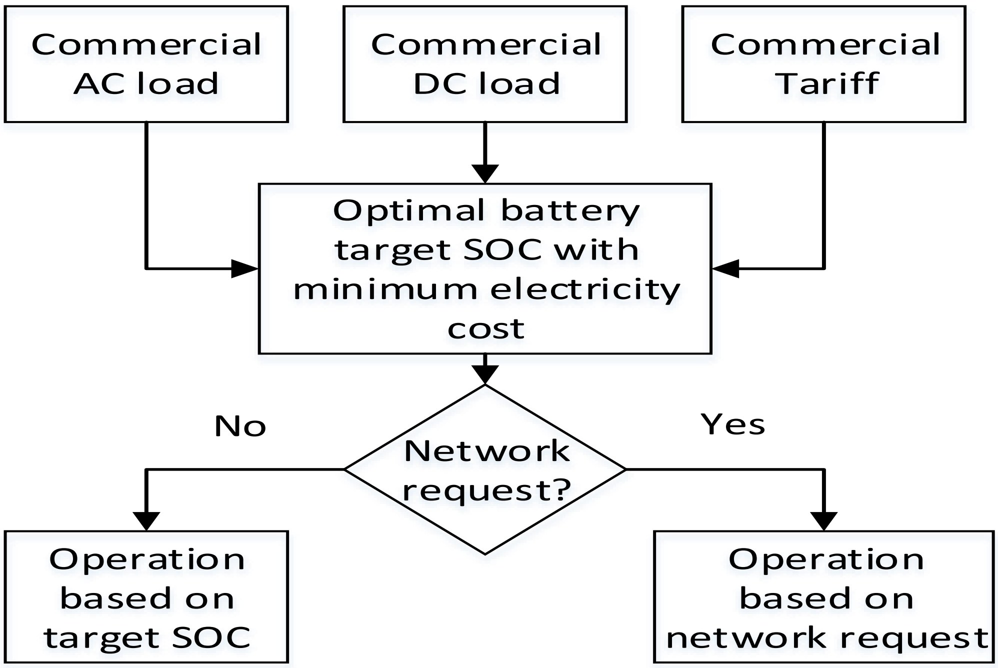
In the commercial UPEs, PV sub-systems are standalone. Consequently, 1) the DC loads in commercial are only supported by battery; 2) battery can be only charged from grid.

The principles of the commercial logic for the SoLa BRISTOL project are based on three primary objectives:

- Ensure that the battery can provide power for DC lighting and PC's
- Avoid energy purchase from grid outside low tariff periods where possible
- Provide capacity in reserve to support push/pull requests from WPD

In the commercial system, battery charge and discharge follow the target SOC, which is designed to include all these objectives. The target state of charge is designed using optimization algorithm to minimise customer electricity cost considering the commercial loads and tariff as shown in Figure 6. The network high demand information is reflected in the tariff therefore the target SOC can both benefit customer and reduce demand peak in the network.

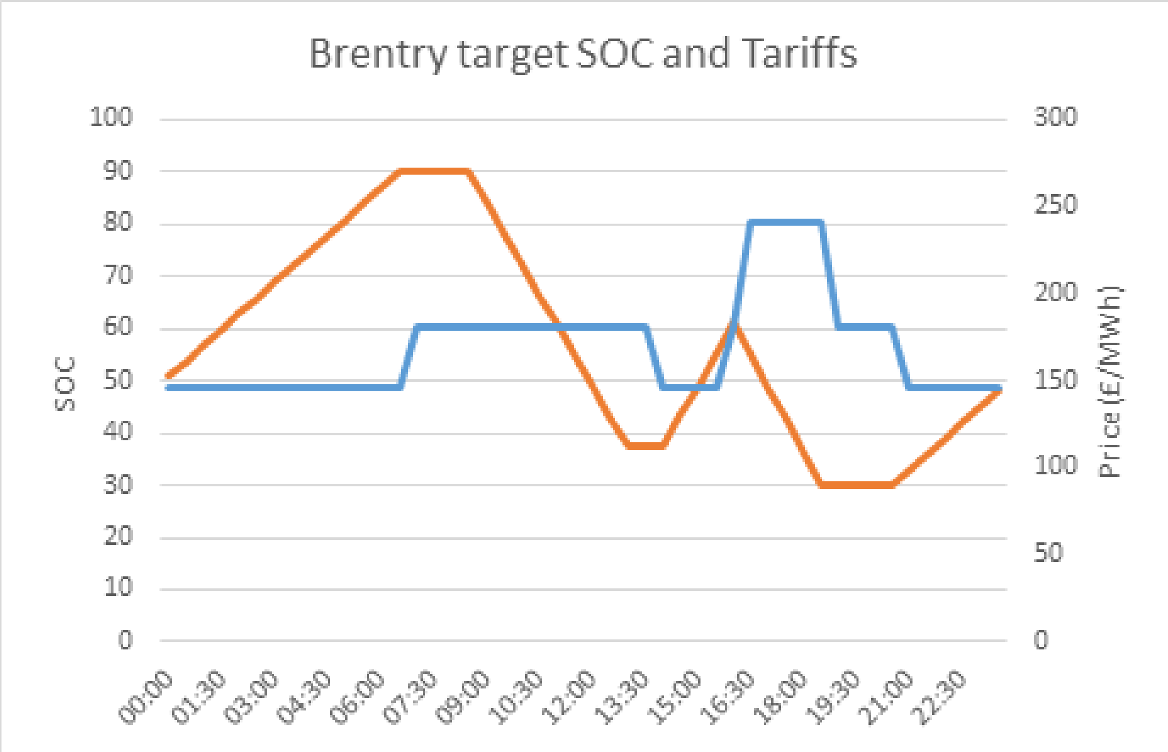
Figure 6: Target SoC process



Source: Project Team

The example of a target SOC for Brentry School, which has largest DC load, is shown in Figure 7, where the orange line is target SOC and the blue line is the tariff.

Figure7: Brentry School Target SOC and Tariffs



Source: University of Bath

The target SOC is designed to

- pull power from grid during lowest rate at night.
- push power out to support DC lighting and PC in commercial working time.
- take advantage of lowest rate during afternoon

push power out to gird (AC system) to reduce energy purchase from the grid as well as reduce the network demand peak

2.5 Sub-station Measurements

Though substation equipment is distinctly different from the domestic properties, it is included here as it is the feeding end for the domestic properties. The sub-station equipment was designed to provide monitoring and communication capabilities at the sub-station. The supply-side monitored data at the sub-station is used for quality of supply study. The SE is a vital communication link for appropriate parameter passing to its associated sites. Each group of domestic, school and the office installation has its own associated serving sub-station.

A total of 11 sub-station monitoring sites have been installed. Substation installations provide the capability to monitor up to five feeders, with each feeder consisting of three phases. The metering equipment in Figure 8 shows the five feeder meters marked from 1 to 5. Figure 9 shows the connections to/from the bus bar. The four cables on the left (L1,L2,L3 & the neutral) are from the transformer side and on the right are the outgoing five feeder cables. As can be seen, there are two feeder cable types. Feeder cable 1 & 2 (on left) are higher capacity cables compared to the feeders 3,4 & 5 which are the right three cables.

Figure 8: Metering Equipment

Source: Project Team

Figure 9: Installation

Source: Project Team

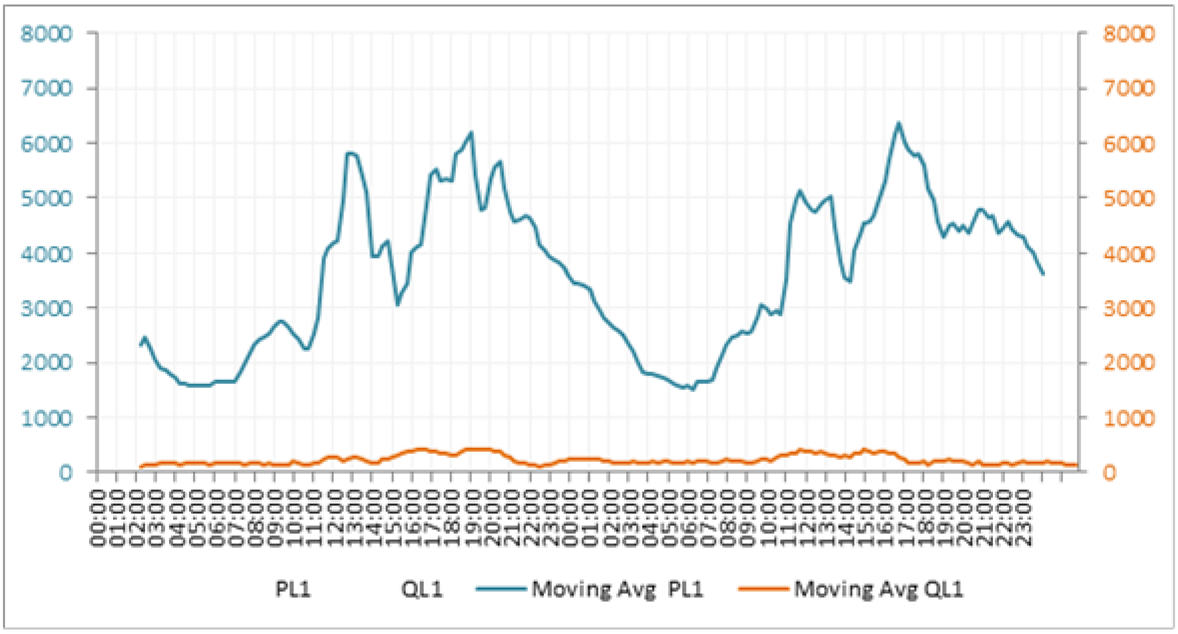
The voltage measurements were taken with direct connection at the bus bar and current transformers were used to provide individual phase current for all phases of all the feeders of substation.

The meters were used in three phase four wire configuration. These meters were capable of providing a combination of 80 measured and calculated parameters per sampling period. The sampling periods could be selected to be between 5 seconds to half an hour. The data collected at the sub stations were at fifteen minute intervals.

A small sample of substation data plots are provided below. These are typical values which were observed at the substations.

In Fig. 10 Substation 5 on Feeder 2's Phase 1's moving average traces show active and reactive powers (blue and orange traces respectively) for a period of 48 hours of 10th & 11th Oct 2015. The active & reactive powers are in Watts.

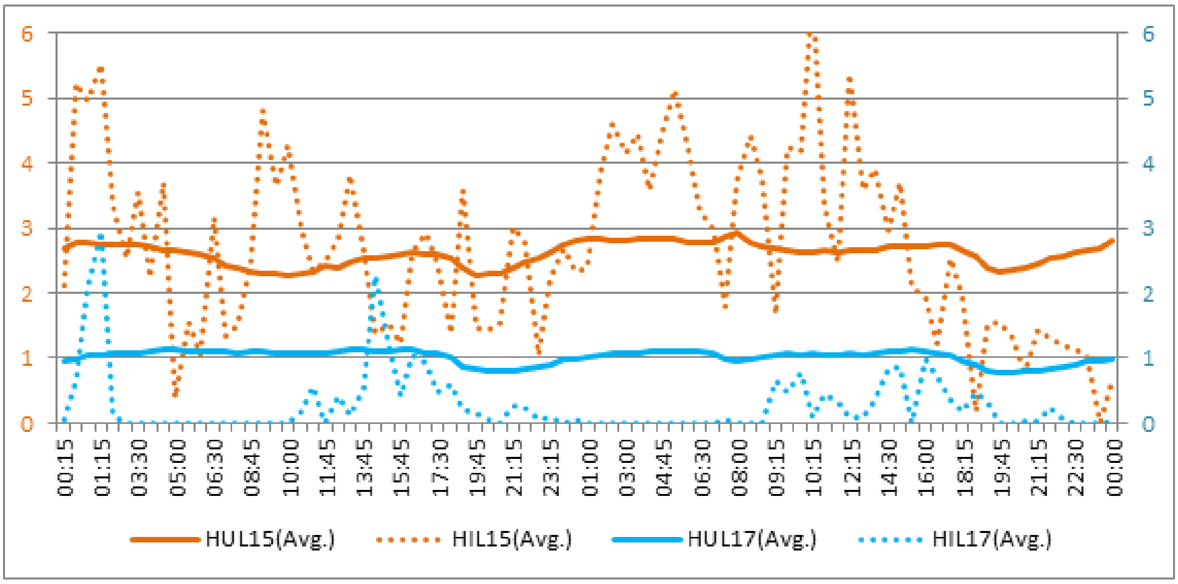
Figure 10: Sub05 Feeder 02 Active and reactive power



Source: Project Team

Figure 11 below shows four traces depicting voltage and current harmonics of the 5th & 7th order for the same 24 hour period as above. The units of measurement for voltage harmonics are as % of fundamental, and the current is in (A). The 5th voltage harmonic wave value is shown as solid orange trace and the 7th voltage harmonic is the solid blue trace. The associated 5TH & 7TH current harmonics are shown as dotted traces in Amps.

Figure 11: 5th & 7th Voltage and Current harmonics



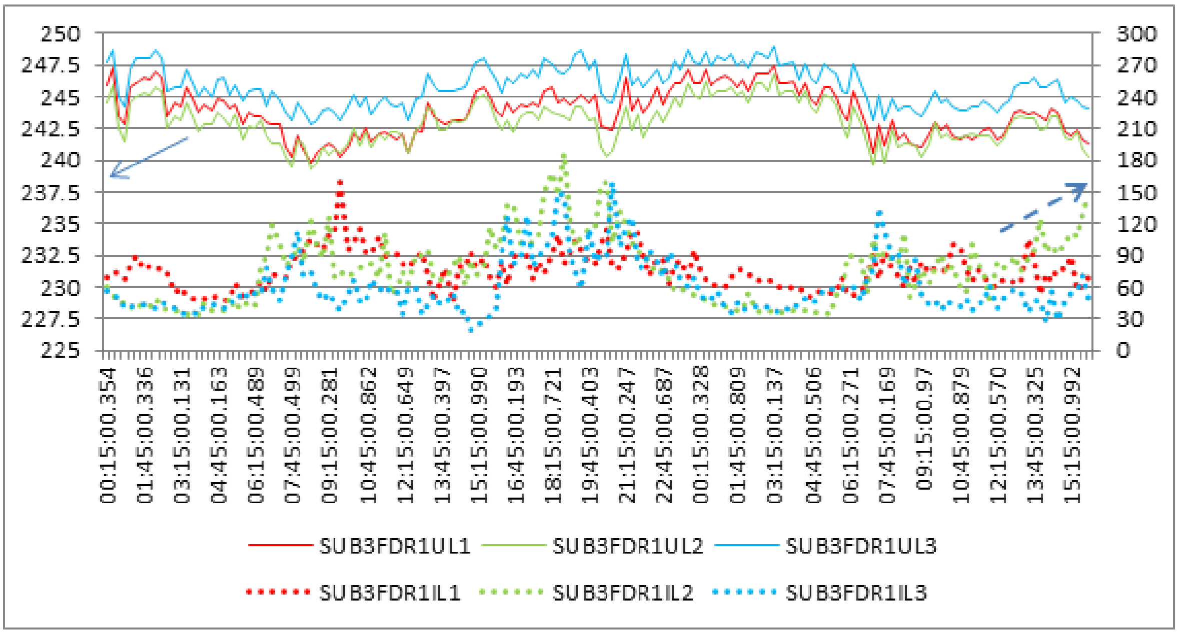
Source: Project Team

The 11th & 13th harmonics were also recorded but had no significant values. As can be seen the 5th harmonic is the dominant of the four harmonic values recorded.

Figure 12 shows 15 minute resolution Voltages and Currents at Substation 03 on Feeder 01. The measurement time stamp on the X-axis (hour : minute : second : millisecond) are shown for a period of around 40 hours, starting at midnight. In this plot, the three solid lines show the three phase voltages for L1 (red) L2 (green) & L3 (blue) and the voltage amplitudes are on the left-Y-axis. Corresponding current values are shown with same phase associated coloured dotted lines and the current amplitude values are shown on the right-Y-axis.

For ease of visualisation, a 24 hour period can be divided into five load-zones starting from midnight, consisting of: Late-Night-Trough, AM Peak, Midday-Trough, Evening-Peak and To-Midnight-Trough. During these five load-zones the load-zone trends can be classified as either ascending or descending. These load-zone load-change trends can be identified as Descending, Ascending, Descending, Ascending, Descending, in that sequence respectively for the above mentioned load-zones. These load-zone current demands reflect on the line voltages which have an inverse relationship, such that the Ascending load current results in Descending voltage and vice versa. It must also be noted that exception to this simple viewing tip is that the auto tapchangers can influence this relationship. In Fig. 12 decreasing load current dependent Ascending voltage rise can be seen around 03:00 on both nights.

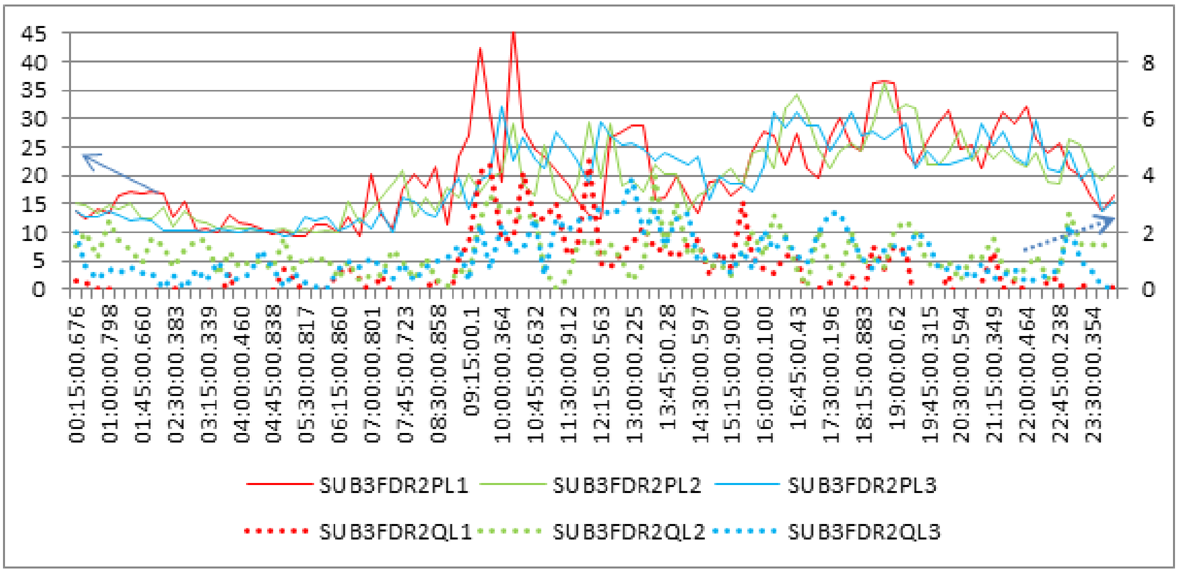
Figure 12: Sub03 Voltage and Currents



Source: Project Team

Looking further at the Active and Reactive Powers (PLx & QLx) for Substation 03 Feeder 02 over a period of 24 hours, figure 13 shows power values in kW. The active powers are shown with solid lines and corresponding reactive powers are shown with dotted lines for the three phases of the feeder number 2. The Active power amplitudes are on left-Y-axis and the reactive power amplitudes are on the right-Y-axis. A step change in Active power (SUB3FRD2PL1) demand shown by solid red trace around 09:15 & 10:30 reflects in similar step change in Reactive power for the same phase (SUB3FDR2QL1) as shown by dotted red trace. An interesting observation can be made between 12:15 & 13:45 active power increase is not matched by the reactive power. This can be attributed to the quality of load being brought on line.

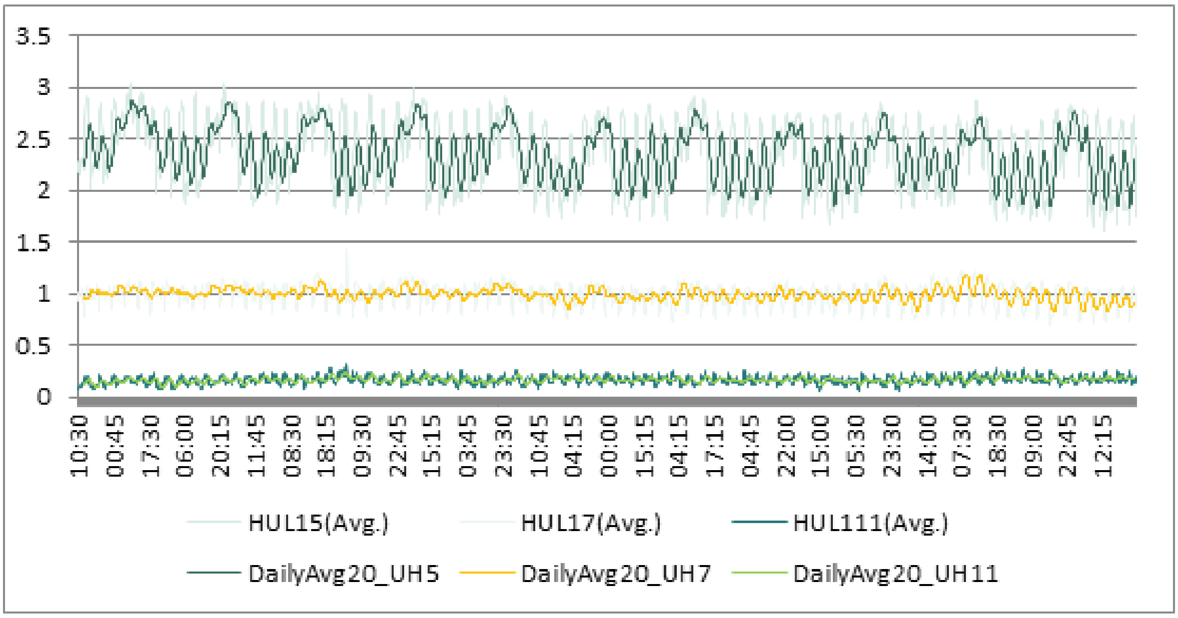
Figure 13: Active Power PLx & Reactive Power QLx



Source: Project Team

Fig. 14 shows plots for 5th, 7th and 11th Voltage Harmonics values at Substation 5 on feeder 1 for an extended period of 12 weeks. Here each cycle represents a 24 hour period. In this plot the 11 weekends show higher voltage harmonics compare to weekdays (5th harmonic top trace).

Figure 14: Sub5 Fdr1 Phase 1 Daily Avg20 5th , 7th & 11th Voltage harmonics



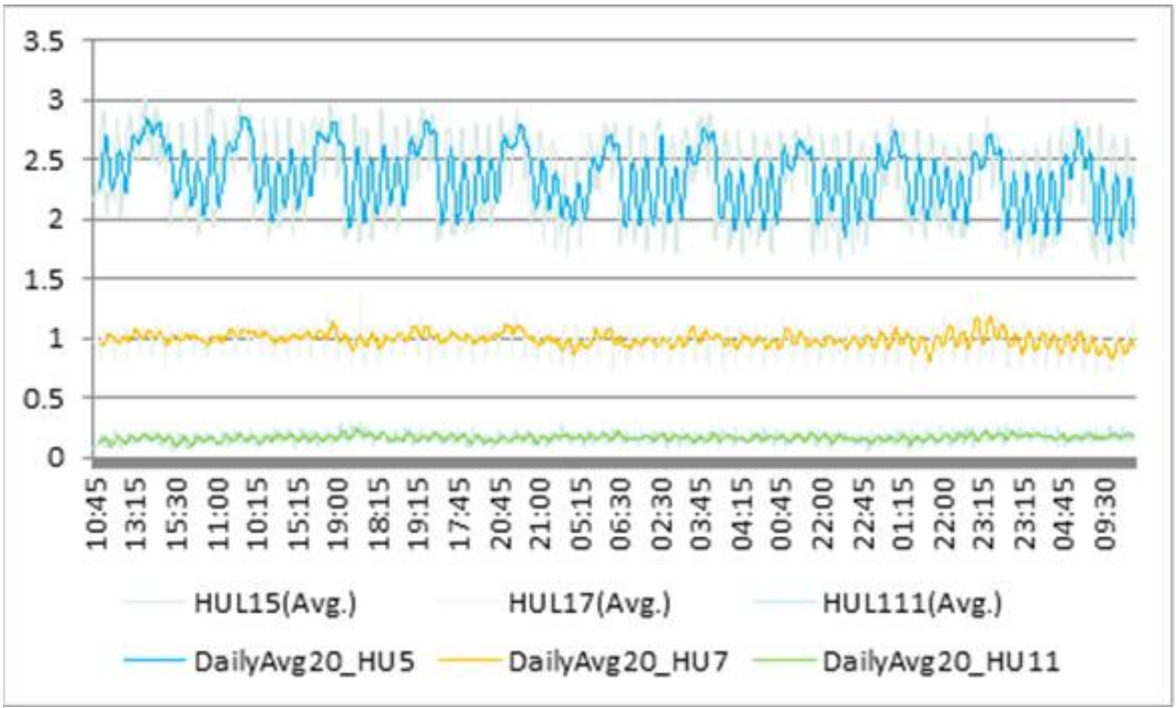
Source: Project Team

In Figure 14 the 7th & 11th voltage harmonics also show the similar weekday & weekend trends, though not as clearly. The voltage harmonics are presented as % values.

Continuing at the same substation (Sub5) but a different feeder (Feeder 3), Figure 15 shows 5th, 7th and 11th Voltage Harmonics for a period of 10 weeks.

Similar to Fig. 14 above, weekday and weekend harmonic variations are also noticeable in Fig. 15. Here also the weekends showing higher Voltage Harmonic values. Again as indicated earlier the Voltage Harmonics are measured as % of voltage.

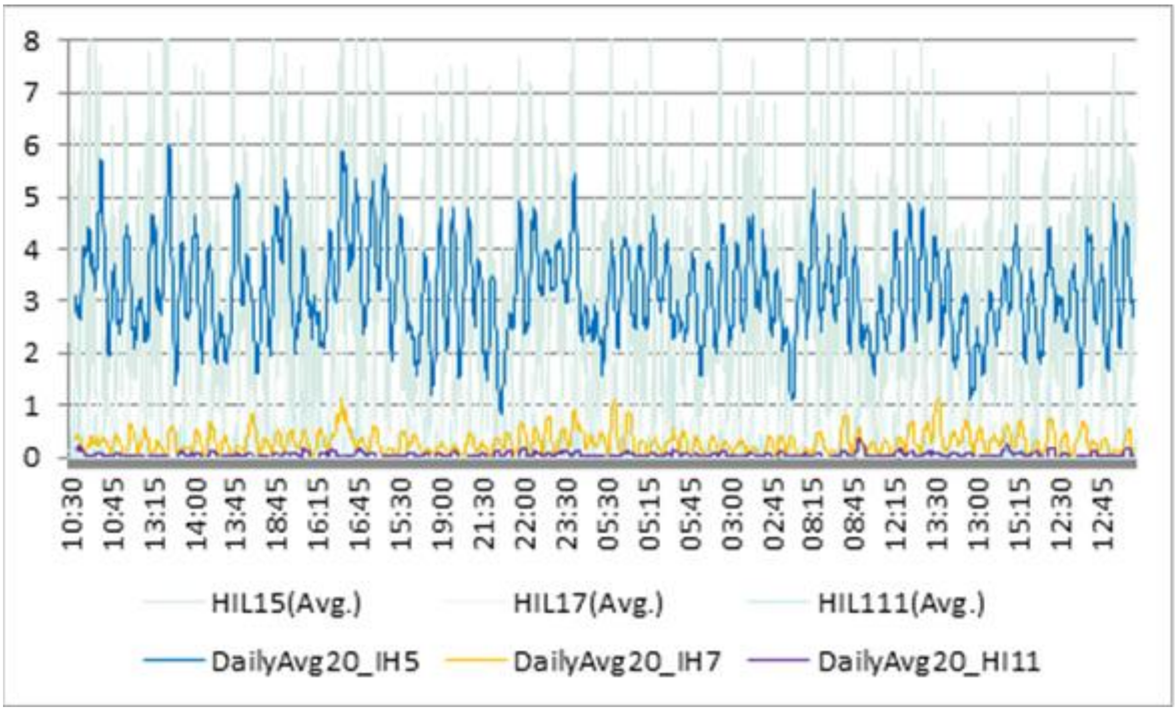
Figure 15: Sub5 Fdr3 Daily averaged 20 Voltage harmonics 5th , 7th & 11th



Source: Project Team

Figure 16 shows the three Current Harmonic values at the Substation 5 on Feeder 2. Here the 5th current harmonic (top bold blue trace) has the highest value and the 11th harmonic (purple bottom trace) is low enough not to warrant any remedial action. This plot shows around 10 weeks of Current Harmonics.

Figure 16: Sub5 Fdr2 Daily Avg20 Current Harmonics H5, H7, H11



Source: Project Team

To conclude this short review of the harmonics, it is worth a mention that the harmonics are highly user load quality dependant and no general overarching universal remedial actions can be recommended. These are site specific activities and the observations made during this project provide site specific observations only.

In view of the increasing trend of deployment of higher power factor loads, it is expected that the quality is likely to improve without additional measures.

SECTION 3

Project Timeline

3.1 Summary

This section describes the overall project timeline and in particular focuses on the customer facing aspects of the project. The customer elements were of course of primary concern to the project team as SoLa Bristol was fundamentally about engaging with end users to determine the feasibility of using new technology to benefit both parties.

This focus meant therefore that considerable effort was dedicated to creating the right approach to planning customer contact and the use of events and publications to communicate the relevant project messages in a coherent and easy to understand way.

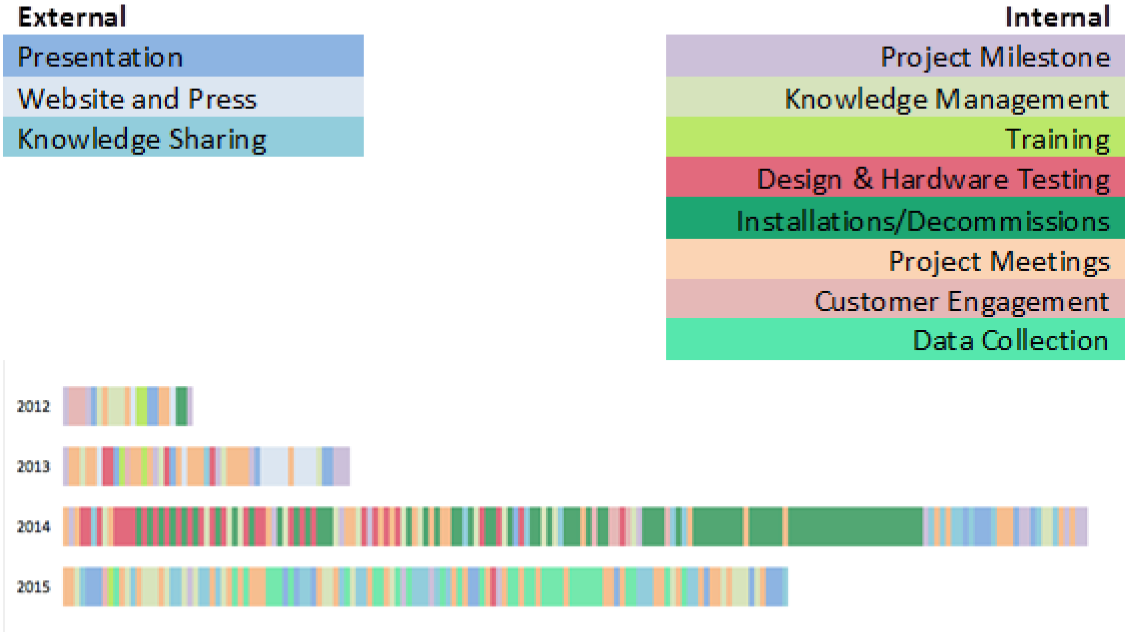
3.2 Project Lifespan

A project will not succeed if it is being conducted in isolation; it is vital that LCNI projects share, communicate, and reflect on their progress. SoLa Bristol has engaged in a wide range of internal and external dissemination and knowledge-sharing activities with a range of partners. In this section we summarize the types of events we have attended and contributed to, alongside key stages within the SoLa Bristol project, highlighting the extensive range of activities and tasks required to fulfil a LCNI project.

There have been 386 events over the project life span so far, of which 80 have involved external dissemination and knowledge sharing events. During the project lifespan the focus of the project has shifted, in 2014 we see a clear shift to the testing and installation of equipment, while 2015 has focused more or data collection and knowledge sharing.

To provide an easy overview the figure below (fig 17) highlights the wide range of activities that are involved in SoLa Bristol, it is interesting to note how the project focus fluctuates during the project lifespan, for example the dramatic increase in events and interactions during 2014, the main phase of the project and shift to data collection and knowledge sharing in the final year of the project.

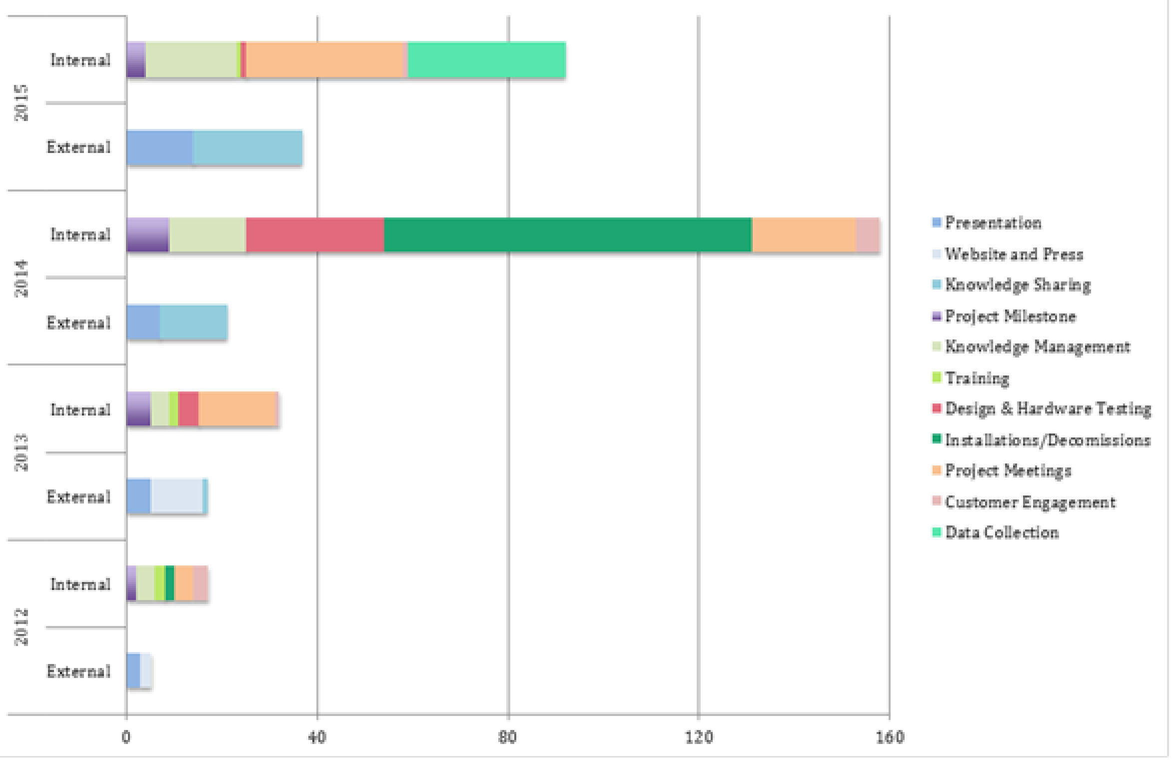
Figure 17:Overview of range of activities undertaken



Source: University of Bath

In Figure 18 we show the activities split by internal and external activities, it is apparent that during 2014, when the focus of the project was on installations, the majority of project interactions were internal. However in 2015, when data was being collected and analysed, the project shifted to become more outward looking and knowledge sharing, attending a number of key events and sharing a wide range of learning topics.

Figure 18: Internal and External events by year



Source: Project Team

3.3 Timeline & Events

A full list of the 385 events are provided in the timeline (Table 2), it is clear from this that project members have continuously been engaged in this project, such as through project trials, customer engagement activities, data collection and knowledge sharing events.

Figure 19: Key to dissemination activities

Key to Activities

External	Internal
Presentation	Project Milestone
Website and Press	Knowledge Management
Knowledge Sharing	Training
	Design & Hardware Testing
	Installations/Decommissions
	Project Meetings
	Customer Engagement
	Data Collection

Source: Project Team

External	Date	Internal
	2012	
	03 February 2012	Project Start Date
	26 April 2012	Customer drop in sessions
	12 May 2012	Sign up of 60 potential customers
	12 May 2012	12 schools and an office registered interest in the project
	01 June 2012	Project Progress Report
University of Bath WPD conference	17 July 2012	
	16 August 2012	Knowledge Capture - LCNF Bidding process
	21 August 2012	Meeting with Press Office
	31 August 2012	WPD Knowledge Capture
	04 September 2012	WPD & Gallomanor Knowledge Capture
	07 September 2012	KWMC Knowledge Capture
	26 September 2012	Project Update Teleconference

PV Magazine	01 October 2012	
	08 October 2012	BCC equipment training and generation of guidance document
	09 October 2012	BCC equipment training and generation of guidance document
ENA Conference 2012	25 October 2012	
ENA Conference 2012	26 October 2012	
	14 November 2012	Monthly Team Meeting
	22 November 2012	Tablet Design Meeting
Electrical Times	28 November 2012	
	12 December 2012	Ecohouse install
	13 December 2012	Ecohouse install
	31 December 2012	Project Progress Report
	2013	
	14 January 2013	Gallomanor involvement is confirmed
	23 January 2013	Monthly Team Meeting
	12 February 2013	Ofgem Report Meeting
	01 March 2013	KWMC & Tablet Knowledge Capture
	05 March 2013	Progress Meeting
	06 March 2013	Meeting at KWMC
Electricity Storage	12 March 2013	
	04 April 2013	SoLa Bristol hardware tests
	05 April 2013	SoLa Bristol hardware tests
Sustainability Live Event	17 April 2013	
	02 May 2013	Ecohome volunteer training
	02 May 2013	Householders visit to Ecohome
	07 May 2013	Project Meeting
	17 May 2013	Monthly Team Meeting
	20 May 2013	SoLa Partner visit to EcoHouse
	23 May 2013	Schools Engagement Planning Meeting
	30 June 2013	Project Progress Report

	05 June 2013	Householder Interviews
	17 June 2013	Project partner school visits
Bristol Solar City	21 June 2013	
	24 June 2013	Project Update Meeting
Tablet design features on Artist's website	24 June 2013	
	26 June 2013	Schools Engagement Meeting
	27 June 2013	Schools Engagement Meeting
	27 June 2013	Bristol City Council Schools Meeting
Interview with Birmingham research group	08 July 2013	
	08 July 2013	Factory Acceptance Testing
	04 September 2013	Test home installs complete
	09 September 2013	Householder Interviews
	16 September 2013	Tablet Meeting
	17 September 2013	Tablet Meeting
	18 September 2013	Tablet Meeting
	19 September 2013	Tablet Meeting
	23 September 2013	Initial Installation Report R2
Energy Institute conference	08 October 2013	
Bristol Post	10 October 2013	
BBC Points West	10 October 2013	
Bristol 247	11 October 2013	
Bristol Business	11 October 2013	
Bristol City Council	11 October 2013	
	16 October 2013	Analytics and customer savings meeting
Knowle West	23 October 2013	
Connecting Bristol	24 October 2013	
Demand Response Blog	28 October 2013	
Low Winter Sun	30 October 2013	
	07 November 2013	KWMC Knowledge Capture
ENA 2013	12 November 2013	

ENA 2013	13 November 2013	
	17 December 2013	Data Protection Plan approved
	17 December 2013	Customer Engagement Plan approved
	31 December 2013	Project Progress Report
	2014	
	21 January 2014	Engagement meeting
	14 February 2014	Combined domestic FAT report M3
	19 February 2014	Project Meeting
	24 February 2014	Loft Boarding
	26 February 2014	Loft Boarding
Attended flexible plug and play	26 February 2014	
	27 February 2014	Loft Boarding
	27 February 2014	Householder Interviews
	28 February 2014	Gallomanor meeting
	03 March 2014	Loft Boarding
	04 March 2014	Loft Boarding
	06 March 2014	Loft Boarding
	10 March 2014	Battery Lifts
	10 March 2014	Domestic Install
	11 March 2014	Loft Boarding
	11 March 2014	Domestic Install
	12 March 2014	Loft Boarding
	12 March 2014	Domestic Install
	13 March 2014	Loft Boarding
	17 March 2014	Domestic Install
	17 March 2014	Battery Lifts
	18 March 2014	Domestic Install
	18 March 2014	Loft Boarding
	19 March 2014	Domestic Install
	19 March 2014	Loft Boarding

	19 March 2014	Householder Interviews
	20 March 2014	Loft Boarding
	24 March 2014	Domestic Install
	24 March 2014	Battery Lifts
	24 March 2014	Householder Interviews
	25 March 2014	Domestic Install
	25 March 2014	Householder Interviews
	25 March 2014	Loft Boarding
	26 March 2014	Domestic Install
	26 March 2014	Loft Boarding
	27 March 2014	Loft Boarding
	31 March 2014	Project Meeting
	31 March 2014	Commission date
	01 April 2014	Domestic Install
	01 April 2014	Householder Interviews
	01 April 2014	Loft Boarding
	02 April 2014	Domestic Install
	02 April 2014	Loft Boarding
	03 April 2014	Domestic Install
	03 April 2014	Loft Boarding
	07 April 2014	Domestic Install
	08 April 2014	Domestic Install
	09 April 2014	Domestic Install
	09 April 2014	Householder Interviews
	10 April 2014	Commercial FAT report M3
	14 April 2014	Installers meeting
	15 April 2014	Stakeholder meeting
	17 April 2014	Householder Interviews
	22 April 2014	Loft Boarding
	23 April 2014	Commission date

	23 April 2014	Loft Boarding
	23 April 2014	Schools Meeting
	24 April 2014	Loft Boarding
	30 April 2014	Schools Meeting
	01 May 2014	Battery Lifts
	01 May 2014	Householder Interviews
	06 May 2014	Domestic Install
	06 May 2014	Schools Meeting
	06 May 2014	Siemens & WPD Knowledge Capture
	07 May 2014	Domestic Install
	07 May 2014	Schools Meeting
	08 May 2014	Domestic Install
	09 May 2014	Operational Meeting
	09 May 2014	Tablet Meeting
	12 May 2014	Domestic Install
	13 May 2014	Domestic Install
Interview with Cardiff PhD Student	13 May 2014	
	14 May 2014	Domestic Install
	14 May 2014	Householder Interviews
	18 May 2014	Loft Boarding
	19 May 2014	Domestic Install
	20 May 2014	Domestic Install
	20 May 2014	Loft Boarding
	20 May 2014	Householder Interviews
	21 May 2014	Domestic Install
KTN & IET Forum	22 May 2014	
	29 May 2014	Battery Lifts
Synergict	02 June 2014	
	02 June 2014	Domestic Install
	03 June 2014	Domestic Install

	03 June 2014	Householder Interviews
	04 June 2014	Domestic Install
	04 June 2014	Householder Interviews
Australian Renewable Energy Agency	09 June 2014	
	09 June 2014	Domestic Install
	10 June 2014	Domestic Install
	11 June 2014	Domestic Install
	13 June 2014	Autism research meeting
	16 June 2014	Domestic Install
	16 June 2014	School Engagement Meeting
	17 June 2014	Domestic Install
	18 June 2014	Domestic Install
	18 June 2014	School Engagement Meeting
	18 June 2014	School Engagement Meeting
	20 June 2014	Battery Lifts
	23 June 2014	School Engagement Meeting
	26 June 2014	UoB & Gallomanor Knowledge Capture
	30 June 2014	Project Progress Report
	01 July 2014	Domestic Install
	02 July 2014	Domestic Install
	03 July 2014	Domestic Install
	07 July 2014	Domestic Install
	07 July 2014	Office Visit
UK/China Summit as part of Smart Bristol Presentation	07 July 2014	
	08 July 2014	Domestic Install
Ofgem Smart Energy	08 July 2014	
	08 July 2014	Project Meeting
	09 July 2014	Domestic Install
	14 July 2014	Domestic Install
	15 July 2014	Domestic Install

	16 July 2014	Domestic Install
	28 July 2014	School Install
	29 July 2014	School Install
	30 July 2014	School Install
	31 July 2014	School Install
	01 August 2014	School Install
	04 August 2014	WPD School meeting
	04 August 2014	School Install
	04 August 2014	Domestic Install
	05 August 2014	School Install
	05 August 2014	Domestic Install
	06 August 2014	School Install
	06 August 2014	Domestic Install
	06 August 2014	Update Schools meeting
	07 August 2014	School Install
	08 August 2014	School Install
	11 August 2014	Domestic Install
	11 August 2014	School Install
	12 August 2014	Domestic Install
	12 August 2014	School Install
	13 August 2014	Domestic Install
	13 August 2014	School Install
	14 August 2014	School Install
	15 August 2014	School Install
	16 August 2014	School Install
	17 August 2014	School Install
	18 August 2014	School Install
	19 August 2014	School Install
	20 August 2014	School Install
	21 August 2014	School Install

	22 August 2014	School Install
	23 August 2014	School Install
	24 August 2014	School Install
	25 August 2014	School Install
	26 August 2014	School Install
	27 August 2014	School Install
	28 August 2014	School Install
	29 August 2014	School Install
	01 September 2014	Final School commissioned
Community Storage Workshop	24 September 2014	
	25 September 2014	Project Meeting
Meet with Tokyo Institute of Technology Academics.	03 October 2014	
	06 October 2014	Steering Committee Meeting
Consumer Protection sub group	13 October 2014	
Vice Chancellor visit to Psychology Research	14 October 2014	
Solar Energy UK	15 October 2014	
Consumer Protection sub group	16 October 2014	
LCNI Conference	20 October 2014	
LCNI Conference	21 October 2014	
LCNI Conference	22 October 2014	
Public Engagement event at UoB	05 November 2014	
	06 November 2014	Learning report meeting
	10 November 2014	Pre focus group meeting
	12 November 2014	Gallomanor debate kit testing
ENA 2013	14 November 2014	
	17 November 2014	Office commissioned
	18 November 2014	Final house commissioned
Balancing Demand and Generation	20 November 2014	
Citizens Advice Bureau phone interview	24 November 2014	

	25 November 2014	SoLa Focus groups
	25 November 2014	Decipher my data – School visit
Guangzhou Award Ceremony - part of Smart Bristol	28 November 2014	
	05 December 2014	Learning report meeting
	11 December 2014	Change request CCR 004 Approved
	16 December 2014	SoLa Project meeting
	31 December 2014	9.4 Early Learning Report
	31 December 2014	Project Progress Report
	2015	
	12 January 2015	SoLa JSC meeting
	13 January 2015	Conference Call
	20 January 2015	Visit to School to observe lesson
SoLa Bristol included in Dept for Education stand at BETT	23 January 2015	
Energy Storage Operator Forum	27 January 2015	
LGC Award shortlisting	28 January 2015	
Smart Metering UK & Europe Summit	28 January 2015	
	28 January 2015	Ashton School visit
	29 January 2015	Kit to BCC for training
	03 February 2015	Siemens installation of kit at UoB
	04 February 2015	SDRC Analysis meeting
	05 February 2015	Householder interviews
Attended Low Carbon London event	09 February 2015	
	10 February 2015	SDRC Catch up meeting
	19 February 2015	Householder interviews
	23 February 2015	Householder interviews
	24 February 2015	Householder interviews
	02 March 2015	Settings & Report Meeting
	03 March 2015	Householder interviews
London Parliament Meeting	10 March 2015	

LGC Awards	11 March 2015	
	12 March 2015	Householder interviews
	13 March 2015	Change request CCR 005 Approved
	17 March 2015	Householder interviews
EDF SoLa Visit	18 March 2015	
Citizen's Advice workshop	19 March 2015	
	19 March 2015	Project meeting
Bath Taps into Science	20 March 2015	
	23 March 2015	Householder interviews
	24 March 2015	SDRC Catch up meeting
	25 March 2015	Data Collection at house
	30 March 2015	Project Meeting
	31 March 2015	Substation visit
	07 April 2015	Joint Steering Committee Meeting
	07 April 2015	SDRC 9.5 Meeting
	15 April 2015	Report meeting
	17 April 2015	Substation and House visit
	20 April 2015	Network Trials
	21 April 2015	Network Trials
Utility week	22 April 2015	
	22 April 2015	Network Trials
Utility week	23 April 2015	
VC Let's Talk Event UoB	23 April 2015	
Bristol Smart Energy City collaboration event	23 April 2015	
Utility week	24 April 2015	
	24 April 2015	SDRC 9.5 Meeting
	27 April 2015	Householder interviews
	28 April 2015	Householder interviews
	28 April 2015	Avonline Schools meeting
DfE visit Psychology UoB	30 April 2015	

	30 April 2015	KWMC Data collection
	01 May 2015	Householder interviews
Ofgem visit KWMC	07 May 2015	
Discussions with Ecotricity	07 May 2015	
	08 May 2015	SDRC 9.5 Meeting
	13 May 2015	Substation visit
	15 May 2015	Outage Trial
	19 May 2015	SDRC 9.5 Meeting
	20 May 2015	Office interviews
	20 May 2015	Outage Trial
	20 May 2015	9.7 Outage trials and report
	21 May 2015	Outage Trial
Teddinet conference	21 May 2015	
Teddinet conference	22 May 2015	
Battery storage discussion with Toby Costin	26 May 2015	
	31 May 2015	9.5 Networks Benefits Report
Bristol Smart Metering	04 June 2015	
	09 June 2015	Schools visit
Venture Fest, Engine Shed, Bristol	09 June 2015	
	10 June 2015	House decommissioning meeting
	10 June 2015	Schools visit
	11 June 2015	Workshop meeting
BrEPS conference	15 June 2015	
BrEPS conference	16 June 2015	
	17 June 2015	Schools visit
	17 June 2015	SDRC 9.5 Meeting
	18 June 2015	Taunton Battery testing
	30 June 2015	Project Progress Report
	13 July 2015	Project meeting
	15 July 2015	Battery testing, house 27 removed

	03 August 2015	Schools visit
	04 August 2015	Project meeting
	05 August 2015	Schools visit
	07 August 2015	House visit
	10 August 2015	Project meeting
	12 August 2015	Battery test
	17 August 2015	Battery test
	19 August 2015	Battery test
	20 August 2015	Ecohome visit
	20 August 2015	Engineering meeting
	22 August 2015	Battery test
	22 August 2015	Substation Visit
	24 August 2015	Battery test
	24 August 2015	Substation Visit
	24 August 2015	Schools visit
	26 August 2015	Battery test
	26 August 2015	Ecohome visit
	27 August 2015	Dissemination event planning
	27 August 2015	Knowledge capture meeting
SoLa Dissemination event	04 September 2015	
	14 September 2015	Gallomanor and WPD future work meeting
	15 September 2015	Ecohome visit
	15 September 2015	School visit
IET Standards meeting, expert advisor	16 September 2015	
Bristol Smart Metering	29 September 2015	
Bristol Smart Metering	30 September 2015	
	06 October 2015	Final report meeting
	07 October 2015	Gallomanor meeting
	07 October 2015	Battery test
	08 October 2015	Householder Interview

	12 October 2015	Knowledge capture meeting
	12 October 2015	Battery test
Solar Energy UK	13 October 2015	
Solar Energy UK	14 October 2015	
	16 October 2015	Final report meeting
DECC Storage Event	21 October 2015	
	22 October 2015	Storage meeting
	23 October 2015	SoLa Meeting
	29 October 2015	Householder Interview
	02 November 2015	SoLa Meeting
	11 November 2015	KWMC Knowledge Capture
	13 November 2015	WPD Knowledge Capture
Energy Symposium University of Bath	16 November 2015	
	17 November 2015	Gallomanor Knowledge Capture
	18 November 2015	KWMC Project Interview
	19 November 2015	SoLa Meeting
LCNI Conference	24 November 2015	
LCNI Conference	25 November 2015	
LCNI Conference	26 November 2015	
CSE Meeting	30 November 2015	

Table 2- All dissemination events

With the project ongoing until the close down report in March 2016 it is anticipated that activities, especially knowledge dissemination, will continue. In particular we anticipate the data and knowledge generated during this project will inform a range of future academic and industry focused projects.

In the following section we highlight the methods of dissemination that were used during this project.

3.4 Dissemination

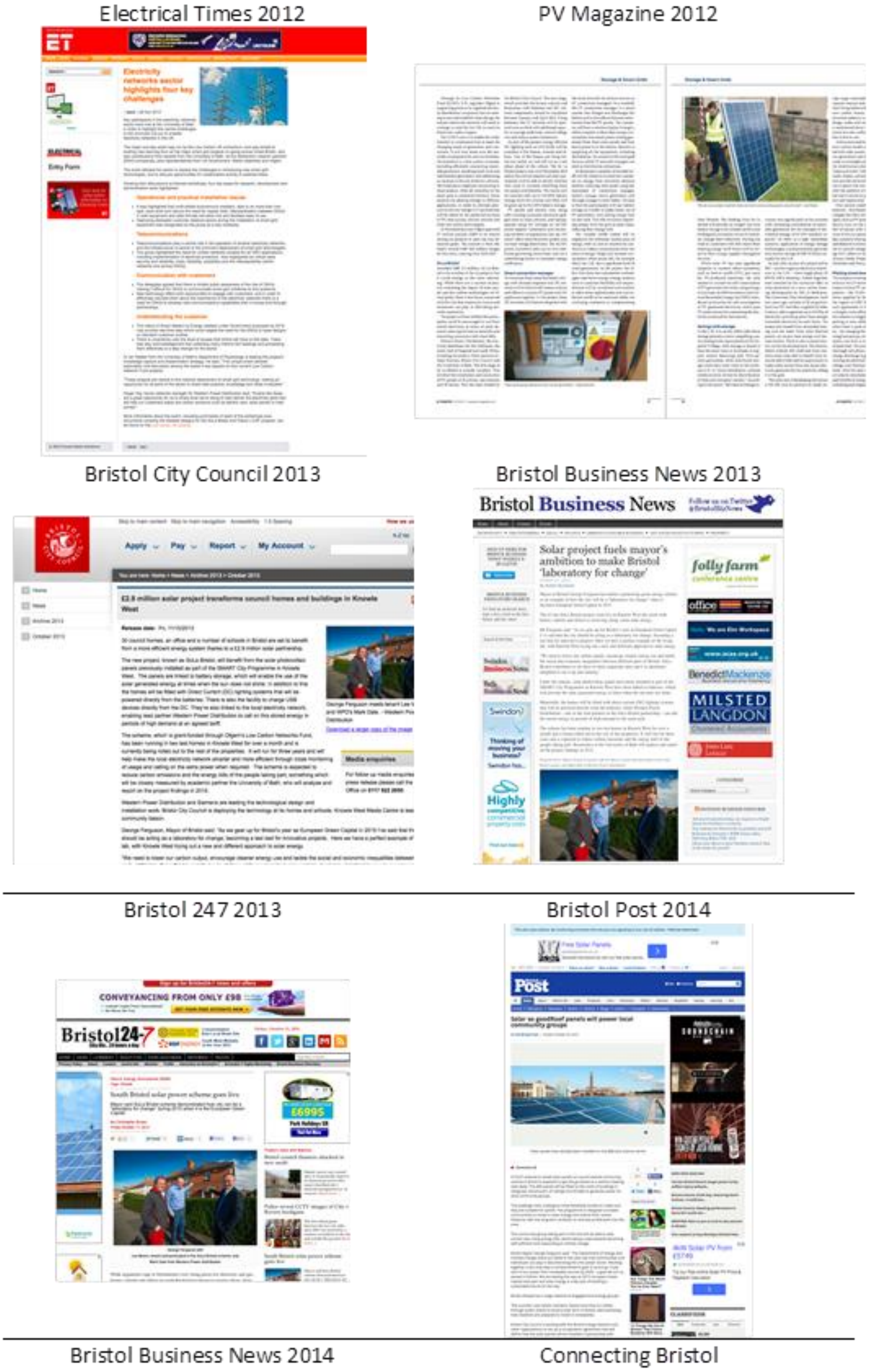
3.4.1 Websites

Press releases are a key tool for reaching external audiences. These might be general, or targeted towards a particular audience such as industry press, and so provide a useful and flexible method for sharing information with a range of audiences. It is also important that a project is aware of how it is being represented by the press and keeps track of articles, which relate to the project. Below we provide a sample of some of the press releases relating to SoLa Bristol published by external sources.

- http://www.electricaltimes.co.uk/features/article.asp?articleid=6887
- http://www.danewatkins.com/2013/06/knowle-west-media-survey.html
- www.bristolpost.co.uk/Council-houses-Knowle-West-solar-power/story-19917878-detail/story.html
- http://www.bristol247.com/2013/10/11/south-bristol-solar-power-scheme-goes-live-12561/
- http://www.bristol-business.net/solar-project-powers-mayors-ambition-to-make-bristol-green-laboratory-for-change/
- www.bristol.gov.uk/press/%C2%A328-million-solar-project-transforms-council-homes-and-buildings-knowle-west
- http://www.bristol.gov.uk/press/%C2%A328-million-solar-project-transforms-council-homes-and-buildings-knowle-west
- http://www.connectingbristol.org/2013/10/24/mayor-of-bristol-promotes-new-sola-bristol-energy-project-in-knowle-west/

- http://www.connectingbristol.org/2013/10/24/mayor-of-bristol-promotes-new-sola-bristol-energy-project-in-knowle-west/
- en.escn.com.cn/article/show/10442.aspx
- http://www.evepia.co.uk/how-should-the-uk-support-the-uptake-of-domestic-solar-pv-storage/
- http://www.myelifenow.com/2013/08/how-should-uk-support-uptake-of.html
- www.bristolpost.co.uk/Solar-goodRoof-panels-power-local-community/story-23036959-detail/story.html

Figure 20: Various pieces of publicity throughout the project



Source: Project Team

3.4.2 Industry and academic publications

Throughout the project life span outcomes and learnings of the SoLa Bristol project have been disseminated to a variety of audiences, in particular to those who work in the industry and those who conduct academic research in this area. In the section below we provide details of publications from the SoLa Bristol project relevant to these audiences.

3.4.2.1 Industry Reports

During the SoLa Bristol project various learning outputs from this project have been made available to the industry. For reference, key documents are listed below.

June 2012 Project Progress Report

https://www.ofgem.gov.uk/publications-and-updates/bristol-six-monthly-report-june-2012

December 2012 Project Progress Report

http://www.westernpowerinnovation.co.uk/Document-library/2013/WPD-PPR-SoLa-BRISTOL-December-2012.aspx

June 2013 Project Progress Report

http://www.westernpowerinnovation.co.uk/Document-library/2013/PPR_WPD_SOLA_BRISTOL_MAY2013_PUBLIC.aspx

December 2013 Project Progress Report

http://www.westernpowerinnovation.co.uk/Document-library/2014/So-La-Bristol-Project-Progress-Report-Dec-2013.aspx

June 2014 Project Progress Report

http://www.westernpowerinnovation.co.uk/Document-library/2014/WPDT2003_May14PPR_Sola-Bristol_Issue1.aspx

December 2014 Project Progress Report

http://www.westernpowerinnovation.co.uk/Document-library/2014/Sola-Bristol-Nov-14-PPR-V1-0.aspx

June 2015 Project Progress Report

http://www.westernpowerinnovation.co.uk/Document-library/2015/SOLA-BRISTOL-Progress-Report-May-2015.aspx

Confirmation of Bristol design

http://www.westernpowerinnovation.co.uk/Document-library/2012/Confirmation-of-the-SoLa-BRISTOL-design-v1-0.aspx

Domestic properties installation report

http://www.westernpowerinnovation.co.uk/Document-library/2013/Sola-Bristol-Installation-report.aspx

Early Learning Report 2014

http://www.westernpowerinnovation.co.uk/Document-library/2014/Sola-Bristol-Operational-early-learning-report-fin.aspx

Measure Impact on the LV Network December 2014

http://www.westernpowerinnovation.co.uk/Document-library/2015/SDRC-9-5-REPORT-Final.aspx

3.4.2.2 Academic Publications and Presentations

Kaushik, S., Dale, M., Aggarwal, R., Smyth, A., Redfern M. and Waite, K., (2014). **Project SoLa BRISTOL migration from 'ecohome' to 'integrated homes'.** In: *Proceedings of the Universities Power Engineering Conference*. IEEE Computer Society Press, pp.1-5.

Kaushik, S., Bale, P., Aggarwal, R., Dale, M., Redfern M. and Smyth, A., (2013). **Project SoLa BRISTOL and the 'ecohome;.** In: *Proceedings of the Universities Power Engineering Conference*. IEEE Computer Society Press, pp.1-5.

Li, R., Wang, Z., Le Blond, S. and Li, F. (2014). **Development of time of use price by clustering techniques.** In: *PES General Meeting/ Conference and Exposition.* IEEE.

Martin, S. (2015). **"The Kettle goes on at 7" Are energy behaviours movable in relation to energy tariff forecasts?** at *British Environmental Psychology Society Conference: Environmentally Sustainable Lifestyles.* Sheffield.

Martin, S. (2015). **The SoLa project: Energy use in social housing** at *ENLITEN: What do you know about energy literacy?.* Bath.

McCullen, N., Walker,I., Natarajan,S. and Parget, J. (2014). **Smart Meter roll-out strategy and its effect on energy savings at community level***.* In *Behave Energy Conference.* Oxford.

Wang,Z., Gu, C., Li, F., Bale,P., and Sun, H. (2013). **Active Demand Response Using Shared Energy Storage for Household Energy Management**, *IEEE Transactions on Smart Grid,* vol. 4, pp. 1888-1897.

Zhao,C., Dong,S., Li,F., and Song,Y. (Accepted).**Optimal Home Energy Management System (HEMS) with Mixed Types of Loads**, *CSEE Journal Of Power And Energy Systems*

Zhao,C., Dong,S., Gu,C and Li,F. (Under Review). **New Problem Formulation for Optimal Demand Side Response in Hybrid AC/DC Systems**, *IEEE Transactions on Smart Grid.*

Zhao, C., Gu, C., Li, F. and Dale, M. (2015). **Understanding LV network voltage distribution – UK smart grid demonstration experience**. In: *Innovative Smart Grid Technologies Conference (ISGT)*, IEEE Power & Energy Society. pp.1-5.

Zhao,C., Shi,H., Li,R. and Li, F,. (2015). **Demand side response performance assessment: An impact analysis of load profile accuracy on DSR performances**, in *Power & Energy Society General Meeting, 2015 IEEE*, pp. 1-5.

Zhao,C., Shi,H., Zhang,Z. and Li,F. (Under Review). **DSR Performance Analysis: Assessment of Demand Reduction Effect on LV network**, in Power & Energy Society General Meeting, 2016 IEEE.

SECTION 4

Domestic

4.1 Summary

Domestic properties were monitored at three levels, In-system, In-house and at-repository. Domestic system's monitored data was saved at two locations, first within the system and second at-repository. Both in-system and at-repository datasets are saved at different locations to enhance the data availability, should the communication system becomes unreliable. The following section provides some details on the data point selection along with associated reasoning behind the data point identification and potential use of the data during and post trials. Further within this section data is presented and interpretation of the data is provided.

4.2 Measured Data

Domestic properties generate and consume data. There are three data types with differing use, for dynamic use, for storage and for consumption. The dynamic data is used within the system for internal operational activity. In-house data is pure consumption data type providing the user with at a glance system status. At-repository dataset is used for analysis. In-system stored dataset comprises of 1 minute averaged data. In-house data is presented to the consumer on tablet PC through system's WiFi interface alongside visual indicators showing dynamic battery voltage and potential battery voltage alarm LED on the consumer unit.

The stored data comprises on the AC side of voltages, currents, frequencies, active and reactive power, energy, power factor, harmonics etc. On the DC and PV sides similar parameters were recorded at multiple locations by multiple sub systems for cross correlation and for the purposes of built in redundancies. This was to ensure that post project future research and teaching tasks could be undertaken.

The data sets are identified as high and low resolution data sets. The high resolution data has granularity level of one minute averaged and the low resolution data has 15 minute granularity. The data storage format within the system is equipment vendor dependant and requires some general and other custom analysis tools. In future however, with industry wide concerted effort through standardising process some common formats may emerge and be adopted.

Considering the amount of data collected per site, the cost of transmission of data from various sites to the data repository at Bath, client confidentiality due to data containing user behaviour, and transport channel bandwidths available (on cost basis), it was agreed that only the fifteen minute low resolution data will be transmitted out of most of the domestic properties.

Enhanced system flexibility, though additional costs to the equipment, was introduced both from data retention and operational viewpoints. The system flexibility could have been better utilised if some of the project partners not had been engaged on fixed price contracts and in one specific case, a partner had moved to a similar trials project elsewhere on a larger project leading to reduced engagement.

L35	Fixed price partner contracts limited the flexibility of the final system due to additional equipment costs.

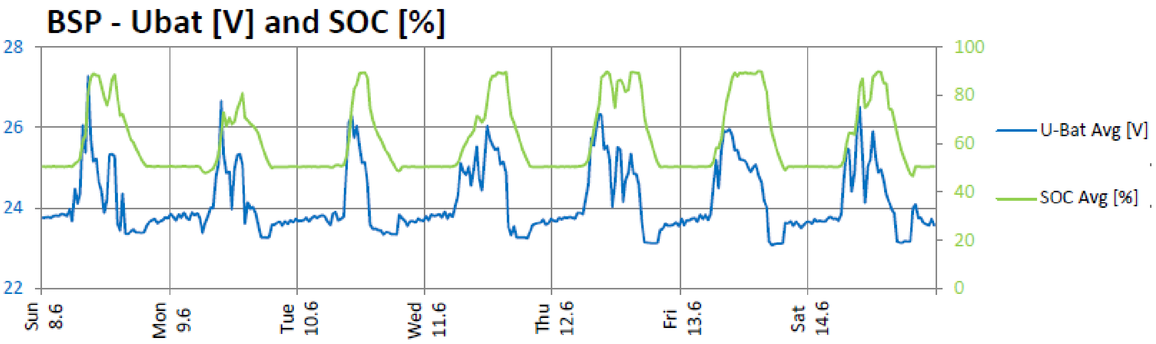
L36:	Partners taking part in similar trials with other projects may show reduced engagement following delivery of their workstream.

4.2.1 Voltage, Current & Load Shift AC-DC

Following section provides some observations on the voltages at certain locations, starting from the domestic through to substation. As the dataset comprises of 26 domestic properties over a period of over one year, not all data can be discussed here.

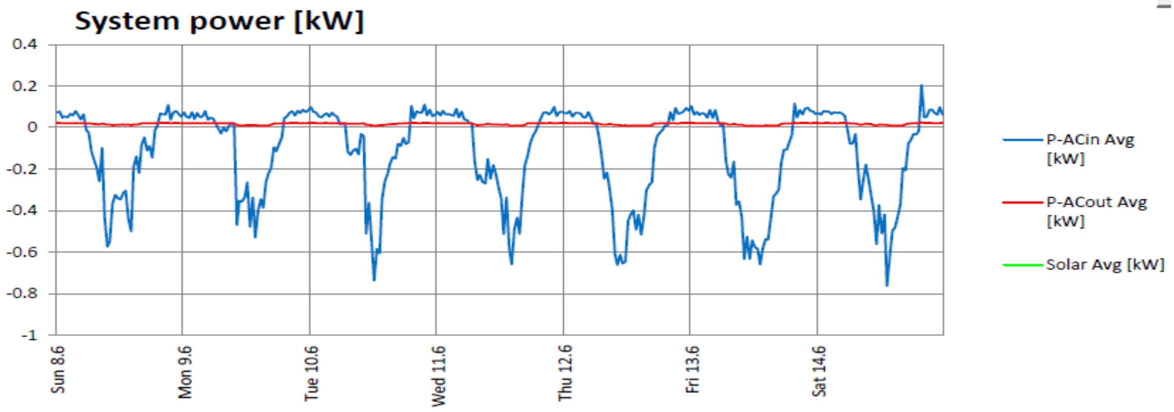
In an energy storage system, the battery's state of charge is one of the critical parameters, as the battery has to support the DC lighting load. Figs 21 & 22 below show two plots from site 07 which is non-optimally orientated with PV array facing south-southeast. This site became operational on 8th July 2014 and has a 2kWp PV installation. A seven day plot from 8th-14th June2015 shows the system charged the batteries from 50% state of charge to 90% state of charge as shown in Figure 21 and simultaneously exported around 32 kWh to the AC grid while supporting the DC lighting/USB loads shown in Figure 22.

Figure 21: Battery Voltage & State of Charge



Source: Project Team

Figure 6: Simultaneous Export to Grid

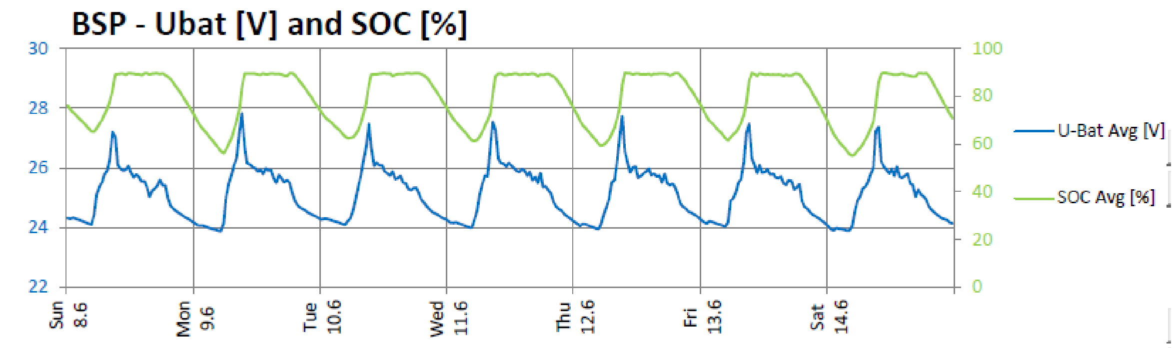


Source: Project Team

The battery capacity lower limit of 50% is to provide for DC loads irrespective of availability of PV the next day. The benefits are discussed further within this report.

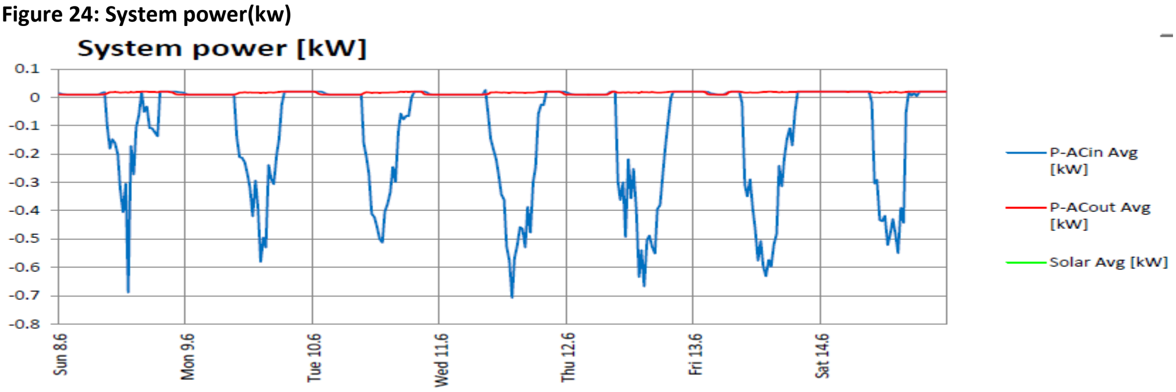
Similar seven day's data plots for site 01 is also shown in Figs 23 & 24 below.

Figure 23: BSP Ubat(V) and SOC(%)



Source: Project Team

Figure 24: System power(kw)



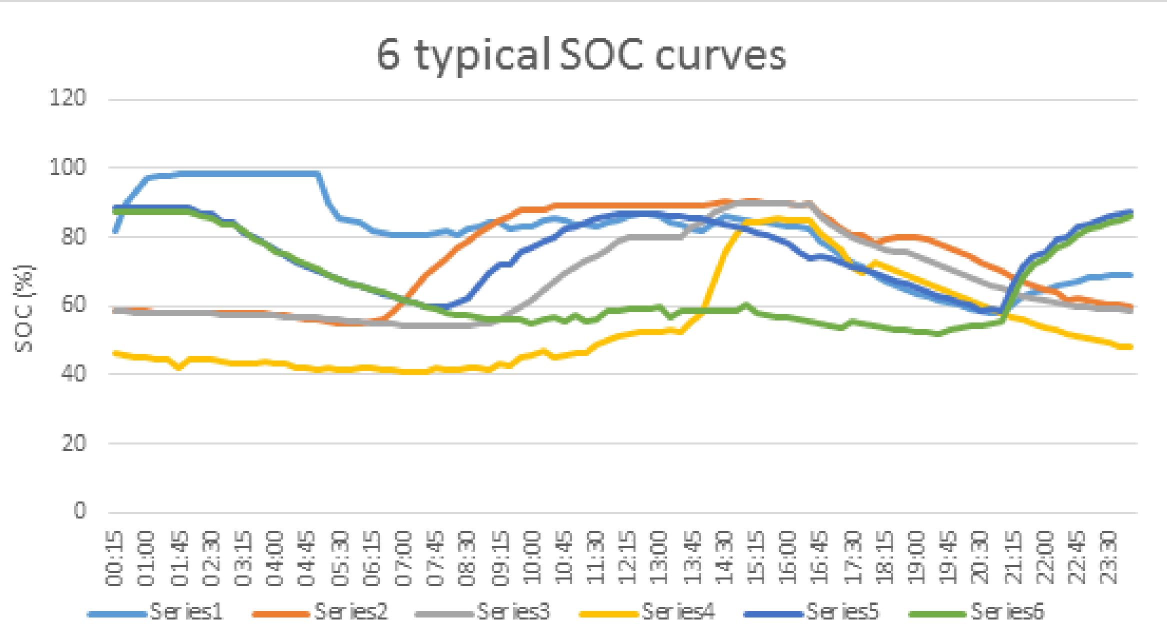
Source: Project Team

4.2.2 Measured EMS performance

4.2.2.1 Battery operation strategies

For engaged domestic customers, the power pack was installed and configured before November 2014. The smart metering data of state-of-charge (SOC) in 11 households connected at Ilminster Avenue substation are analysed from 22th November, 2014 to 30th June, 2015. For each domestic customer, the battery SOC is extracted to represent the pattern of EMS strategy. K-means algorithm is employed to categories the SOC for purpose of differentiating battery operation strategies. As an example, the clustering results of house 6 are presented in Figure 25

Figure 25: 6 typical SOC curves



Source: Project Team

As shown in the above figure, battery SOC curves generally can be categorized into 4 EMS strategy types:

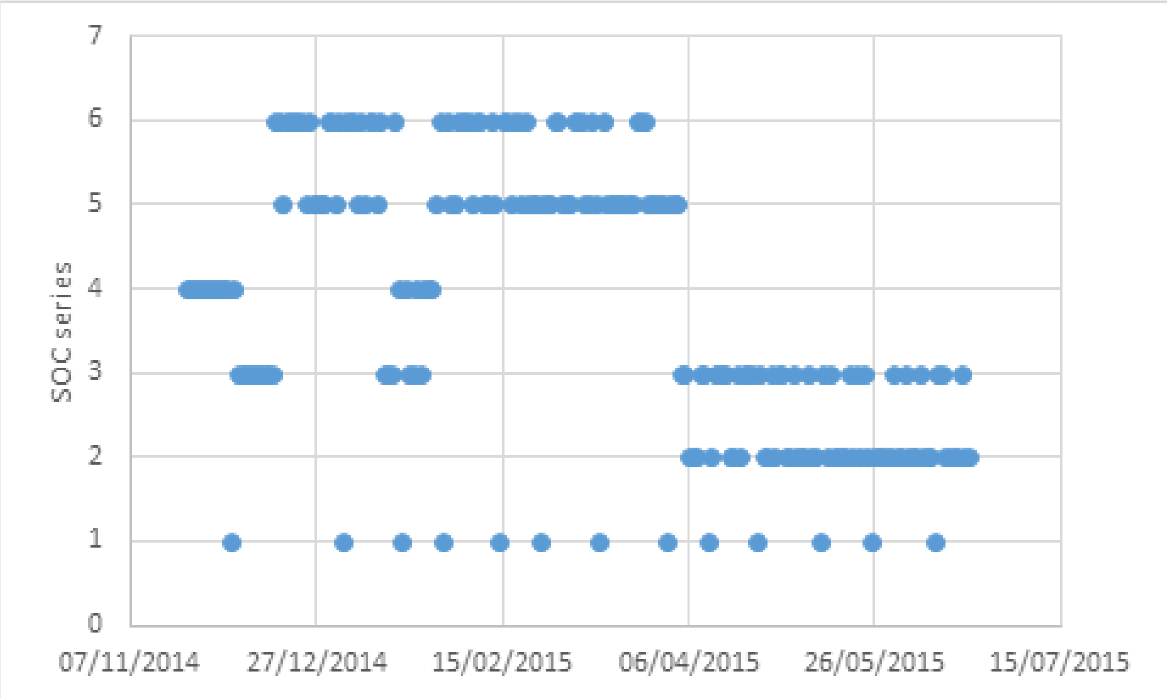
1. Monthly charge up: for series 1, SOC rise up to the full capacity then discharges as normal, this type of SOC represents the charge up process at 4th of each month.
2. EMS test strategy: for SOC curves present in series 4, the battery does not absorb PV output, but can conduct fixed afternoon charge up. Then the energy is exported to support system during peak time period. Since PV output does not affect the battery SOC in this EMS strategy type, differing weather condition cannot affect the SOC curves.
3. Strategy type 1: for SOC curves presented in series 2, series 3 and series 4, the battery does not charge in the evening, the energy that battery discharges to support the system in peak time is provided by absorbing PV output. In winter time, for different

weather conditions, series 3 represents the sunny days and series 4 represents the cloudy days. (Series 4 represents a combination cluster that merges the winter cloudy results with the test results before 5th Dec). In summer time, for different weather conditions, series 2 represents the sunny days and series 3 represents the cloudy days (Series 3 represents a combination cluster that merges the winter sunny results with the summer cloudy results).

4. Strategy type 2: for SOC curves presented in series 5 and series 6, the battery charges up in the evening then discharge before PV kicks in to create capacity space for absorbing PV output. Series 5 represents the SOC curve in sunny days, while series 6 represents cloudy days.

The time and dates of different SOC applied is shown in Figure 26. It clearly shows the "Monthly charge up" (series 1) is applied each month. EMS test strategy (series 4) is applied between 22nd Nov to 4th Dec. Type 1 strategy (series 2, 3 and 4) is applied in three time periods: early December, mid-January and after April. Type 2 strategy (series 5 and 7) is applied in two time periods: December to January and February to April.

Figure 26: Time & Dates of different SOCs



Source: Project Team

According to the results in Figure 26, the EMS system has 5 strategy periods except the monthly charge up process and EMS test process. The conclusion is demonstrated in table 3:

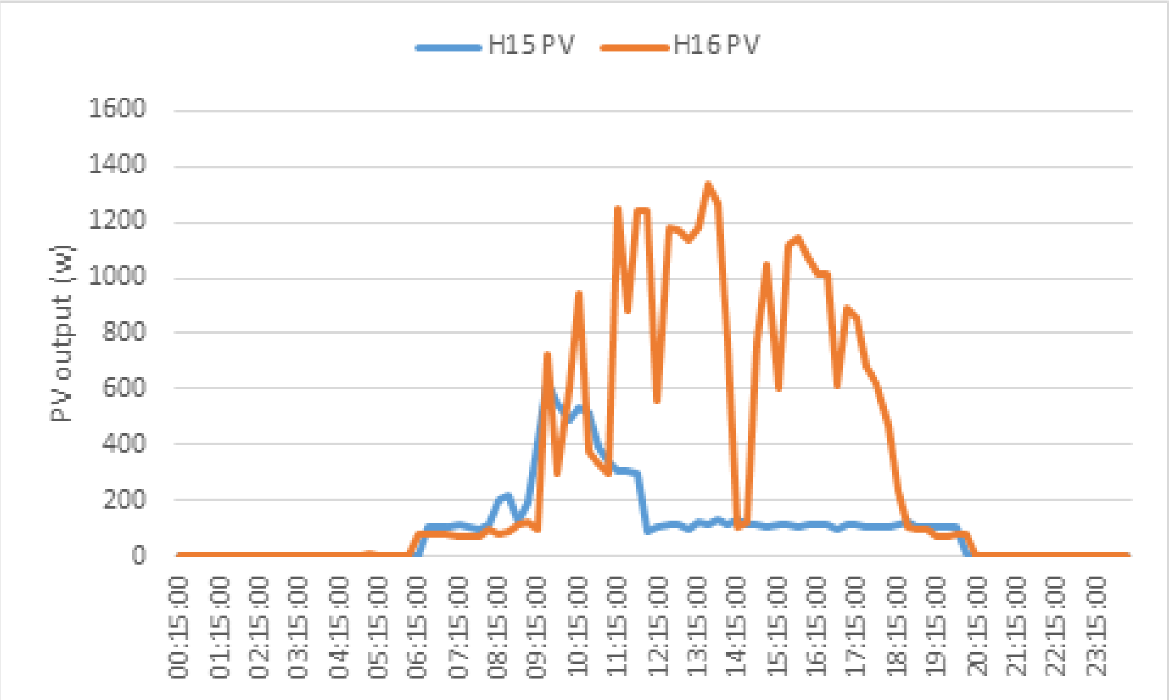
Strategy Periods	Period of Dates	Strategy Type
1	5th Dec. 2014 - 16th Dec. 2014	Type 1
2	17th Dec. 2014 - 15th Jan. 2015	Type 2
3	15th Jan. 2015 - 3rd Feb. 2015	Type 1
4	4th Feb. 2015 - 13th Apr. 2015	Type 2
5	14th Apr. 2015 - 30th Jun. 2015	Type 1

Table 3 Different battery operation strategies applied time

4.2.3 Location impact to PV output (PV face direction)

The house location and PV installation location significantly influence the output of PV output. House 15 and 16 are located close, which are connected on the same feeder and the same node. However, the PVs face east and south respectively in house 15 and house 16. Figure 27 & 28 show the PV output of the two houses on 15 and 16 April, which were both sunny days[1]. The results clearly show that, compared to that in house 16, the PV output in house 15 is low from noon because of its direction.

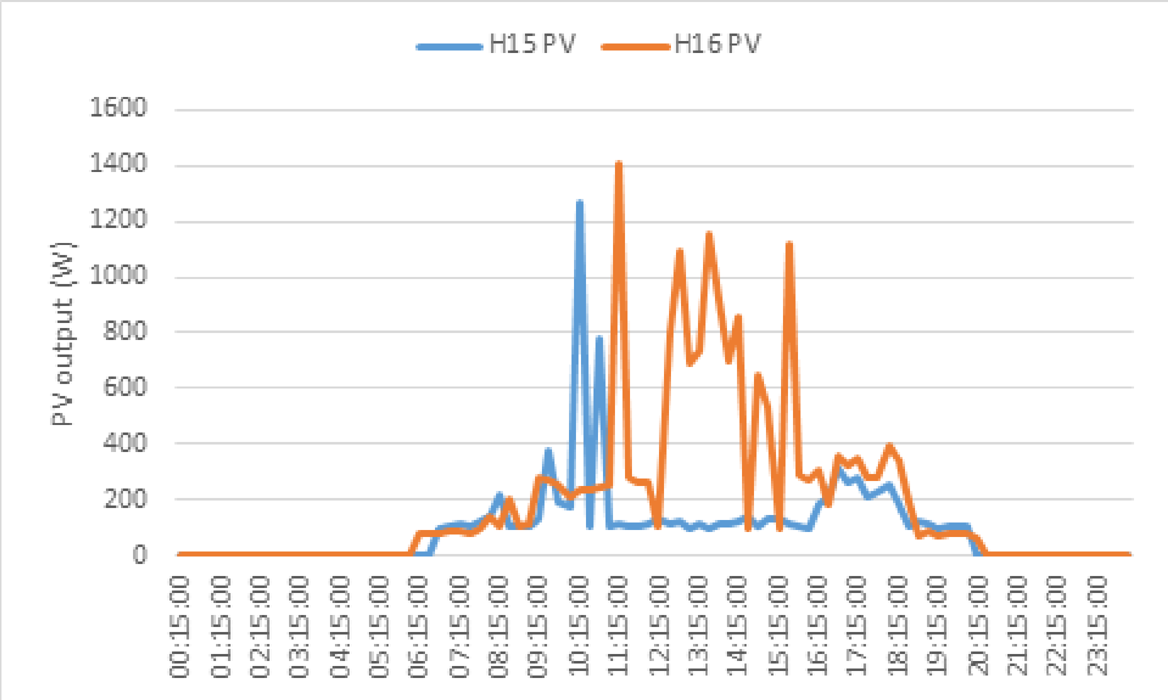
Figure 27: PV output of House15 &16 on 15TH April



Source: Project Team

[1] Weather online UK http://www.weatheronline.co.uk/

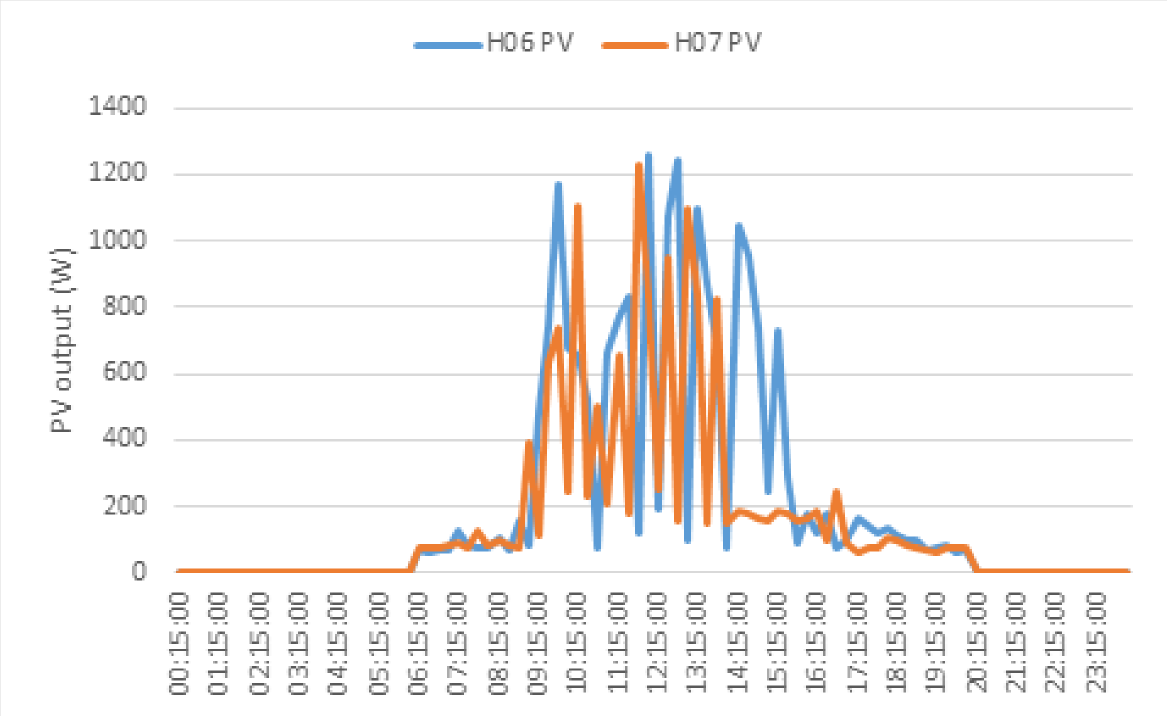
Figure 28: PV output of House15 &16 on 16TH April



Source: Project Team

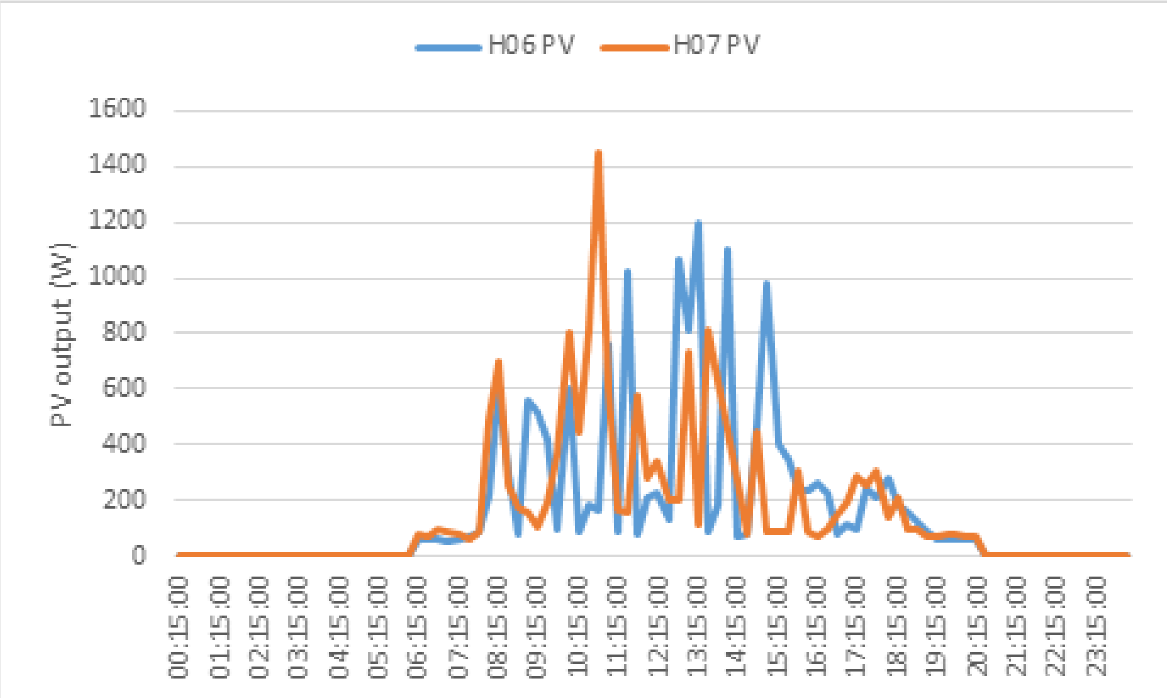
In comparison, House 6 and 7 are neighbouring and adjacent, which are also connected on the same feeder and the same node. The PVs both face southeast. figure 29 & 30 shows the PV output of the two houses are similar on 15 and 16 April.

Figure 29: PV output of House 6 and 7 on 15 April



Source: Project Team

Figure 30: PV output of House 6 and 7 on 16 April



Source: Project Team

L37	The house location and PV installation location significantly influence the output of PV output.

4.3 Ecohome Learning

The Ecohome is a specifically designed show case property, comprising of three bedrooms, kitchen and dining area on the ground floor and sitting room and study area on the first floor with a small terrace. This property benefits from a due south orientation with both east and west having outer glazed walls to enable solar thermal capture. These walls have heat retaining glazing. Alongside the SoLa Bristol installation other low carbon technologies demonstrators were also installed within this property.

The installation work of the SoLa Bristol equipment was completed and simultaneously the grid connection approval was obtained during Dec 2012. As part of this installation all AC lighting loads were converted to DC LED lighting loads. The micro grid deployed used a low-voltage-DC bus based technology distributing power within property at safe extra low voltages (SELV). The DC lighting loads and USB charging sockets run from nominal 24Vdc. The installed batteries are valve regulated lead acid batteries with 200Ah capacity. With this type of bus, battery charging voltages in excess of 28Vdc may be present which mandates that all loads are at least 32Vdc tolerant and suffer no undue effects when used for prolonged period at such voltages.

This sub-metered property imports/exports all its AC energy through the adjacent Create Centre, which is a multi-user business incubator.

Figure 31: Ecohome- First SoLa property and its associated equipment

Source: Project Team

As a standalone property without associated substation monitoring or wide area communication infrastructure for external operational intervention, this site was configured to run on a 24-hour-cyclical-time-based system.

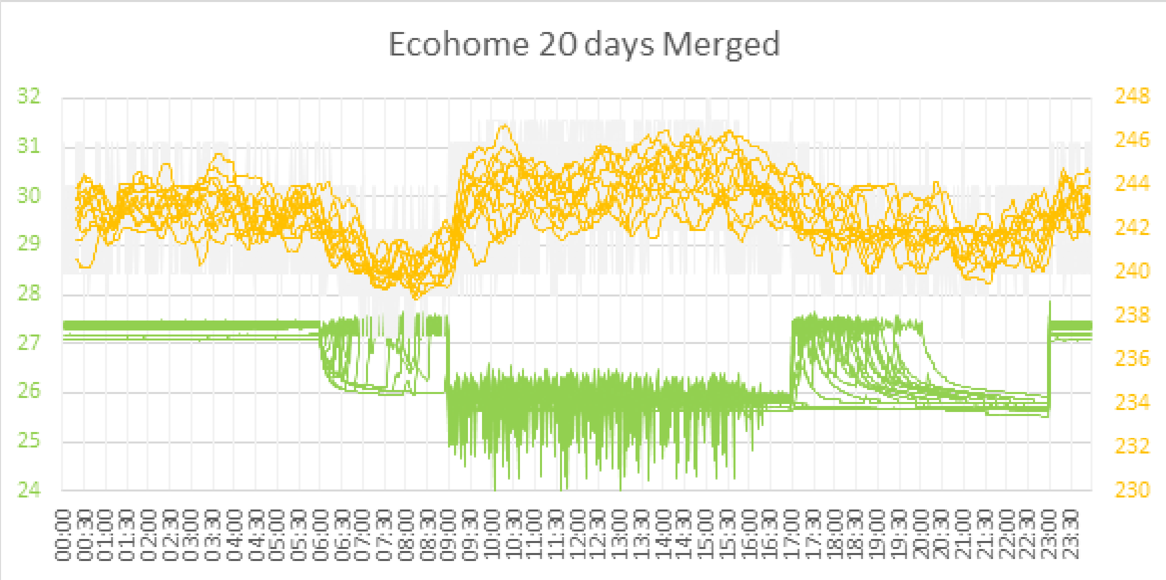
This mode of operation was based on a hypothetical scenario which assumes that occupants at the property are in full time employment and leave the property by 9 am and return after 5pm. With this assumption the cyclic system was setup to ensure the batteries were fully charged during the day time PV generation and the surplus generation was exported to the grid. This is a pro-consumer configuration where the battery's state of charge is the primary driver. In this case the exported energy was supporting the Create Centre's AC loads.

Ecohome's location can be described as a property situated at the end of a feeder. In case of the Ecohome, the nearest AC loads are located some 50 or so meters away, within the Create Centre.

Properties located on the furthest end of the feeder benefit the feeder in multiple ways. For instance, these properties when exporting to grid, help prevent "lower-voltage-limit-violation" as these properties do not contribute to upper-voltage-limit-violation through export tapering and contribute to the thermal stress reduction within the substation-near-end 1/3rd section of the feeder during daytime when the feeder is under moderately-high demand

In Figure 32 below it shows the AC and DC voltages profiles over twenty days and over 24 hour periods. The battery voltage shows that it is released from float charging state at 06:00 and is allows to rest till 09:00. It exports from 09:00 to 17:00 and is allowed to charge from PV from 17:00 till dusk.

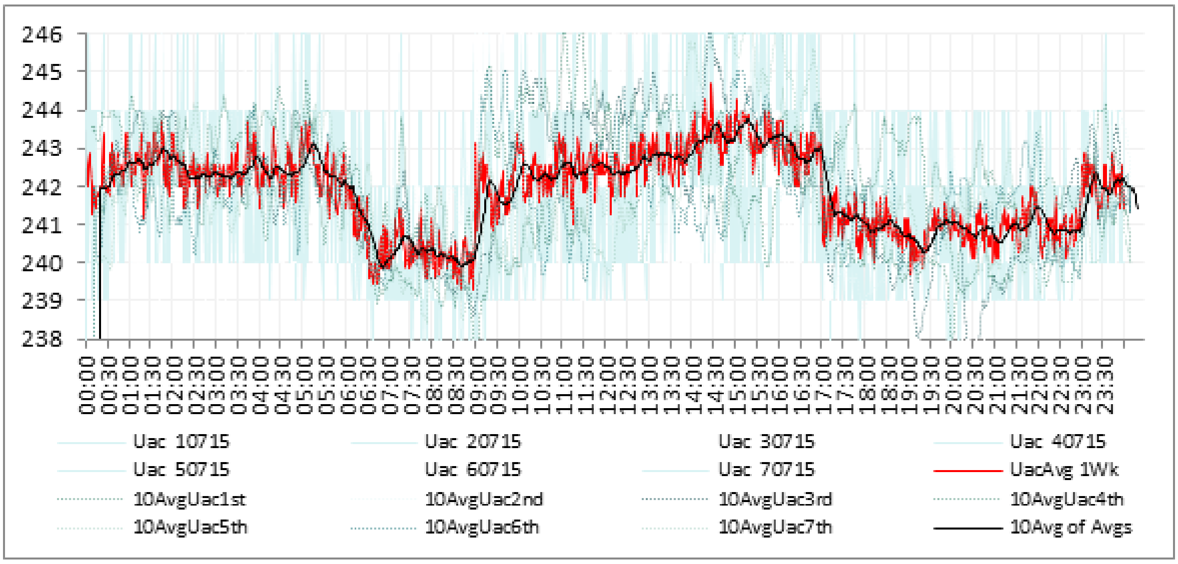
Figure 32: Ecohome export to grid twenty day averages



Source: Project Team

In case of the Ecohome, the non-proximity of other AC loads helps visualisation of the voltage support provided by the property as seen above. The following two figures show averaged export to grid setups. The two cases discussed below are for periods of two separate weeks. The two different import/export profiles used are shown below in Fig.33 & Fig. 34. During this test the objective was not to maximise the PV to grid export as conventional PV installations do but to show the differences between export to grid separately from the PV and battery. In Figure 33 the export period is set from 09:00 to 17:00 and is observable through the AC voltage lift. In Figure 34 the export periods are 07:00-09:00 & 18:00-22:00

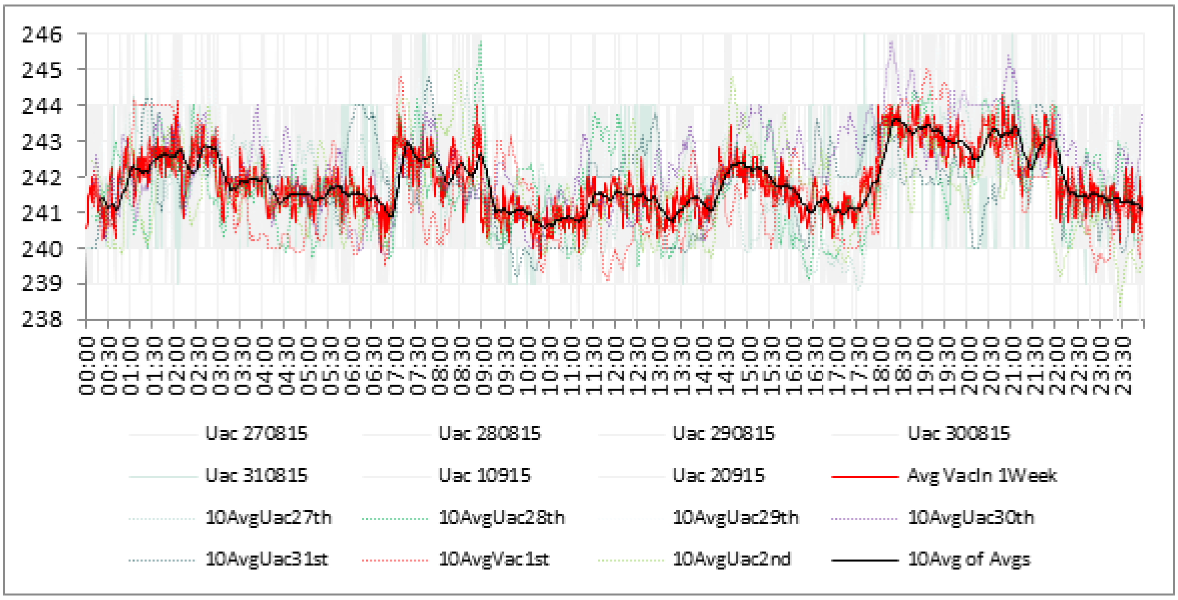
Figure 33: Ecohome exporting PV contribution from 09:00-17:00



Source: Project Team

Changing the contribution to the grid from battery source during the two export windows AM & PM) is shown in Fig. 34. Here the export to grid is from 07:00-09:00 & from 18:00-22:00

Figure34: Ecohome export Battery contribution 07:00-09:00 & 18:00-22:00

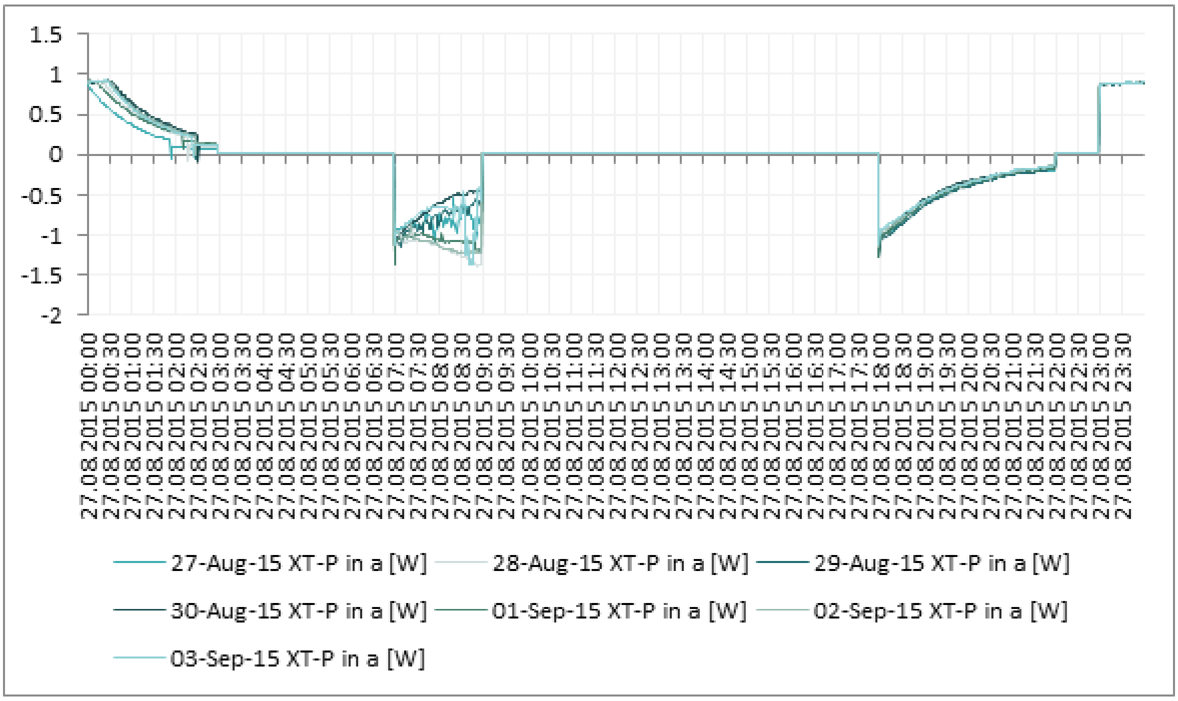


Source: Project Team

These modes of operation are further explored using other system variables within the system's dataset.

Figure 35 below shows the power being exported to the grid in kW during AM and PM windows. The negative power values are being exported from the system and the positive values are the power import. The two AM & PM export to grid windows show the export power tapering. The PM window tapering shows the battery service capacity declining as the battery gradually gets exhausted. In the AM export window the same battery exhaustion tapering takes place, except that the rising PV activity begins to contribute to the export to grid effort, hence the multiple value traces are present within the AM window, indicating PV's nondeterministic nature in contribution. During the 4 hour PM window between 18:00-22:00 the tapering due to the declining battery capacity as it gradually gets exhausted is to be utilised for battery state of health determination as part of future work at the University.

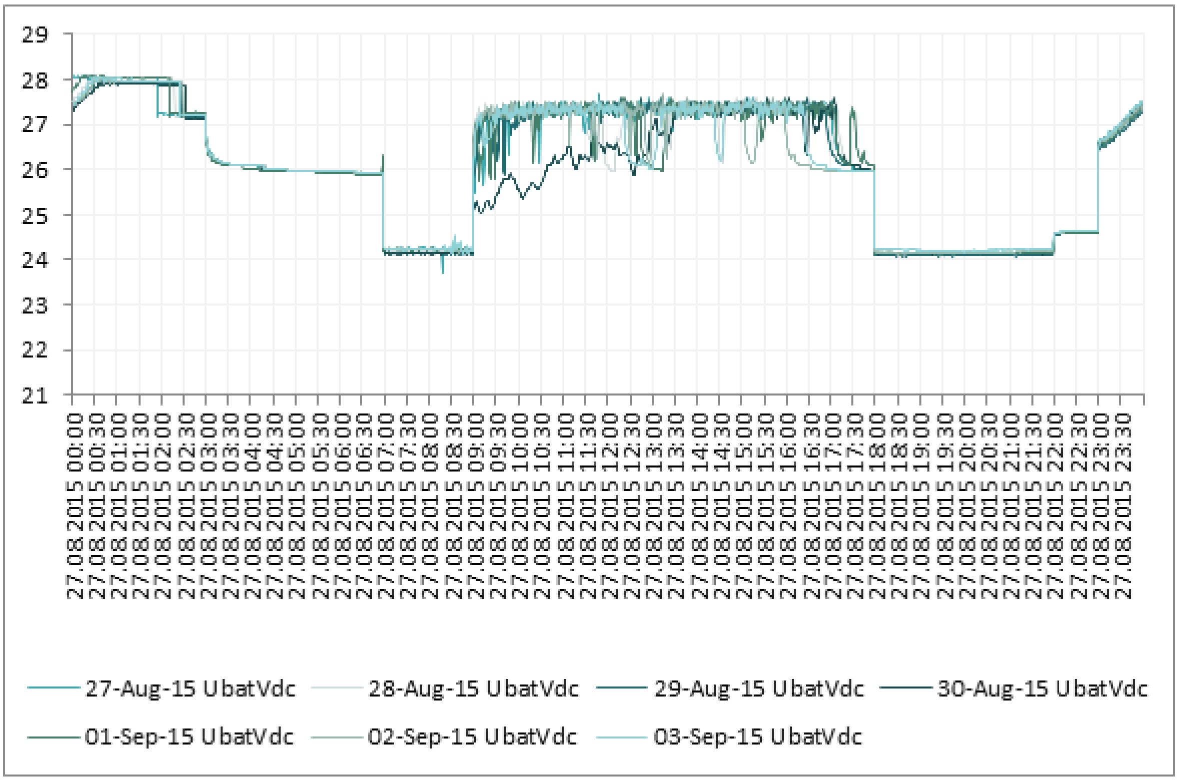
Figure 35: Power being exported to the grid in kW during AM and PM



Source: Project Team

Observing the same activity using the DC bus values, is shown in Fig. 36, here the battery voltages are restricted to fall below a pre-set level while the system batteries are exporting. This is a variable limit and is set to 24 volts for this test. The PV charging periods between 09:00 to 18:00 show the PV's charging variability.

Figure 36: Export to grid period battery voltages



Source: Project Team

In summary the Ecohome's standalone time based system's operation has provided useful real data over the last three years and has provided a field based experimentation platform. Post decommissioning is likely to provide other useful learning in due course.

SECTION 5

Commercial

5.1 Summary

As indicated earlier, the commercial systems cover both the schools and offices, with the necessary additions to the system. The Commercial sites do have an onsite PV system but unlike the Domestic systems, these PV installations though linked through monitoring, are standalone systems.

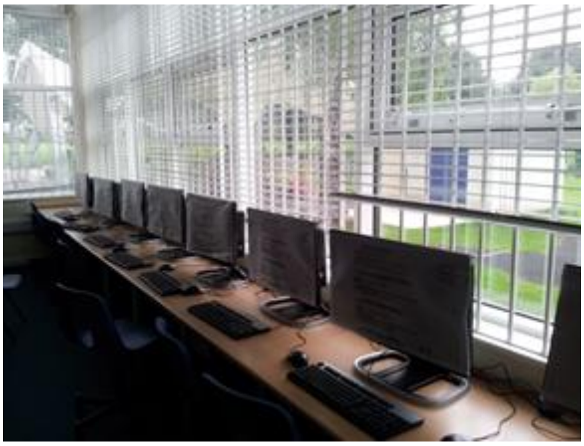
At the project concept stage it was expected that all schools would use the DC PCs but during schools engagement visits it became apparent that a common DC platform would not be suitable for all participating schools.

This section presents details of three schools & two offices, where the equipment support expectations were considerably different to what the school's expectations were, as covered in next section. The school with the largest DC load and IT suite is shown below. This school also had the longest run of DC micro grid due to the location of the SoLa system which can be seen adjacent to the building in Fig. 37. The IT suite layout is shown in Figs. 38 & 39 .

Figure 37: SoLa Bristol project school

Source: Project Team

Figure 38: Commercial System supporting schools IT suite with DC PCs and lighting



Source: Project Team

Figure 39: Commercial System supporting schools IT suite with DC PCs and lighting

Source: Project Team

5.2 IT Equipment diversity

The schools from user perspective had three requirements, desktop DC PCs support, laptop/tablet PCs charging and the DC LED lighting. As the charging of laptop/tablet PCs could be performed either through the USB port or using the plug top power supply, but with the varying requirements of plug top power supply from model to model, efforts were concentrated on devices capable of being charged through the USB port (Tablet PCs) and a dedicated DC bus for the desktop PCs.

The largest desktop DC PC loads were in the IT suite of 30 DC PCs and the IT suite's lighting of 12 units needed to be supported throughout the year.

The second school had a diverse range of laptops in use. This school had one Toshiba laptop charging trolley and one Apple tablet charging trolley with a content sync algorithm running alongside USB charging to update the OS and associated applications during charging. This was acharging and updating function was provided using a custom made, yet commercially available, charging trolley. The SoLa system was not intended to implement such device specific custom devices which had proprietary charging algorithms with embedded data transfer protocols. With this in mind the standard USB charging points were made available.

The Council office site was in the process of upgrading their laptops and users were uncertain whether to use a common platform or to continue to let their staff use laptops of choice.

With diversity of equipment from a charging and day time use perspective, two supply categories were provided. First to support the desktop DC PCs and to enable standard USB port based charging using clustered USB charging.

Figure 40: Gang USB charging points (Schools & Offices)

Source: Project Team

In the third school and Knowle West Media Centre(KWMC) office laptop charging was facilitated through the use of gang USB charging. The gang USB sockets are shown in Figure 40 above.

In summary, from SoLa Bristol trials and learning perspective, the large number of desktop DC PCs, clustered USB charging points and the differing number of lighting points at various sites, provided the diversity required for this study. These loads presented differing load characteristics on the DC micro grid.

5.3 DC LED lighting

As mentioned above, the lighting load requirements varied from site to site. One school had just four lighting points compared to the other school which required 12 lighting points. The council office site was the largest user of lighting points in an open plan office arrangement requiring 38 lighting points.

All properties along with the open plan Bristol City council office sites were converted from AC lighting to DC LED lighting. The council office had 38 existing light fittings, where each lighting point was equipped with Thorn lighting units using Philips TLD 58Watt lamps and associated ballasts.

The AC lighting point circuit load comprises of combined load of the Lamp and the Ballast. The Ballast loadings (losses) vary depending on the type of ballast used. The old electromagnetic ballast losses used to be around 22%, with usage of low loss ballasts, the losses were reduced to 12% and with the electronic ballast the losses were further reduced down to around 10%. The AC lighting loads used at the office site were a mixture of low loss (12%) and electronic ballasts (10%). The LED lighting sources used to replace the existing fittings were white LEDs which were single-phosphor-blue-LEDs with an integral DC-DC converter consuming below 30 watts per lighting point. This wattage rating included the DC-DC converter's power consumption as well. The DC-DC converter in the LED lamps can be as efficient as 94% or even higher. All schools and offices were equipped with same lighting units.

Generally the LED life time is expected to be around 25K hours with lumen maintenance down to around 75% over its life, however, in this short run experimental setup the lumen maintenance could not be determined with absolute certainty. Considering that the estimated lumen loss, in general is around 1% per 1000 hours of use,however this figure depends on various factors such as heat sink efficiency, the number of switching cycles during the usage period and how hard the LEDs are driven.

The Council office DC lighting load had the coincidental benefit that the DC microgrid cable run on this site was the shortest (below 2 meters) to the distribution point as the SoLa system was located adjacent to the building's external wall. This office also had four emergency flood lights which were not replaced. The DC bus based lighting performed the dual role of normal day usage and also emergency lights as these were unaffected by mains fail.

The other office with moderate number of DC lighting loads was the KWMC training room.

5.4 Inter phase balancing

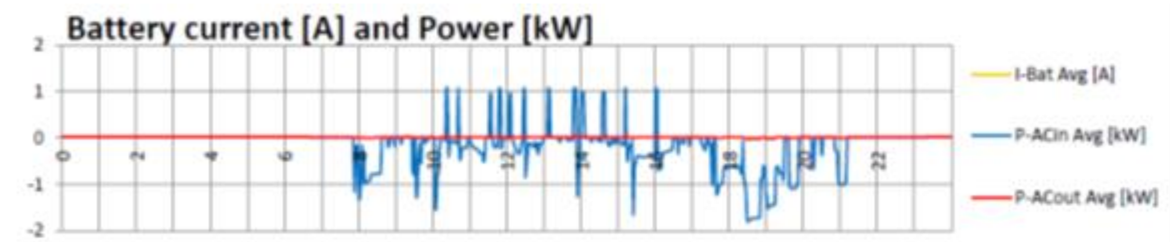
Considering that from the DNO perspective, within the distribution network, phase load balancing is also of interest alongside AC to DC load shifting (through LED or Battery), this third study area, specifically from the KWMC commercial site, was to demonstrate phase balancing.

The commercial three phase system is capable of exporting up to 11.5 kW AC. As shown below in a number of plots, commercial systems can be deployed for active phase balancing. The operation was tested using just 1kW as an example. Higher power levels and frequent interruptions were not tested and require further investigation in view of feeder stability.

In Figures 40-42 below the three plots are from 14th Apr 2014. The three separate inverters are simultaneously controlling their own charge/discharge paths independently. The load balancing is performed between phases L2 & L3. Phase L1's operation during 21:30-23:00 is independent of the activities of L2 & L3 as shown in Figure 41.

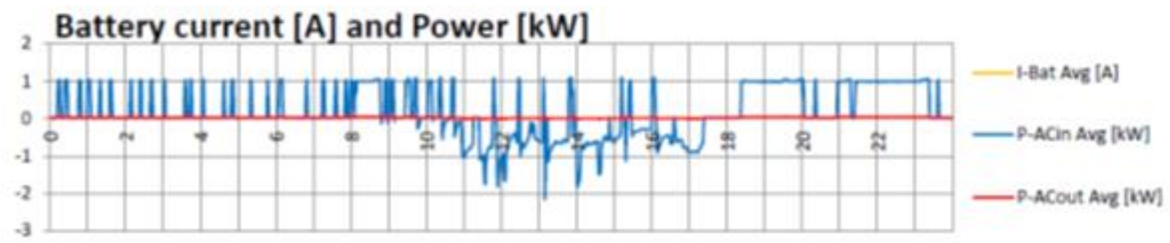
Phase L2 is importing 1kW from the grid (Fig. 50 where +ve = import) between 21:30 to 23:00 at the same time phase L3 is exporting to the grid (Fig. 42 where -ve = export) during the same period between 21:30-23:00.

Figure 41: Phase L1 inverter idling between 21:30-23:00 (0 kW)



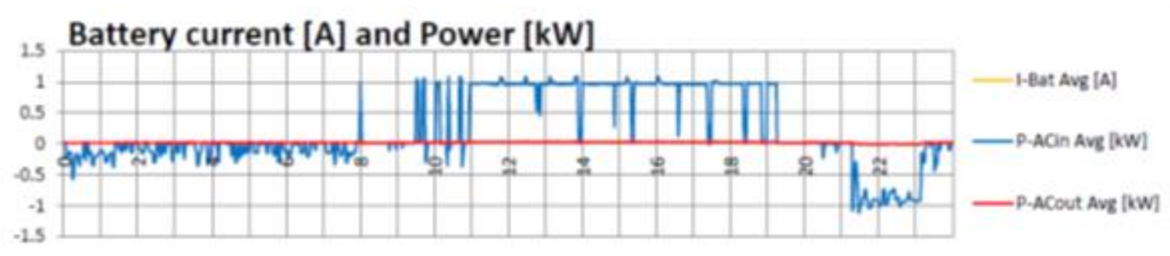
Source: Project Team

Figure 42: Phase L2 inverter Importing between 21:30-23:00 (+1 kW)



Source: Project Team

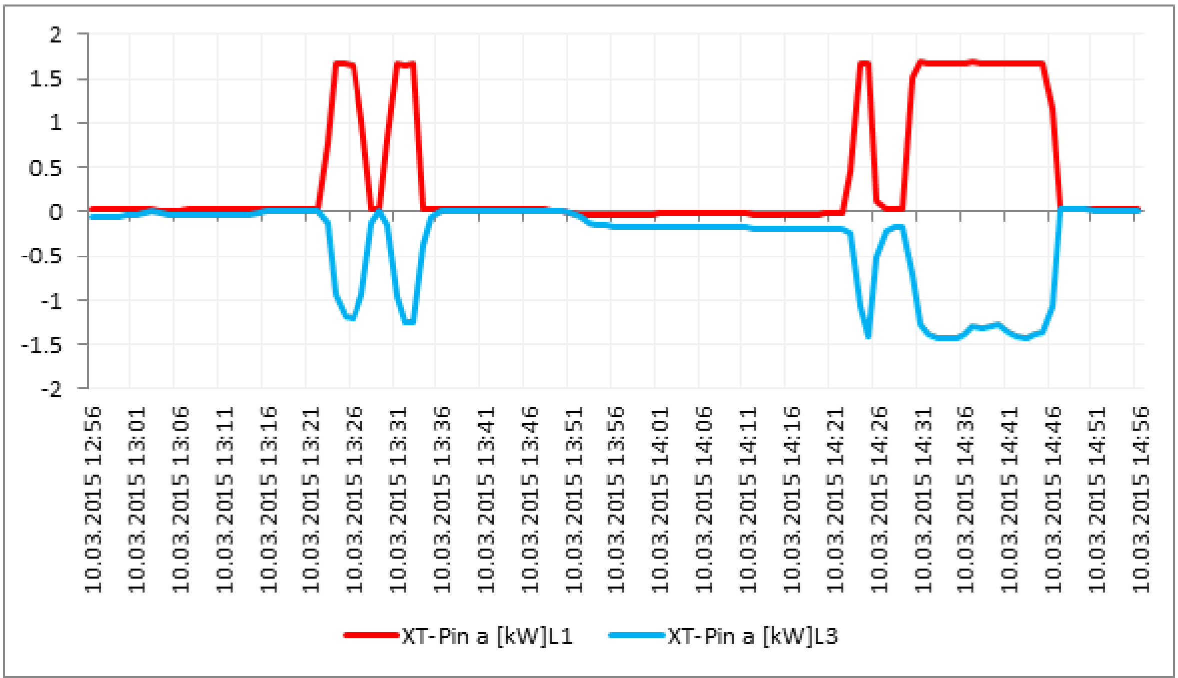
Figure 43: Phase L3 inverter exporting between 21:30-23:00 (-1 kW)



Source: Project Team

A similar phase balancing view is provided in Figure 44. Here phase L1 is the net importing phase and the phase L3 is the net exporter to the grid during day light hours. This provides a platform for further investigation into system accessed automated response system and/or locally/centrally controlled operation. This automated response aspect was beyond the scope of SoLa Bristol. Further investigation areas to explore are the effects of self-managing phase balancing with associated risk of instability and quantification of benefits in identified situations.

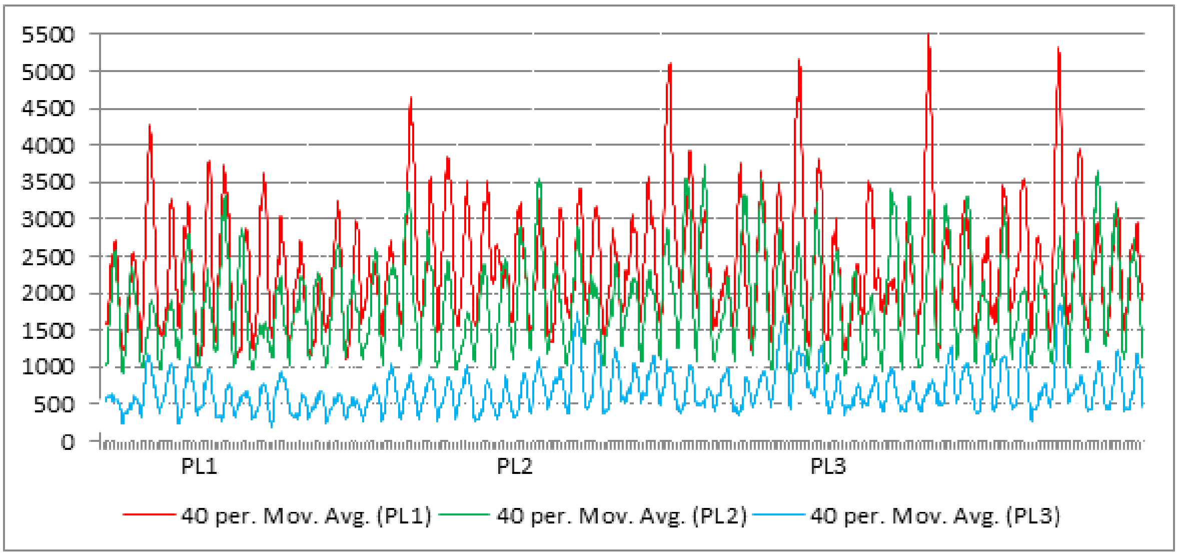
Figure 44: Phase balancing between phases L1 & L3



Source: Project Team

Figure 45 shows three months of power value data for the three phases on a single feeder in Substation 5. The plots shown are rolling average values for visual clarity. Each cycle represents one day’s power cycle. The above mentioned phase balancing equipment could be utilised on such a candidate feeder to evaluate the phase balancing and its pros and cons.

Figure 45: Sub5 Fdr1 power values from 18Sep to 13 Nov 2015 (averaged)

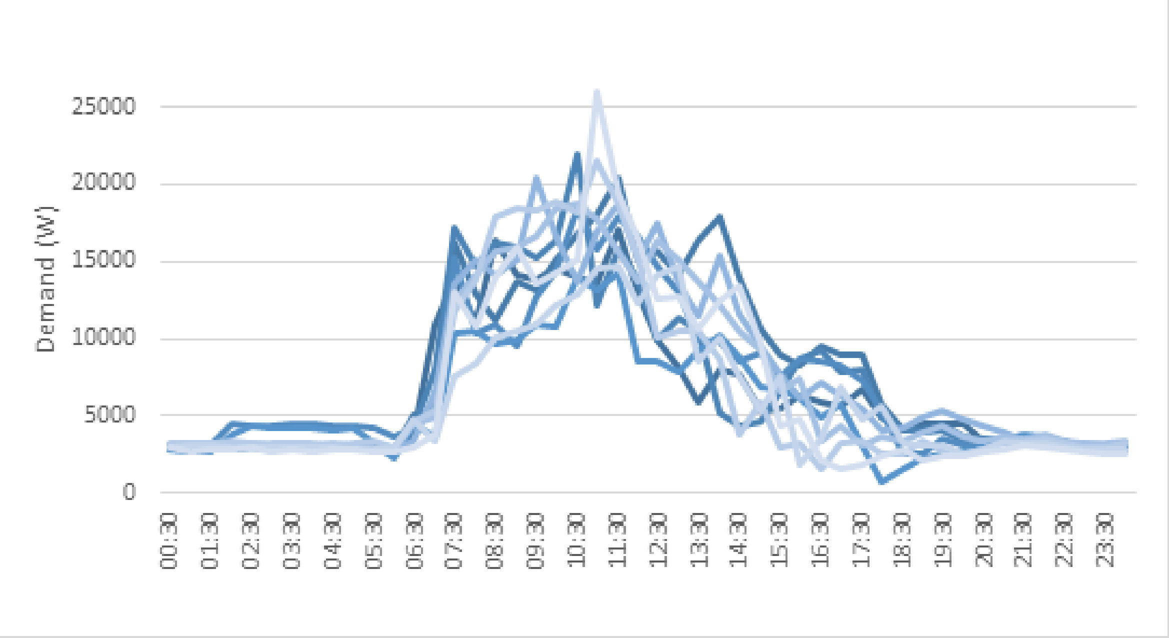


Source: Project Team

5.4.1 Demand Differences

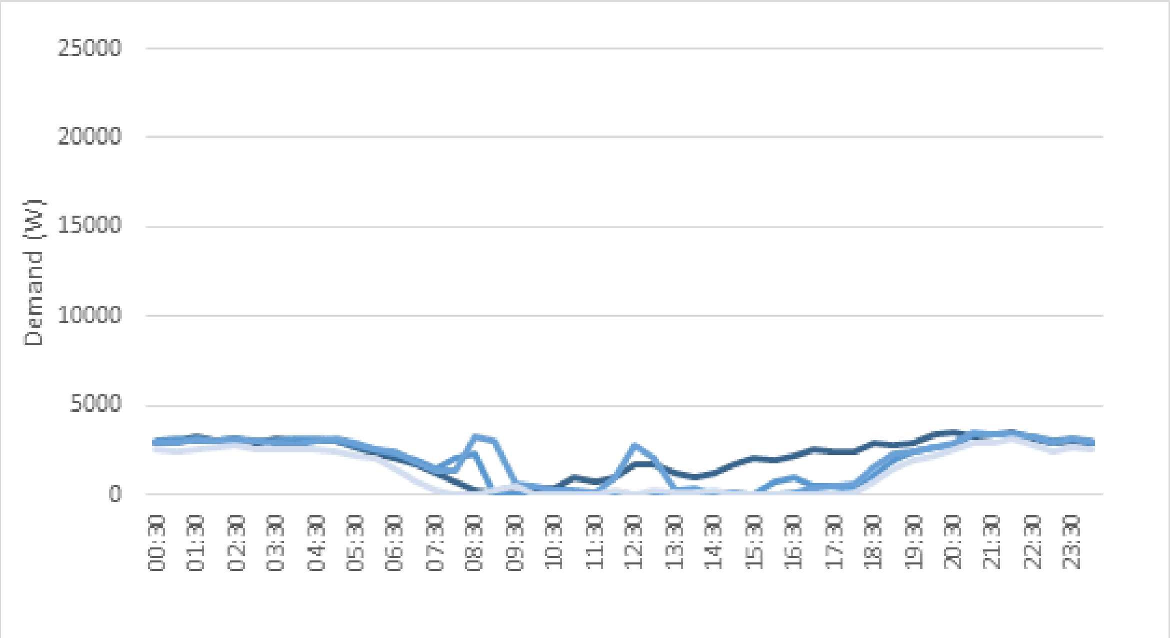
In the commercial sites, both the demand pattern and magnitude were different to domestic customers'. The demand peak was around noon rather than in the evening; and the magnitude was much higher, which was 20 kW -30kW. One of the main characteristics of the commercial sites demand was the significant demand-difference between weekday and weekend as shown in figure 46 and 47.

Figure 46: Demand of Brentry Primary School on Weekdays



Source: Project Team

Figure 47: Demand of Brentry Primary School on Weekends



Source: Project Team

SECTION 6

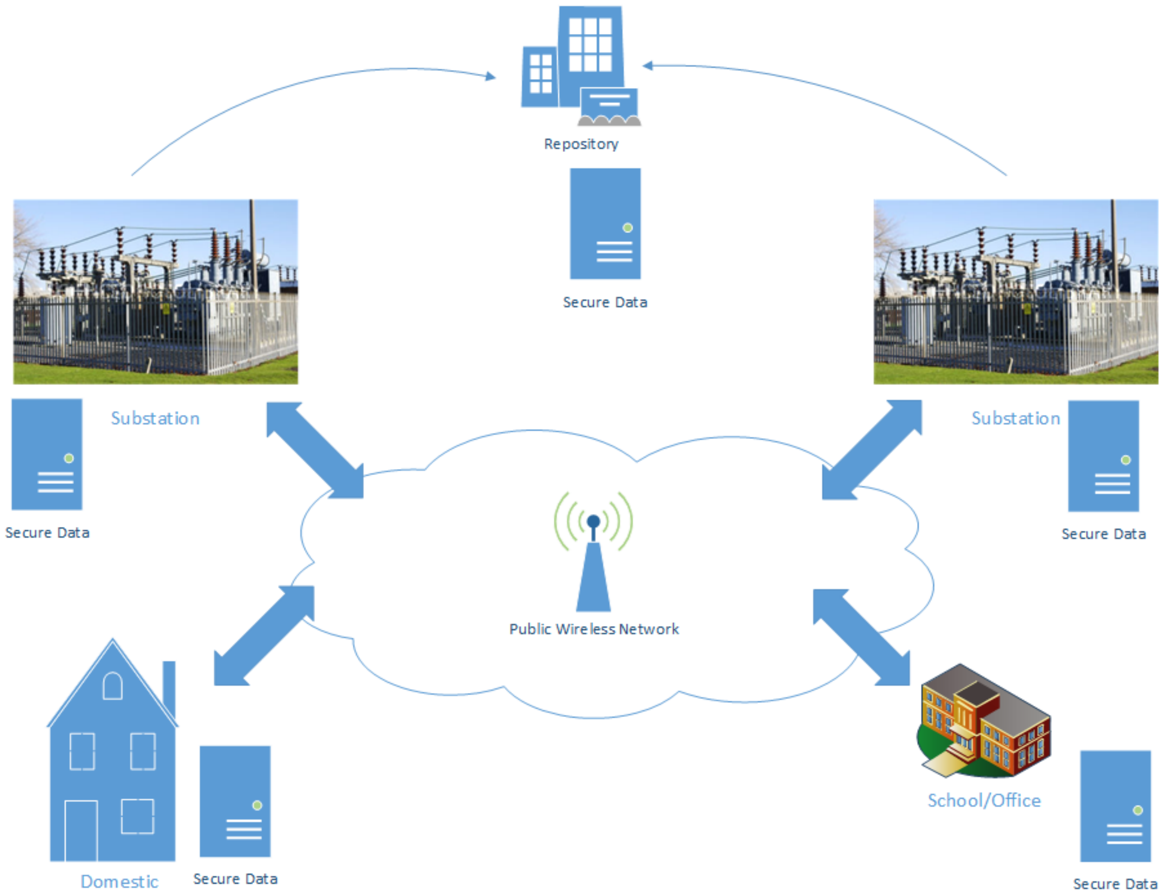
Networks Trials Plans

6.1 Overview

This project's prototype installation was a standalone property, the 'Ecohome', which led to the development of networked homes that have been online for some time. Presented below is an overview of the system. This distributed system comprised of sub-stations, homes, schools, office and a data repository. All of these properties were attached to their allocated sub-station for dual-end performance monitoring and analysis.

A simplified view of the SoLa Bristol system, as described in the system specification, is shown in Figure 48. The system comprised of three distinct sub-systems. These were geographically dispersed and are identified as the Data Repository Equipment (DRE), Sub-station Equipment (SE) and the User Premises Equipment (UPE). All three sub-systems had bidirectional communication capability utilising both the public-radio and public-IP networks.

Figure48: Simplified view of information flow of the SoLa Bristol System



Source: Project Team

The user premises equipment can broadly be classified into two categories, Domestic & Commercial. Though both were grid connected storage systems, the domestic UPEs were single phase units with an integrated PV sub-system, and the commercial UPEs were three phase systems with a PV sub-system as standalone.

The PV installations differed from site to site depending on the available roof area for solar panels and their make, model, efficiency, inclination and orientation. The domestic PV installations ranged from 1.5kWp to 2kWp except the Ecohome which was a 3.4 kWp installation. The commercial (schools and office) installations also varied in their PV plant sizes, for instance one school was 8.9kWp and others were larger.

All installations in this distributed energy storage system used valve regulated lead acid (VRLA) batteries. The battery storage system capacities were 4.8kWh for domestic sites and 22.5 kWh for commercial sites. All properties were wirelessly linked through sub-station equipment to the Data Repository Equipment. All inter installation communication's data contents were encrypted.

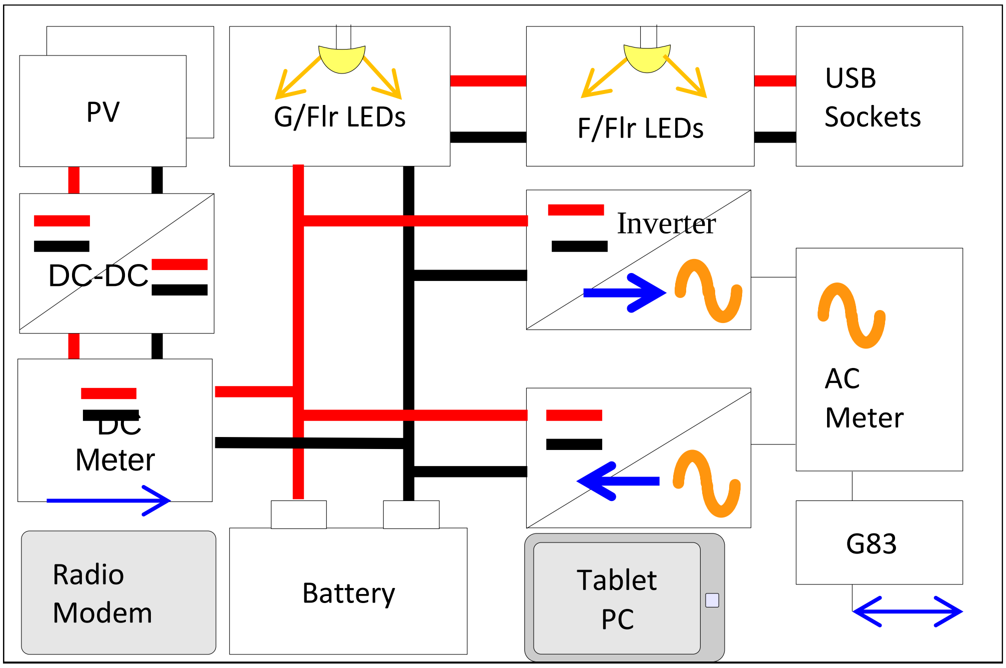
6.2 User Premises Equipment (UPE)

The domestic UPE used is depicted in Fig. 49 showing the various sub systems from PV generation, meters, storage through to output to the grid. The domestic lighting was converted to run on 24Vdc LEDs. This reduced the domestic AC-lighting load by shifting it to DC. The DC micro grid's nominal operating voltage is 24Vdc and the entire house's DC load now was sub 100 Watts which included lighting, USB sockets and the SoLa Bristol system itself with its communication and control components.

The battery charger from PV side was a custom device & the Grid side inverter/charger had been specifically designed for a 24Vdc system. The domestic user had access to the generation and usage data through the use of a tablet PC, which was updated by the system's in-home WiFi.

The system had metering capability both on the PV generation side and on the AC exporting side. The radio modem provided the link to the sub-station and supports the data encryption.

Figure 49: Domestic UPE



Source: Project Team

As mentioned earlier, the energy storage system used VRLA batteries, the domestic properties used four 12Vdc block batteries (12V 200 Ah each) in a combined series/parallel combination. The commercial systems used 12 cells which were series connected (2V 940 Ah) to provide the 24Vdc nominal bus voltage.

All domestic properties bar one used the same make and model of batteries. The exception is the very first installation, which used FiAMM battery blocks. This provided the opportunity to compare battery performance from two different battery manufacturers.

L38	Installation of two different batteries allowed for a comparison of two different battery manufacturers.

6.3 Sub-station Equipment (SE)

The sub-station equipment was designed to provide monitoring and communication capabilities at the sub-station. The supply-side monitoring data at the sub-station was used for quality of supply studies. The SE was a vital communication link for the appropriate parameter being passed to its associated sites. Each of the domestic, school and office installations had its own associated serving sub-station.

A total of 11 sub-station monitoring sites were installed. Substation installations provided the capability to monitor up to five feeders, with each feeder consisting of three phases. The metering equipment is as shown in Figure 50 below:

Figure 50: Installed Metering Equipment

Source: Project Team

The sub-station feeder sensors are shown below.

Figure 51: Sub-station feeder Sensors

Source: Project Team

The SE also served as communications hub for the domestic properties within the area. The user premises equipment (UPE) received configuration and control data through the SE and reported all data through the same SE. The data repository equipment received this data for storage and future analysis. The lowest number of homes on a sub-station was two and the largest number of homes on a sub-station was fourteen.

6.4 Data Repository Equipment (DRE)

The data collected by this equipment was categorised as ‘high’ and ‘low’ granularity data. The data was further classified as ‘local’, ‘remote’ or ‘in-transit’ data. The high granularity data was one minute averaged data and was retained within the property and the low resolution data, sampled at fifteen minute intervals, was exported out of the property. The low resolution data provided the system’s operational status in an upstream direction and the remote commands to the system equipment flowed in the downstream direction with reference to the sub-station. Varying amounts of system operational data was collected within different equipment. The entire system’s operational status indicated data in amounts of around 6 MB per day. The data generated could be polled or spontaneously accessed depending on the nature of the data content. In the event of a fault condition data was spontaneously provided to the substation and subsequently to the DNO.

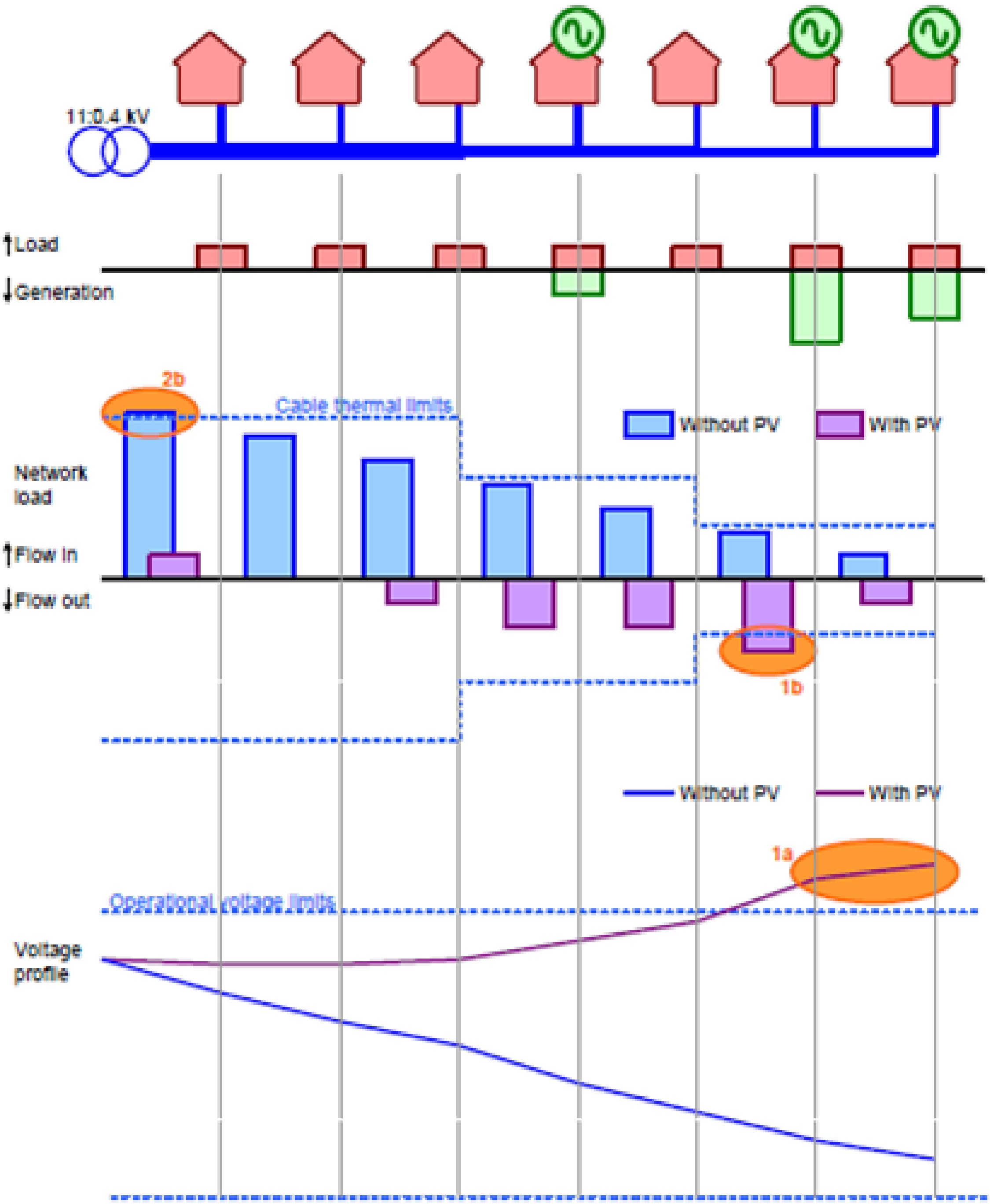
6.5 Network Trial Delivery

For the purposes of highlighting the specific issues which the project sought to solve, a simplistic piece of radial, tapered LV feeder is depicted with distributed loads, which are all assumed to be equal in Figure 52. It was further assumed that some of these properties have generation, which may have been active for some of the time. This is shown in the top part of the figure. The second part of the figure represents the distributed load at each property along the network (in red), and the generation (green).

**Note: the expectation of equal loads from all properties was a working assumption from the tender/ design stage. In practice the homes demonstrated entirely different operational traits; typically these were split into three groups, standard load, high load and Economy 7. The flexibility of the Siemens Energy Management System accommodated each of these variables, accounting for the differences with changes to the operational logic.*

In the third part of the figure the resulting power flows along each section of network are shown – in blue when there is no generation output and in purple with generation. The cable thermal limits are also shown on the diagram. Finally the bottom part of Figure 52 shows the resulting voltage profile (in blue without generation output and purple with output) and again operational limits are shown.

Figure52: Problem Elaboration



Source: Siemens

The introduction of low carbon technologies is expected to result in two specific cases with impacts on the LV network. These are listed below, along with the resulting effects that this project sought to address.

1. Excess generation over load on the local network, resulting in

    1a. Voltage upper limits exceeded, and/or

1b. Thermal limits exceeded (power import); and

2. High peak load, resulting in

2a. Voltage lower limits exceeded, and/or

2b. Thermal limits exceeded (power export).

Three of these effects are highlighted in the power flow and voltage profile graphs of Figure 52 above.

Below are the trial prerequisites / dates and activities for Substation 3 and the connected Houses;

Trial	Dates and Activities
Network Trial 1	20th April from 1700hrs to 1900hrs
Network Trial 1 review	21st April UoB to feedback/discuss data from Trial 1
Network Trial 2	22th April from 1700hrs to 1900hrs
Network Trial 2 review	23rd April UoB to feedback/discuss data from Trial 2
Network Trial 3	28th April from 1700hrs to 1900hrs
Network Trial 3 review	28th April UoB to feedback/discuss data from Trial 3

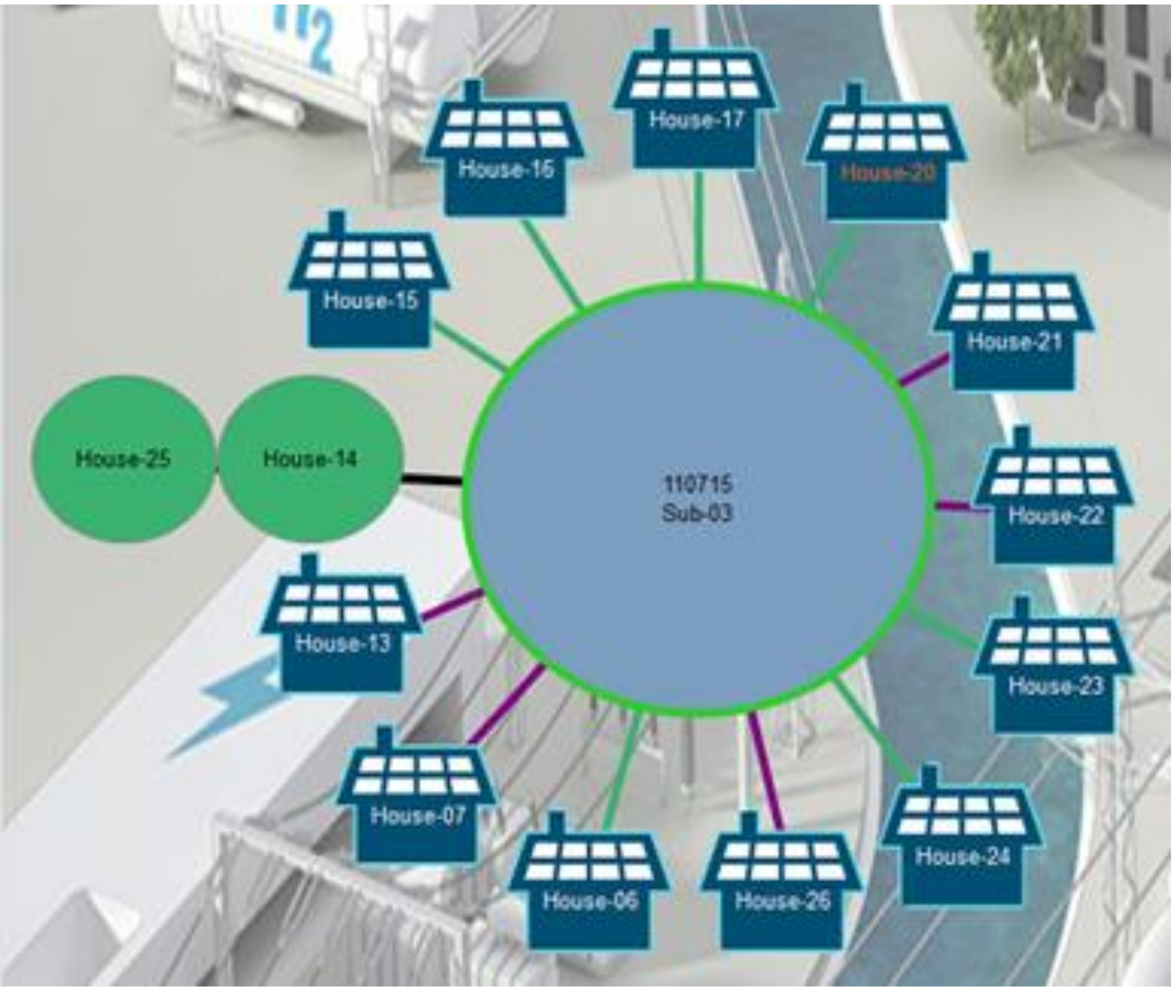
Table 4: Trial prerequisites

Each trial was performed as follows and was only associated to houses connected to substation 03.

Before each trial all house batteries were forced to charge to 90% SOC during Tariff 1 (1400hrs to 1630hrs). At 1700hrs all house batteries were requested to discharge to grid.

Once the SOC of the batteries has reached 30% SOC, the batteries were forced to charge up to the target SOC (65-70%).

Figure 53: HMI display of the LV substation chosen for domestic property network trials & its connected properties



Source: Siemens

It is important to note that communications or availability of the remote properties influenced the success of the trial. The application of GPRS as a communications medium between the various nodes in the trial network ensured that the availability of buildings could not always be guaranteed. For example Figure 53 above displays both green and purple lines between the substation and its connected nodes, here green represents that the building is available and 'talking' whereas purple denotes that the building is not reporting information, albeit this could be on a temporary basis until the GPRS connection is restored.

The below table shows the connection from the Substation to the Houses

Substation	Feeder	Phase	House Number
3	1	1	13, 15
		2	n/a
		3	16

Substation	Feeder	Phase	House Number
	2	1	6, 26
		2	7, 21
		3	20, 22, 23, 24

Table 5– Numbers of connected properties from 'sub 03' within the SoLa BRISTOL trial

Five individual 'push/ pull' network trials were completed throughout the course of the project, the process applied for each and the associated outcomes are captured below.

20/04/2015 – Domestic Trial One - First Push/Pull trial Procedure

Below are a series of tables detailing the various trials completed and a commentary which details the relevant outcomes;

Period	Trial
1400hrs to 1630hrs	Started to force charge the batteries until 1630hrs (tariff 1) in readiness of the discharge to grid.

Table6: Domestic Trial 1

Result = most the house batteries reached the 100% SOC.

Period	Trial
1630hrs to 1700hrs	Removed the force charging from the batteries, logic operated as normal and the batteries started slowly discharge to meet the target SOC of 89%
1700hrs to 1815hrs	Started to force discharge of the batteries, initial discharge value set to 2000watts, then 1500watts and finally 1800watts.

Table 7: Domestic Trial 1

Result = A mix of batteries discharging to 30% SOC and some only reaching 60% SOC. It looked like most the batteries where supporting the extremely high load of the house and some would have reduced the peak of the network.

Period	Trial
1815hrs to 1900hrs	Started to force charge the batteries until 1700hrs even though this was tariff 3 we need to get the batteries SOC near their target SOC value of 60% so that they would support the evening loads.

Table 8: Domestic Trial 1

23/04/2015 - Domestic Trial Two - Second Push/Pull trial Procedure

Below is a brief description of how the trial was performed;

Period	Trial
1430hrs to 1630hrs	Started to force charge the batteries until 1630hrs (tariff 1) in readiness of the discharge to grid.

Table 9: Domestic Trial 2

Result =started the force charge later this time the SOC of the batteries in the +70% and again most of the batteries reached the 100% SOC target.

Period	Trial
1630hrs to 1700hrs	Removed the force charging from the batteries, logic operated as normal and the batteries started slowly discharge to meet the target SOC of 89%
1700hrs to 1815hrs	Started to force discharge of the batteries, initial discharge value set to 1000watts, then 15 minutes later 1500watts, then 15 minutes later 2000watts, then 15 minutes later 1500watts.

Table 10: Domestic Trial 2

Result = A mix of batteries discharging to 30% SOC and some only reaching 60% SOC.

Period	Trial
1815hrs to 1900hrs	Started to force charge the batteries until 1900hrs even though this was tariff 3 we need to get the batteries SOC near their target SOC value of 60%, some of the batteries managed to reach 100% SOC.

Table 11: Domestic Trial 2

Later in the trial, the sampling rate of the data was adjusted from the 230 at the University of Bath so that the data was captured every minute and hence this gave us a more detailed understanding of the network.

27/04/2015 – Domestic Trial Three - Third Push/Pull trial Procedure

Below is a brief description of how the trial was performed;

Period	Trial
1400hrs to 1630hrs	Started to force charge the batteries until 1630hrs (tariff 1) in readiness of the discharge to grid.

Table 12 Domestic Trial 3

Result = most the house batteries reached the 100% SOC.

Period	Trial
1630hrs to 1700hrs	Removed the force charging from the batteries, logic operated as normal and the batteries started slowly discharge to meet the target SOC of 89%
1700hrs to 1815hrs	Started to force discharge of the batteries, initial discharge value set to 2000watts, then 1500watts and finally 1800watts

Table 13: Domestic Trial 3

Result = A mix of batteries discharging to 30% SOC and some only reaching 60% SOC. It looked like most the batteries where supporting the extremely high load of the house and some would have reduced the peak of the network.

Period	Trial
1815hrs to 1900hrs	Started to force charge the batteries until 1700hrs even though this was tariff 3 we need to get the batteries SOC near their target SOC value of 60% so that they would support the evening loads

Table 14: Domestic Trial 3

28/04/2015 – Domestic Trial Four - Additional Trial – Load Test

The additional trial on SUB03 was to assess the impact of 'no' 'push/pull' from the houses and was just a load test during 1700 to 1900 hrs. The data from this was analysed with the previous three trials data.

28/04/2015 – Commercial Trial One – First Push/ Pull Trial Procedure.

The commercial 'push/pull trial was between Substation 6 and COM1 (Knowle West Media Centre). The trial utilised the same procedure used for the Third Trial (27/04/2015) for the Substation 3 and the connected houses. The watts were increased to utilise the potential of the 3x 3500kW inverters.

Figure 54: HMI display of the LV substation chosen for commercial property network trials and it's connected properties

Source: Project Team

L39	The houses did not show the same load profile, instead the data suggested three distinct groups; standard load, high load and economy 7.

L40	Communications or availability of the remote properties influenced the success of the trial

L41	GPRS did not prove to be a reliable communications method between the nodes in the trial network

6.6 Knowle West Media Centre (KWMC)

The commercial push/pull trial on KWMC took place only on 28/04/2015. The trial results and the result comparison between trial and non-trial day are shown in Figure 55.

On the trial day, the battery SOC shows:

1) an increase at 14:00 and keeps at 100% until 16:30;

2) a significant decrease between 16:30 to 18:15 from 100% to 55% of the SOC;

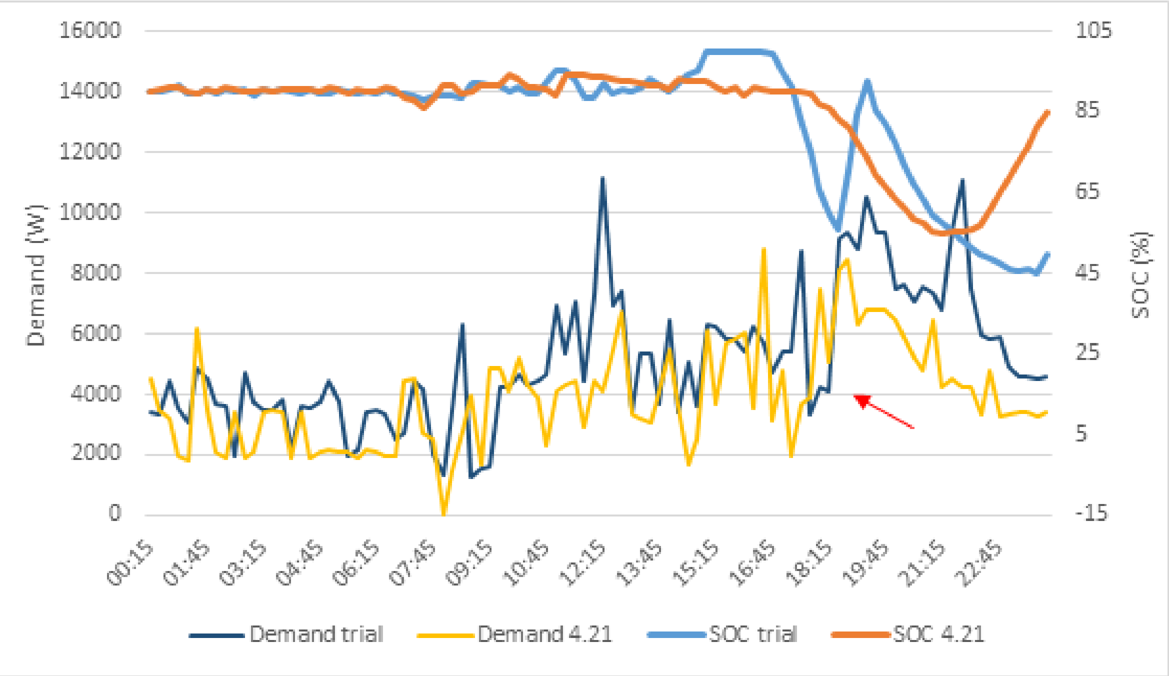
3) an increase to 90% between 18:15 to 19:30; and finally

4) a gradual decrease to 45% between 19:30 to midnight.

For comparison, the SOC of 21 April (a week before) is shown in the figure as well. On the chosen non-trial day, battery stays at 90% of SOC and discharges 30% of SOC at evening after 18:15.

On the trial day, when the battery significantly discharged during 16:30 to 18:15, there was a demand trough shown by the red arrow compared with that on non-trial day. However, the daily demand of KWMC is volatile and has many demand spikes. It was difficult to determine if this demand trough was caused by battery discharging behaviour.

Figure 55: KWMC demand and battery SOC on trial and non-trial days



Source: Project Team

6.7 Homes

The results of the network push/pull trials suggests that 50% of the battery could respond to the network request exactly and could help to reduce network demand effectively. The results of demand comparison between trial and non-trial days shows that there is minor difference on the exporting power during evening peak demand time, which means the PV and battery effects of non-trial operation were similar to the battery effects under network request on an April high PV output day. According to these results, it is deduced that with more PV output, the trial operation could export more power; with less PV output, such as low PV output day and winter time, the trial operation could guarantee the network benefit brought by the EMS system.

More information on home performance is available in report “Measured the impact on the LV network SDRC 9.5”.

SECTION 7

Network Benefits

7.1 Summary

Peak demand reduction and the corresponding investment deferral was considered to be one of the most important benefits brought by distributed batteries and PV to the distribution network. In this section the network peak demand reduction and investment deferral is analysed in depth. Since the penetration of battery and PV was relatively low in the trial network and there was demand uncertainty, the network demand change cannot be reflected in the measured data and the corresponding network investment deferral is minor, at less than £300. When the penetration increases, the network investment deferral is increased to thousands of pounds. An impact analysis is conducted to calculate the relationship between network demand reduction confidence and required battery numbers.

L42	Household demand changes were masked on the phase demand, most likely due to the small proportion of trial properties on the feeder.

7.2 Peak reduction

To determine the demand change brought about by battery storage and PV, substation data was collected from adjacent or close proximity days. Otherwise, the network demand could be influenced by load growth or by season.

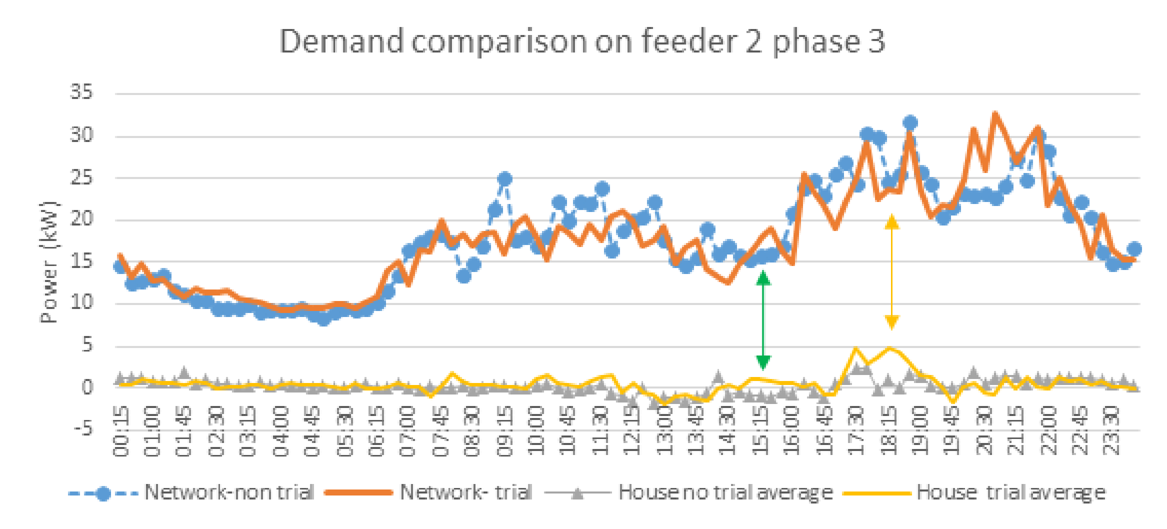
The performance of network demand reduction was assessed by comparing the network demand of trial days and non-trial days. These two types of days were at the end of April, 2015 and had different battery control strategies.

The network effect was analysed on Ilminster Avenue substation. In detail, the data is compared based on the demand of phase 3 in feeder 2 since the DSR penetration rate is highest in phase 3: 10% of households connected at phase 3 have in-home batteries to achieve DSR (4 households in the total 40 households).

The total household demand increase brought by the force charging request is clearly shown in Fig. 56 between 14:30-16:29 and 18:15-18:59 pointed as green and orange arrows. There are maximum 2kW and 4kW demand increase introduced by batteries of 4 tested households.

However, the demand increase cannot be identified on networks. On trial days, there are two small demand peaks, also pointed as green and orange arrows, between 14:00-15:30 and at 18:15 (between two larger peaks). However, there are continued spikes in network demand. There is no evidence that the two demand spikes related to the force charging of the 4 batteries. Therefore, the change shown in household demand between 14:00-16:29 and 18:15-18:59 is masked and not clearly reflected on the phase demand comparison between non-trial and trial days.

Figure 56: Demand comparison on Feeder 2 Phase 3



Source: Project Team

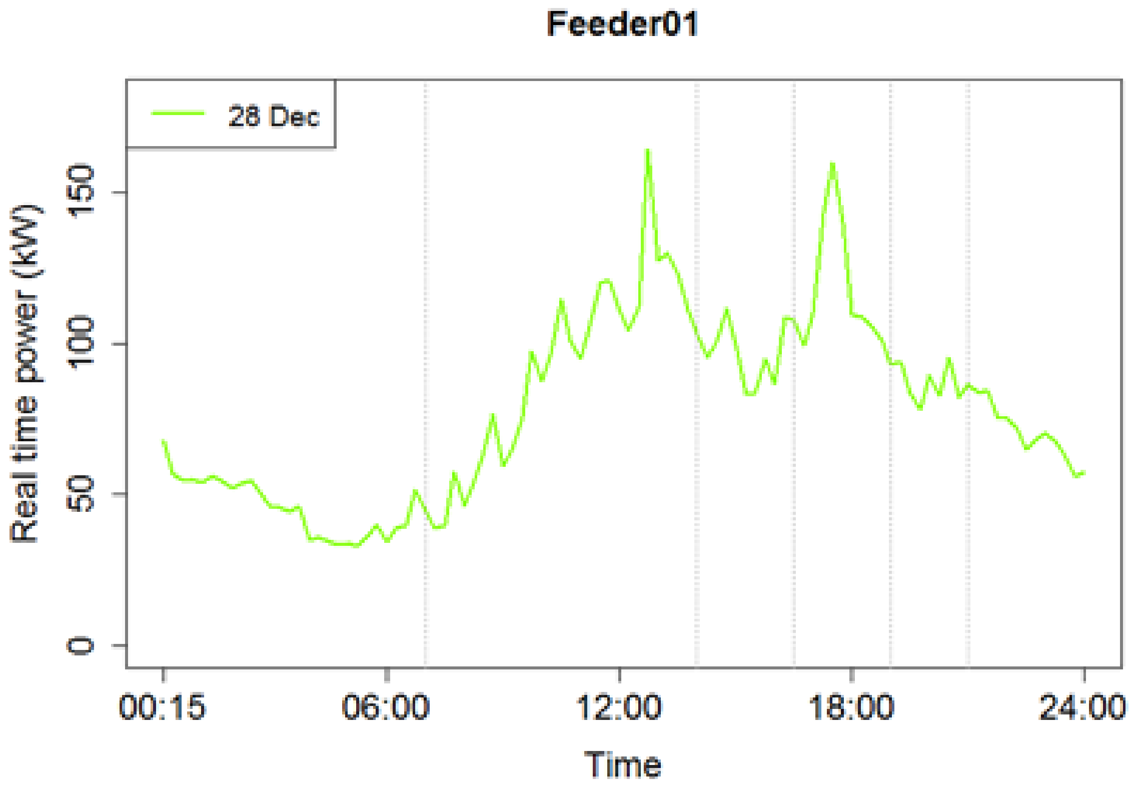
7.3 Network deferral

The peak demand information of each component in Ilminster Avenue substation in 2014-2015 year is shown in the table 15. The load profiles of the peak demand days are shown in Figures 57 to 59 for Feeder 1, Feeder2 and Substation respectively.

	Power (kW)	Date	Time
Feeder 1	164.1	28/12/2014	12:45
Feeder 2	171.5	5/2/2015	17:30
Transformer	317.7	25/12/2014	11:45

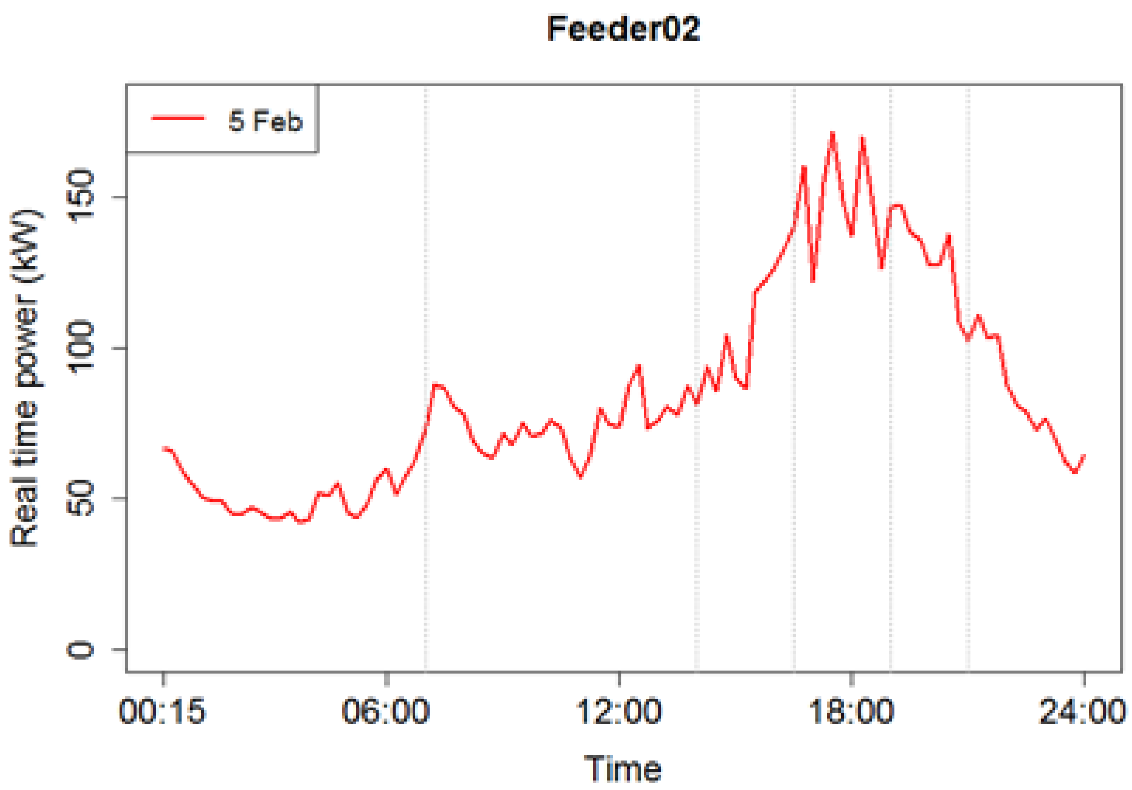
Table 15 Peak demand of Ilminster Avenue substation

Figure 57: Peak demand of Feeder 1



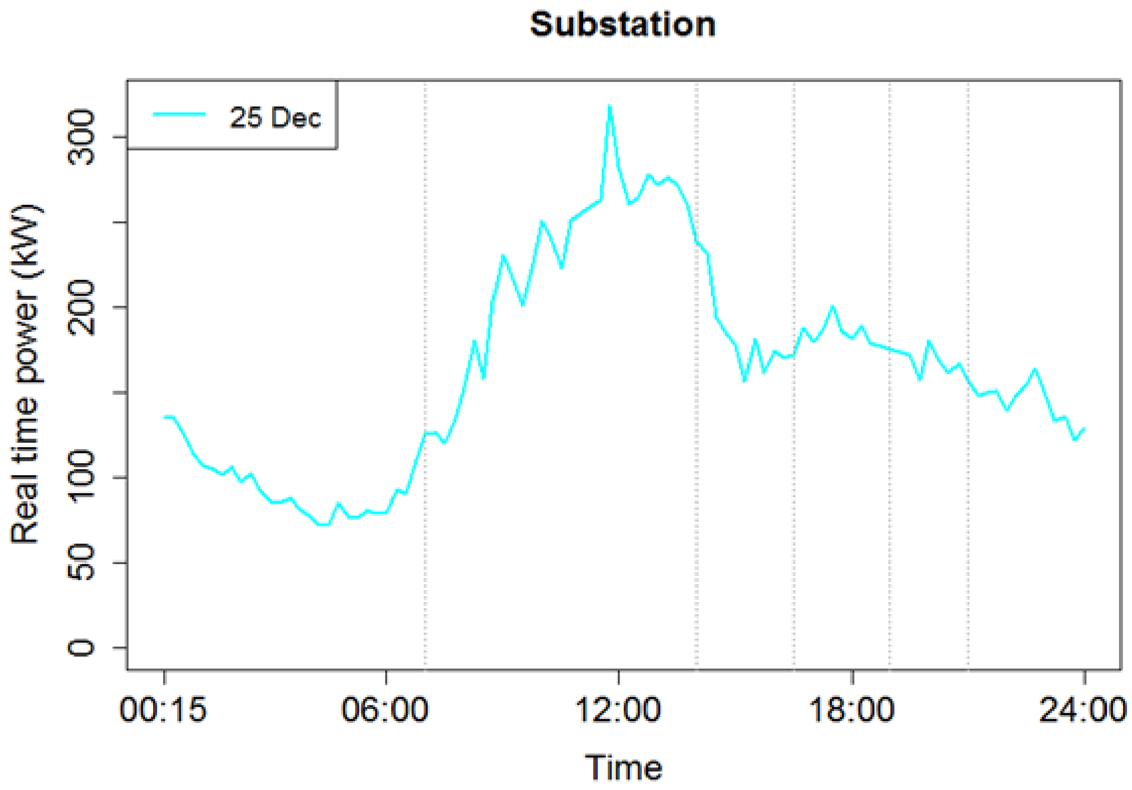
Source: Project Team

Figure 58: Peak demand of Feeder 2



Source: Project Team

Figure 59: Peak demand of Substation



Source: Project Team

Feeder No.	Total Customer No.	Customer with EMS No.
Feeder 1	136	3
Feeder 2	121	8
Total	257	11

Table 16 Customer and EMS number in substation Ilminster Avenue

The investment deferral of Ilminster Avenue substation is calculated and the method is shown in report “Measured the impact on the LV network SDRC 9.5”. The network utilisation of the Ilminster Avenue substation was found to be 42%. On normal days (non-trial days), the average output power from battery to the network is 0.3kW. The load growth was set as 2% and the discount rate was set at 5.6%[2]. The typical unit cost of feeder was £67,200/km and the unit cost of transformers was £26,400[3].

The time-series power flow showed that:

1) in the next 6 years, the feeder connected nodes 29, 30 and 38 will reach the thermal limits;

2) in the next 9 years, the feeder connected nodes 1 and 2 will reach the thermal limits; and

3) the transformer will reach the thermal limits after 45 years.

The result of potential network investment deferral is shown in Table 17.

The EMS system of 11 houses at this substation can defer transformer investment for one year[4]. With the penetration of EMS increased to 30% and 50%, the deferral will be 4 years and 6.5 years respectively.

The EMS system of 3 houses at feeder 1 can defer feeder 1's investment for half year. With the penetration of EMS increased to 30% and 50%, the deferral will be 4 years and 5.5 years respectively.

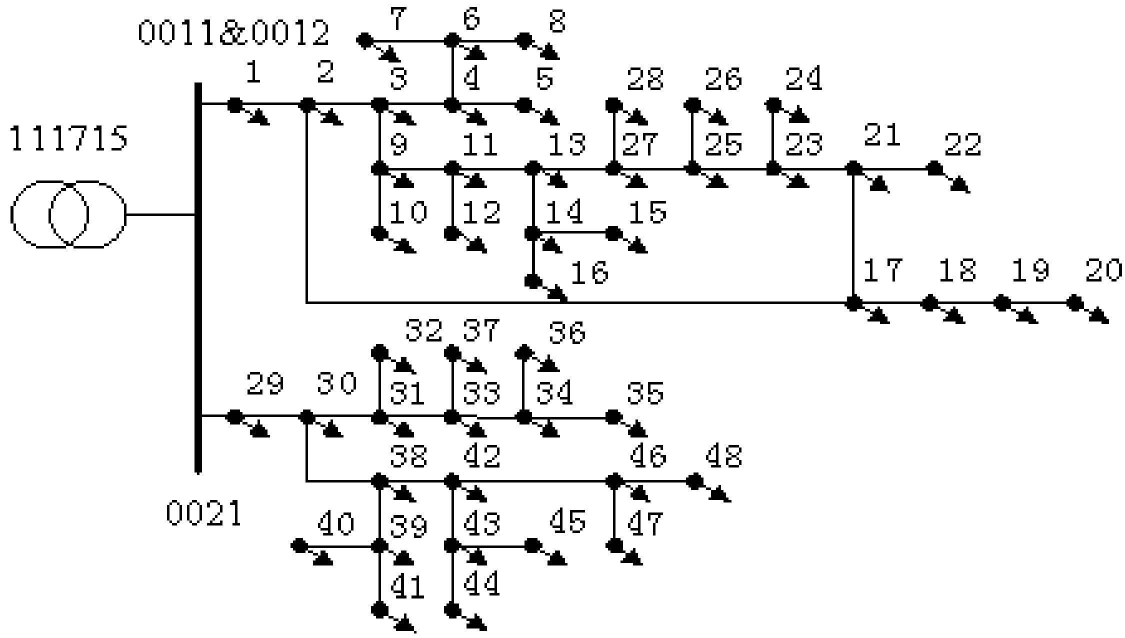
The EMS systems of 8 houses at feeder 2 can defer feeder 2's investment for one year. With the penetration of EMS increased to 30% and 50%, the deferral will be 4 years and 6 years respectively.

2 [1] Western Power Distribution. "CDMC-ARP-April-2015-Pre-Release-South-West-v2," 2014; http://www.westernpower.co.uk/docs/system-charges/CDCM-Annual-Review-Pack/2015/CDMC-ARP-April-2015-Pre-Release-South-West-v2.aspx.

3 [2] "Electricity Distribution Price Control Review Final Proposals - Allowed revenue - Cost assessment appendix " Office of Gas and Electricity Markets, ed., Office of Gas and Electricity Markets 2009.

4 The calculation only takes battery discharge into consideration without considering the uncertain PV output.

Figure 60: Network congestion location



Source: Project Team

	Current penetration (4.3%)	30% penetration	50% penetration
Transformer	£82	£502	£800
Feeder 1	£18.4	£559.4	£903
Feeder 2	£182	£816	£1335
Total	**£282.4**	**£1877.4**	**£3038**

Table 17 Result of potential network investment deferral

If the network utilisation is higher, i.e. larger than current level of 42%, the potential network investment deferral is more significant. The network investment deferral with different network utilisation level is discussed in Section 11, “Future Works”.

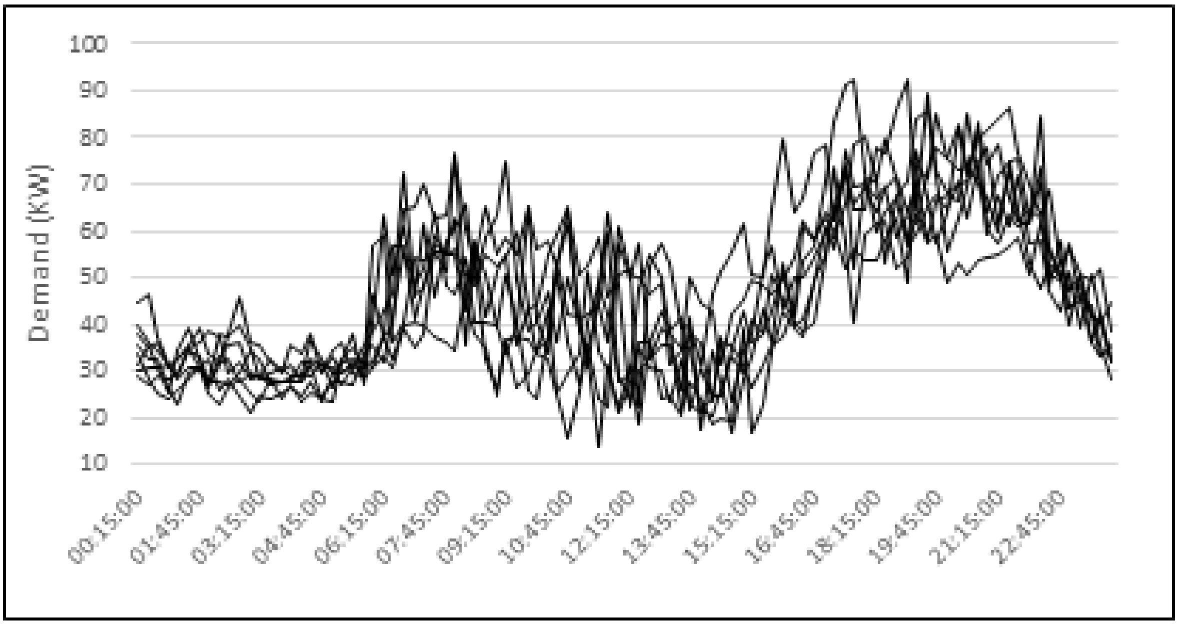
The school connected substation network deferral is available in report “Measured the impact on the LV network SDRC 9.5”.

7.4 Impact Analysis

7.4.1 Network demand uncertainty

In SoLa Bristol, the peak demand reduction effect brought by the battery is masked by the network demand uncertainty. Without sufficient battery capacity or EMS penetration rate, the network demand peak reduction effect from demand side response is hard to be identified and visualised. This section aims to find the minimum battery penetration to make network peak demand reduction meaningful, i.e. how many batteries could make an impact on the network. In detail, the network demand uncertainty is analysed and minimum battery required to bring network demand reduction is calculated.

Figure 61: Load profile uncertainty of feeder1 on substation 3

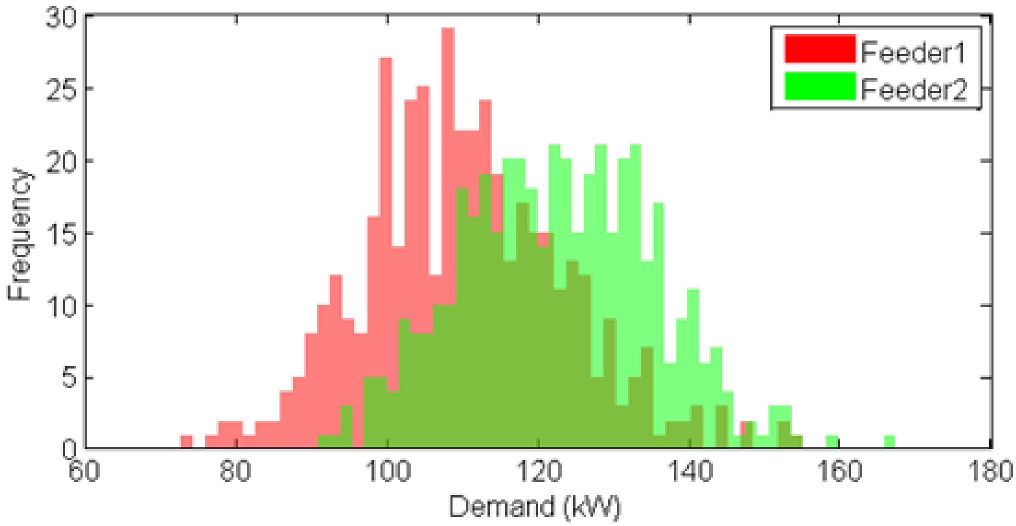


Source: Project Team

7.4.2 Network peak demand distribution

In this study, the peak time is considered between 16:30-20:30. The peak demand distribution of Ilminster Avenue substation in January is shown in Figure 62. The interval of peak demand of Feeder 1 is between 70 to 160kW. In most of the days, the peak demand is concentrated between 90 to 130kW. At Feeder 2, the peak demand interval is narrower, from 90 to 170kW.

Figure 62: Peak demand distribution of Ilminster Avenue substation



Source: Project Team

7.4.2.1 Minimum battery for meaningful demand reduction

The uncertainties in the network demand masks the demand reduction brought by batteries in the project since the penetration of batteries is relatively low. However, when battery installation numbers increase, the network demand reduction should be easier to identify and visualise. The relationship between network demand reduction confidence and required battery number is calculated in this section.

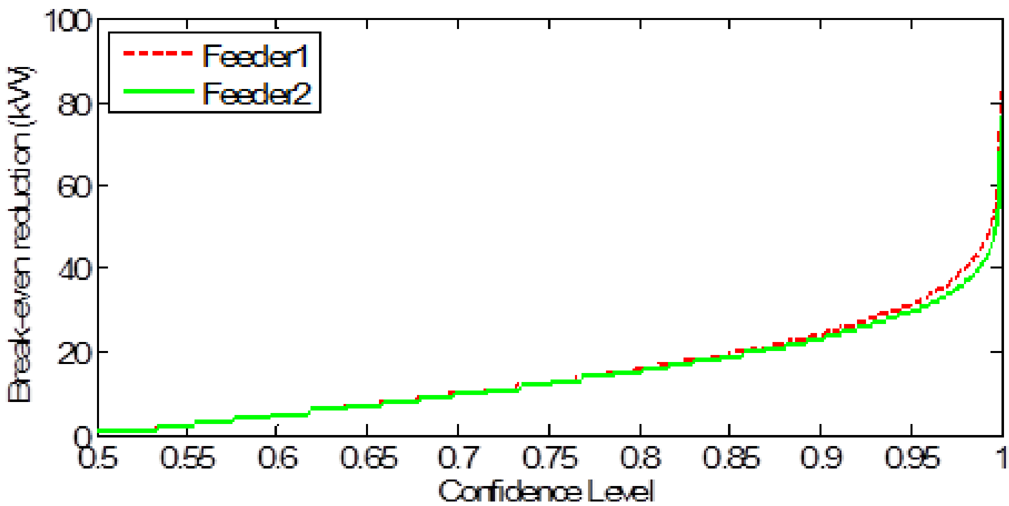
To achieve a meaningful network demand reduction, a minimum demand reduction from battery installations, called “break-even reduction”, was calculated. The “break-even reduction” means the new sampled network demand is just below the original sampled network demand.

The c minimum demand reduction required from batteries to make network demand reduction meaningful in January is presented in Figure 63. The curve represents that there is Y (kW) battery demand reduction required in order to guarantee X confidence level that the new sampled network demand is lower than the original sampled network demand. For example, the two extreme points in the curve of feeder 1: (0.5,0) and (1,83), represent the situation when: 1) the newly measured network demand might or might not (at 50% confidence level)be lower than the original sampled network demand, when there is no battery; 2) the newly measured network demand is 100% lower than the original when battery brings 83kW demand reduction, which is also shown in Table 18.

There is a sharp increase of battery-bring demand reduction when confidence level is larger than 97%, for Feeder 1 from 36kW to 83kW and for feeder 2 from 35kW to 77kW. The minimum battery demand reduction and battery number are shown in Table 18 and Table 19 in detail. Specfically, when there is 95% confidence level that the newly measured network demand is lower than the original measured network demand, the minimum required battery-bring demand reductions are 31kW and 30kW for Feeder 1 and 2 respectively. When the confidence level is 100%, the required battery-bring demand reductions are 83kW and 77kW for Feeder 1 and 2 respectively. The required battery-bring demand reduction in 95% confidence level is only one third of that in 100% confidence level.

Given the battery capacity for the domestic customers, 4.8kWh, 4 hours peak demand time and 60% available SOC, to guarantee the network peak demand reduction at 95% and 100% confidence level,43 and 166 batteries in feeder 1, 42 and 107 batteries in feeder 2 need to be installed.

Figure 63: Minimum battery-bring demand reductions with different confidence level



Source: Project Team

Confidence level (%)	50%	60%	70%	80%	90%	95%	100%
Feeder1 minimum demand reduction (kW)	0	5	10	16	24	31	83
Feeder2 minimum demand reduction (kW)	0	5	10	15	23	30	77

Table 18: Minimum demand reduction

Confidence level (%)	50%	60%	70%	80%	90%	95%	100%
Feeder1 minimum battery No.	0	7	14	23	34	43	116
Feeder2 minimum battery No.	0	7	14	23	32	42	107

Table 19- Minimum required battery numbers

SECTION 8

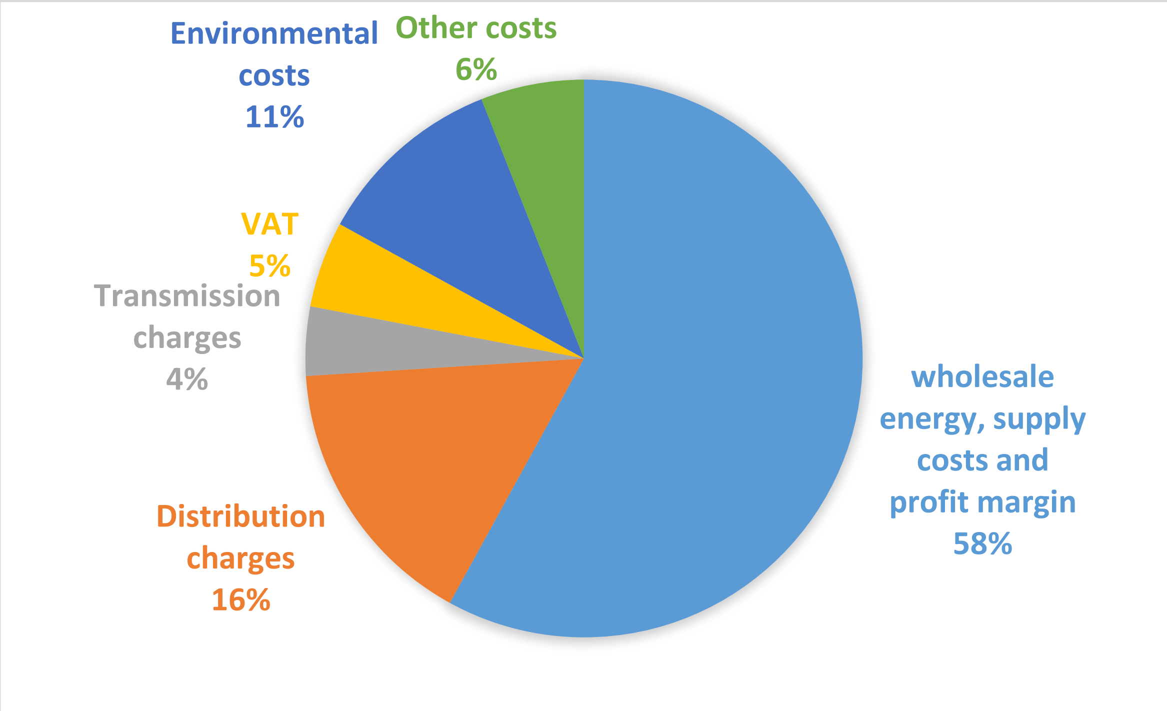
Time of Use Benefits

8.1 Time of Use (TOU) Tariff Design for Energy Storage

Smart tariffs are designed to trigger energy storage in conjunction with PV outputs to achieve demand response for the network and reduce electricity bills for customers. The smart tariff used in SoLa Bristol was developed using hierarchical clustering methods based on wholesale electricity prices. The design process can be summarised as[5]: i) wholesale electricity prices for a whole year are represented by typical price; ii) typical wholesale prices are converted to Real Time Price (RTP) for domestic customers; iii) determine the TOU tariff using hierarchical clustering method.

The wholesale electricity cost is the greatest element of household electricity bill. It covers approximately half of the end-users' bill according to the 2013 survey by Ofgem[6] as shown in Figure 64 and will still be maintained as a significant part of the customers' bill in the future. There could be meaningful electricity cost savings if demand could respond to the wholesale electricity price. Therefore, the "smart tariffs for energy storage" is designed from the wholesale electricity price.

Figure 64: Components of domestic electricity price



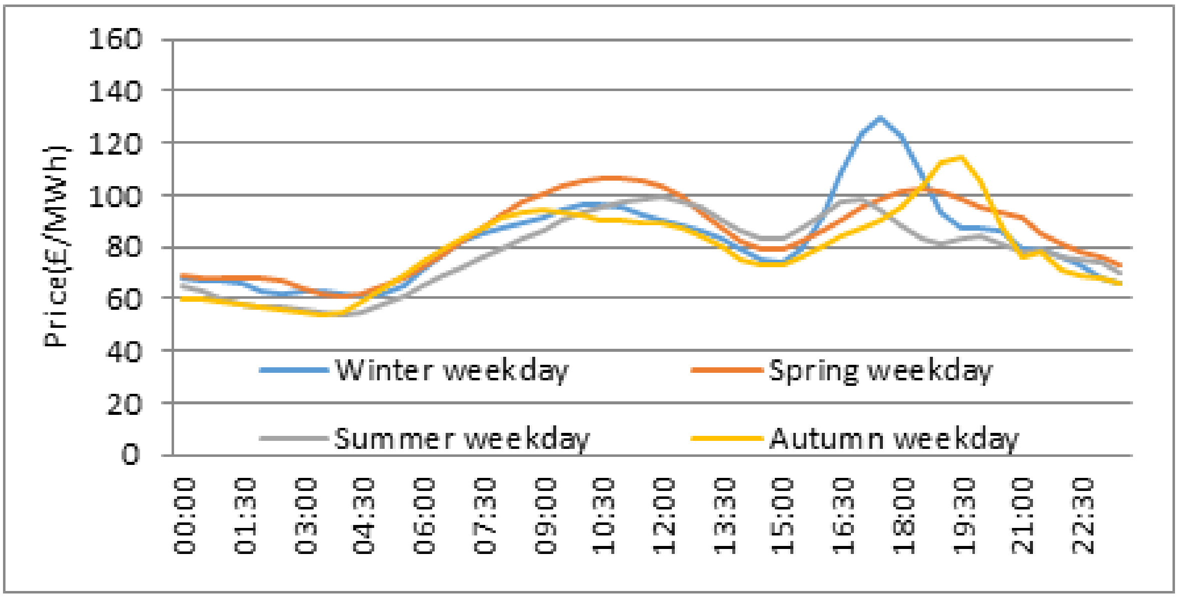
Source: Ofgem

[5] [3] Zhimin Wang Ran Li, Simon Le Blond, Furong Li, "Development of Time-of-Use Price by Clustering Techniques," in Power and Energy Society General Meeting, Washington, D.C., 2014.

[6] Updated: Household energy bills explained – factsheet, Ofgem, https://www.ofgem.gov.uk/ofgem-publications/64006/householdenergybillsexplainedudjuly2013web.pdf

In the GB wholesale electricity market, the electricity price varies every half hour. The real-time pricing (RTP) is the most appropriate pricing scheme reflecting wholesale energy price variation. The example of RTP in four seasons' weekday in 2012 to 2013 is shown in Figure 65. However, it changes frequently during the day and is hard for customers and their devices to respond. As a result, the time-of-use (TOU) tariff used by SoLa Bristol reflected the wholesale electricity price with a high level of accuracy to help use energy storage to shift the customers demand.

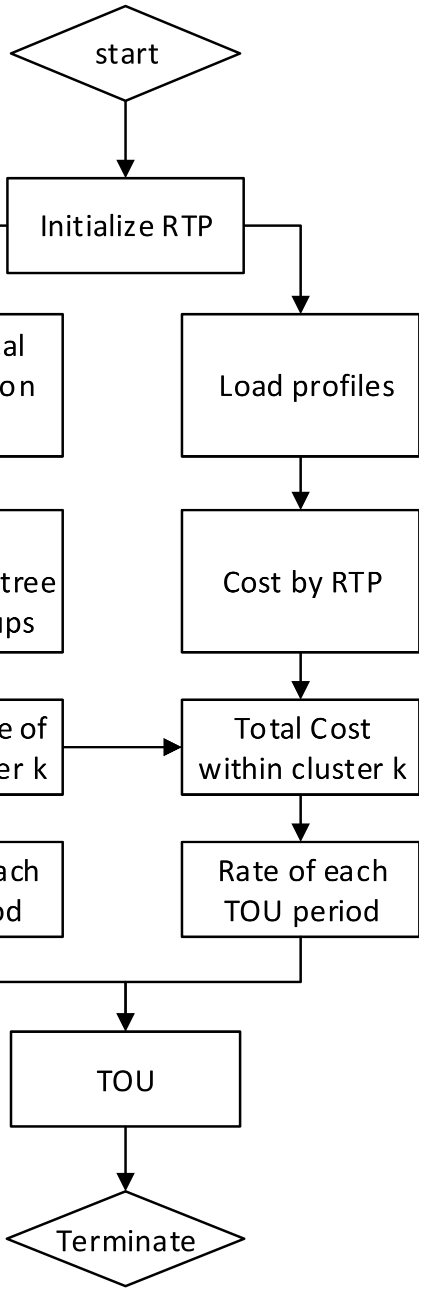
Figure 65: RTP in four seasons' weekday in 2012 to 2013



Source: Project Team

The TOU determination can be divided into two aspects: 1) cluster the 48 RTP value in one typical day into 3 clusters, and each cluster represents one tariff step, such as peak time tariff and off-peak tariff; 2) determine the rate of each TOU tariff step to maintain the total bill unchanged, i.e. for a given load, the bill would be same charged either by RTP or TOU. The steps of the development of TOU are illustrated in flowchart Figure 66.

Figure 66: Flowchart of development of TOU



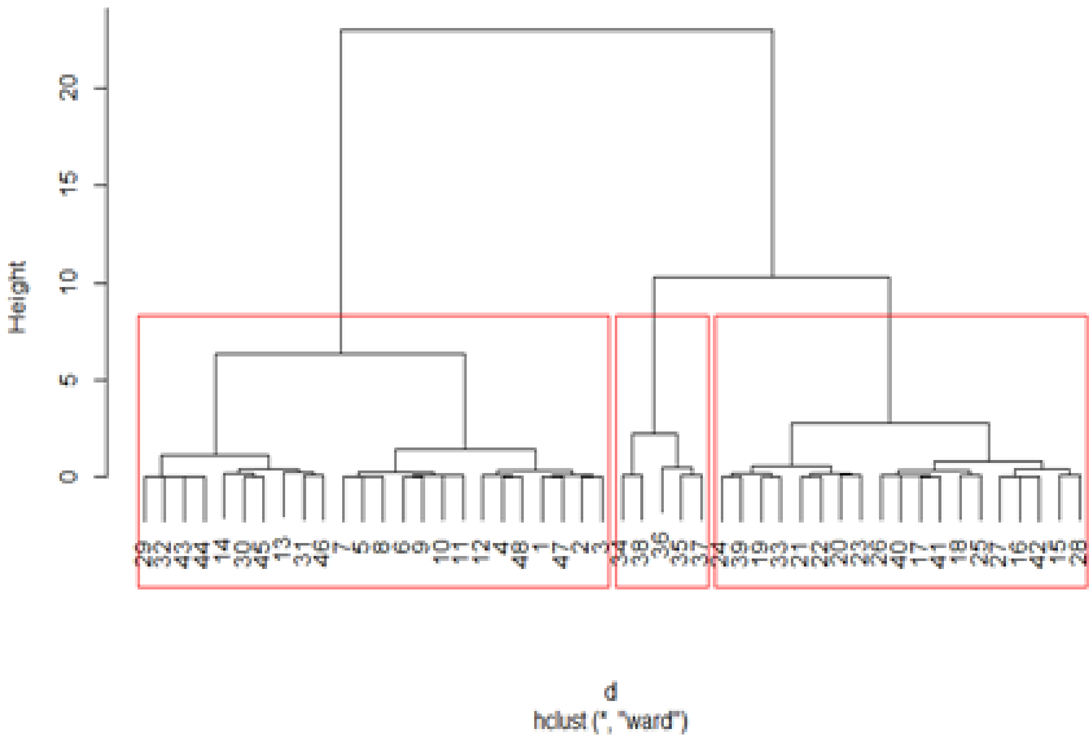
Source: Project Team

The hierarchical clustering method is used to decide the width of each TOU period. The steps are: 1) calculating the distances between any two prices in two settlement periods; 2) merging together the settlement periods with the smallest distances on their prices into hierarchical cluster tree; 3) calculating the new distances between different clusters and forming new clusters until only one cluster remains; 4) calculating final average within-group distance and find the optimal cluster numbers and clusters. The 48 settlement periods of RTP are grouped based on their price distances shown in Figure 67. The within-group distance is reflected on the height of y-axis. The lower average within-group distance indicates a higher similarity within group and vice versa. 3 clusters were partitioned as shown in the red boxes in the figure.

The rate of each TOU period is determined by the formula below, where TOU_{rate} is the TOU rate, RTP_{rate} is the RTP rate, P is the load at time t.

$$\boldsymbol{TOU_{rate}} = \frac{\sum(\mathbf{RTP}_{\boldsymbol{rate}} * \boldsymbol{P})}{\sum \boldsymbol{P}}$$

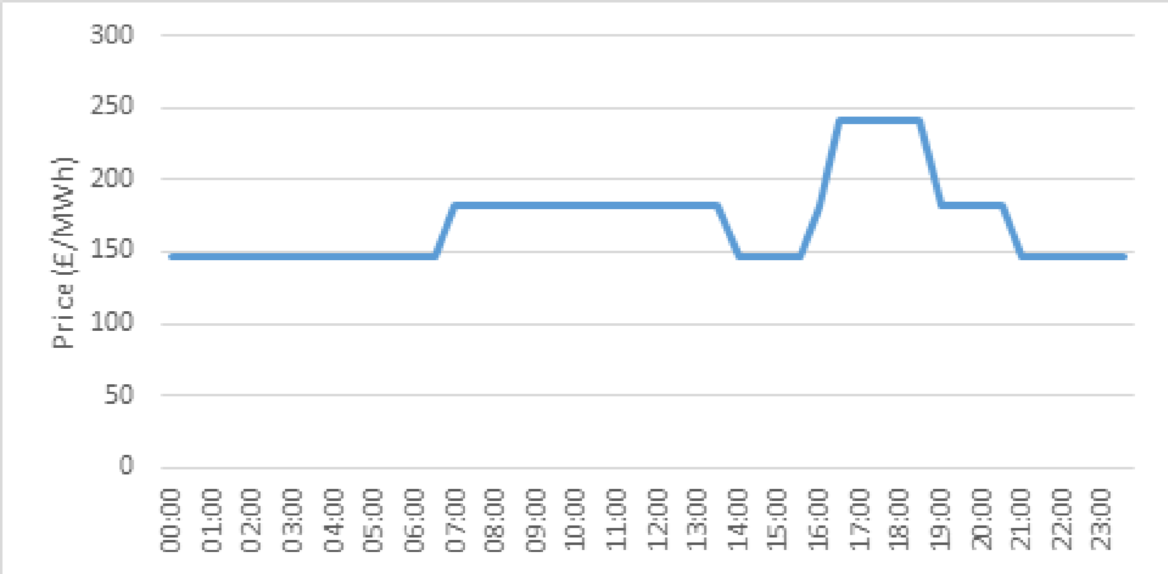
Figure 67: 48 settlement periods of RTP are grouped based on their price distances



Source: Project Team

The result of the winter-weekday TOU is shown in Figure 68.

Figure 68: TOU tariff for domestic customers



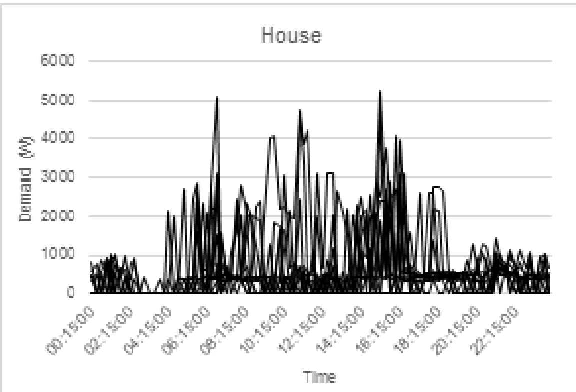
Source: Project Team

8.2 Load profiles

8.2.1 Uncertainties of Domestic Load Profiles

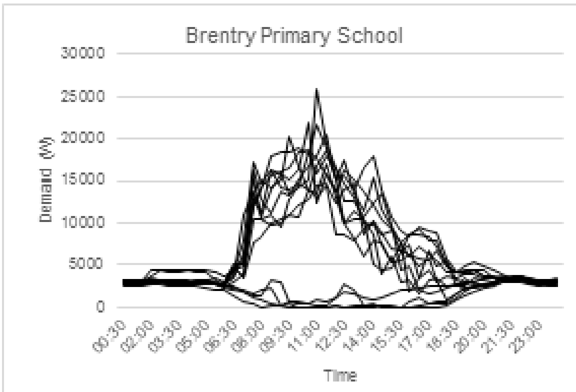
In the project, load profiles of 26 engaged domestic homes were analysed to obtain a better understandings of domestic demand consumption patterns. When compared with non-domestic customers, the domestic load profiles were extremely volatile and uncertain. These uncertainties of domestic load profiles emerge on two dimensions: 1) uncertainties over different types of customers, and 2) uncertainties over different days. The load profile uncertainty of customers is primarily due to unpredictable customer behaviours on energy consumption. The comparison of load profile uncertainties between domestic and non-domestic customers are given in Figures 69 and 70:

Figure 69: Domestic load profile



Source: Project Team

Figure 70: Commercial load profile



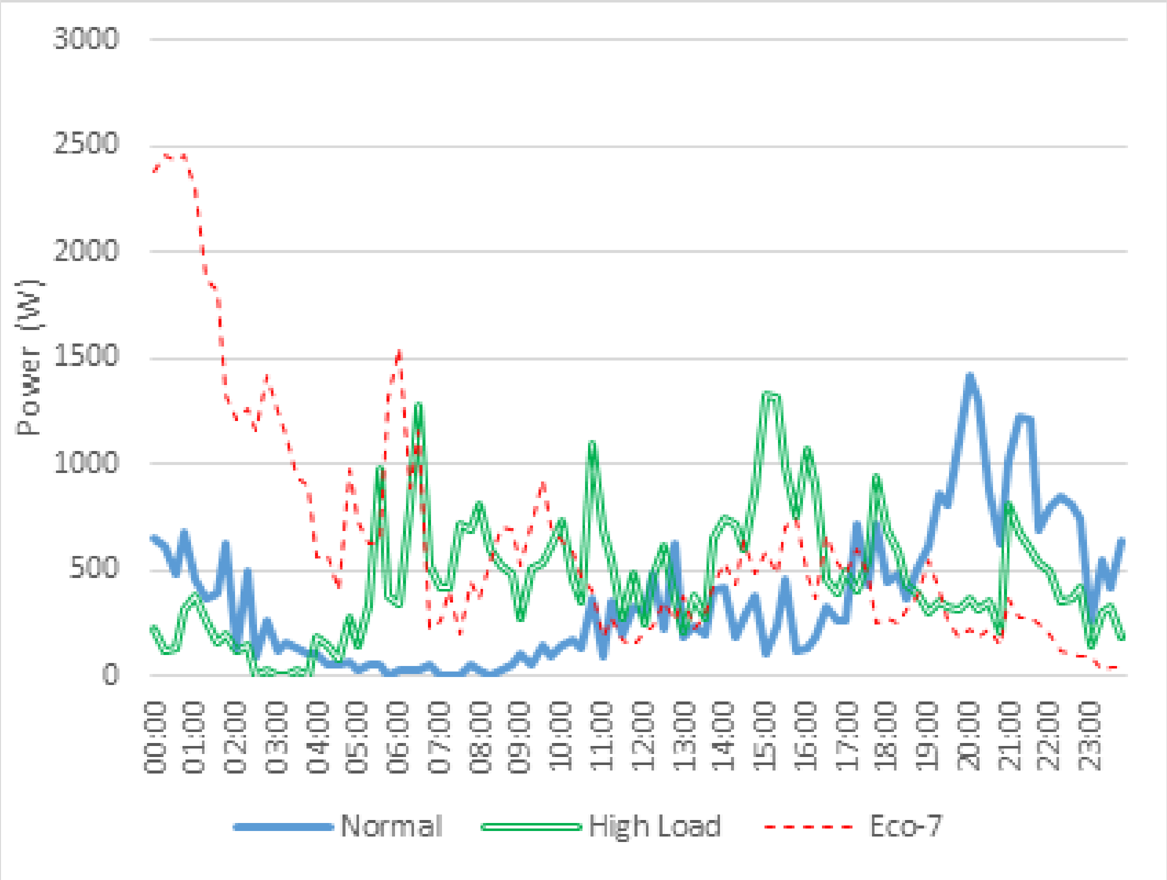
Source: Project Team

8.2.2 Load Profiles Categories of tested customers

In terms of uncertainty over different domestic customers, load profile uncertainties are primarily caused by inherent differences in energy consumption, behaviours and habits of the different customer types. To differentiate categories of domestic load profiles and Clustering Techniques in detail the K-means clustering method, was applied to categorise the captured load profiles over 11 customers located at Ilminster Avenue substation. The result showed(in Fig.71) that there are generally three types of customers differentiated by load pattern: 1) normal homes 2) high load properties, and 3) Economy 7 homes.

The load profile type of each tested customer in the project is listed in Table 20.

Figure 71: Comparison of three typical load profiles



Source: Project Team

House No.	Load type
6	Economy 7
7	Economy 7
13	Normal
15	High daily load
16	Normal

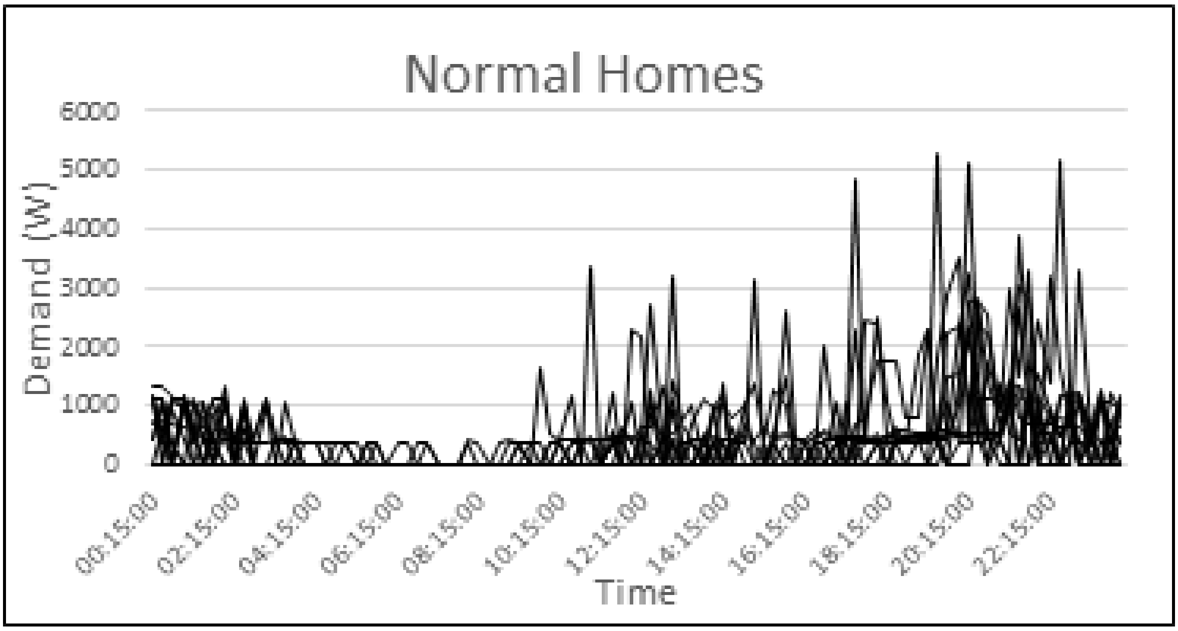
House No.	Load type
20	Normal
21	Normal
22	Normal
23	Normal
24	Normal
26	High daily load

Table 20: Load profile type of tested houses

1) Normal homes

Normal homes refers to the group of customers whose load profiles are the most similar to the national-wide typical load profile proposed by ELEXON in 1990[7]. Load profiles of one of the normal homes over two weeks are presented in Figure 72. As can be seen in Figure 72, the load profiles of normal homes usually have a high evening peak and a relatively lower peak in the daytime.

Figure 72: Two weeks load profiles of normal homes



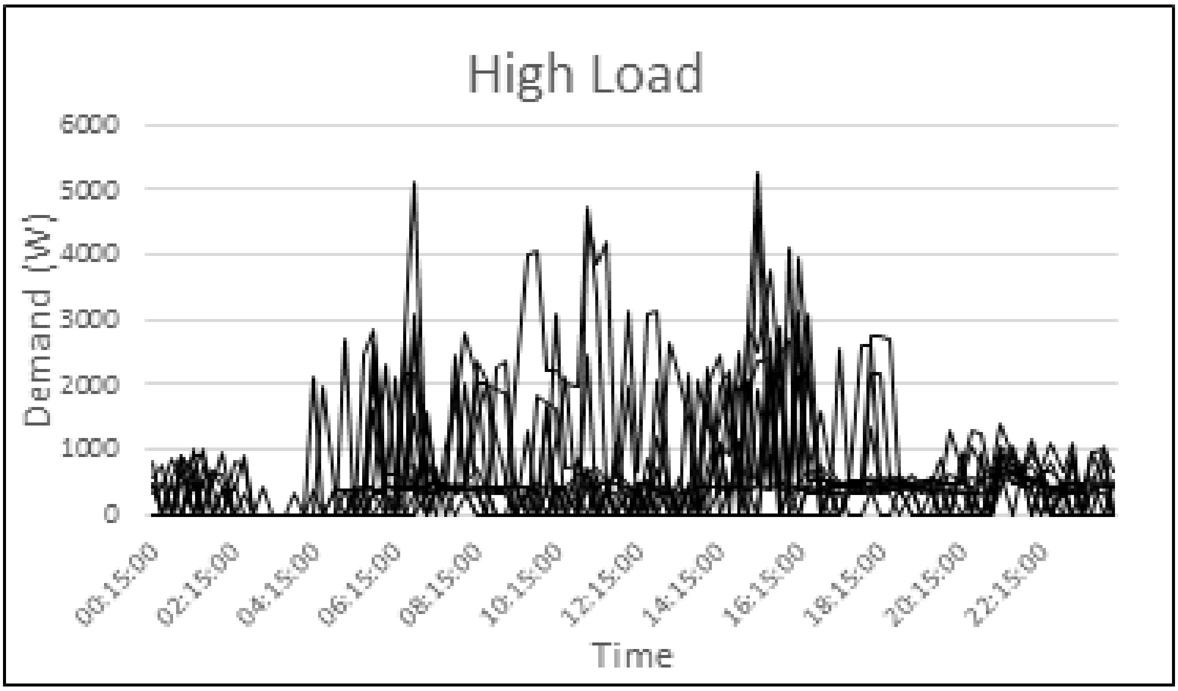
Source: Project Team

7 [4] Elexon, "Load Profiles and their Use in Electricity settlement," Elexon Ltd, 2012.

2) High load properties

In High load homes, customers consume much more electricity during the day time than other customers. In high load homes, there is high demand in the daytime instead of a high demand peak in the evening and a relatively lower peak in the midday. Load profiles of one of the high load homes over two weeks is demonstrated in Figure. 73 as follows:

Figure 73: Two weeks load profiles of high load homes

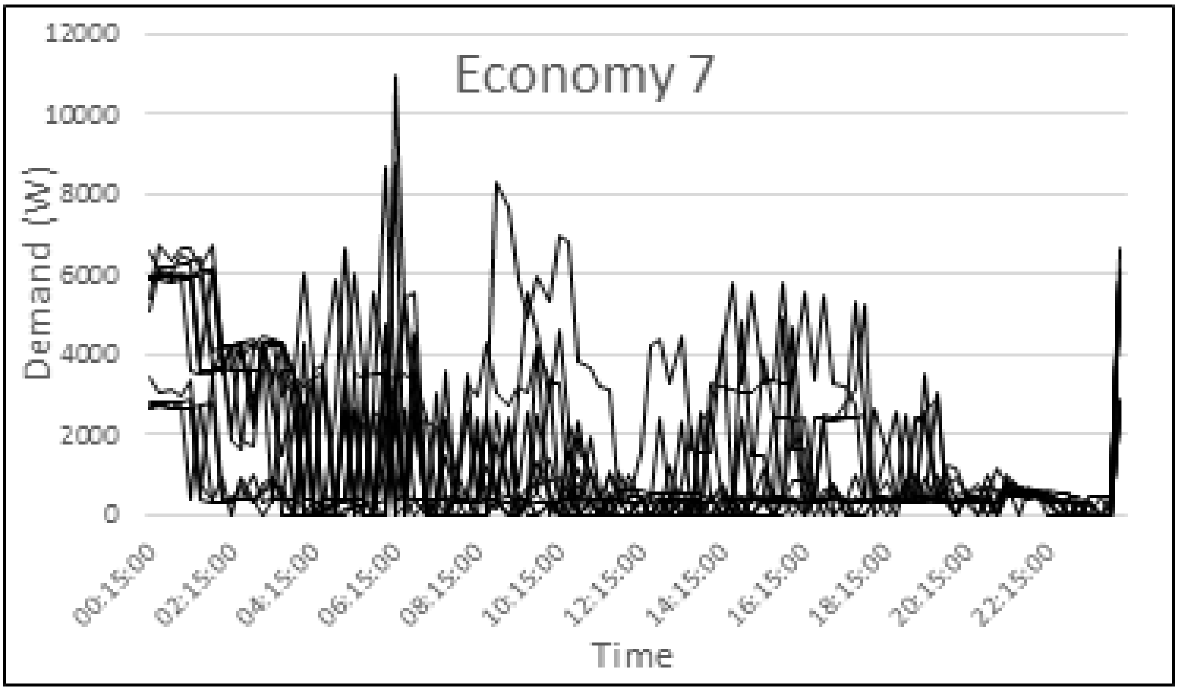


Source: Project Team

3) **Economy 7 homes**

Economy 7 homes refers to the group of customers who benefit from having pre-existing off-peak hot water storage heaters installed. These properties have a dual tariff system, namely, On-Peak & Off-peak. SoLa Bristol trial had a three tariff system where a 'Mid-Peak' tariff was introduced, hence these homes were identified within their own category. The day time demand profile of these homes can be similar to normal homes. The load profiles of one of the Economy 7 homes over 14 days is shown in Figure. 74:

Figure 74: Two weeks load profiles of Economy 7 homes



Source: Project Team

L43	Domestic load profile uncertainty is primarily caused by differing energy consumption behaviour and householder habits.

L44	Load profiles of normal homes usually have a high evening peak and a relatively lower peak in the daytime.

L45	In high load homes, there are high demand in the daytime instead of a high demand peak in the evening and a relatively lower peak in the midday

L46	Economy 7 houses will show a peak from mid-night to 7am, after this they will either mimic a high load or a standard load house, dependent upon the householder behaviour.

8.3 Customer benefits

In the SoLa Bristol project, the domestic customer benefits came from the demand reduction brought by PV and demand shift brought by battery storage, both of which triggered by TOU tariffs. For the Commercial customers (school) benefits came from the demand shift brought by the use of battery storage.

8.3.1 Domestic customer benefits

The domestic customer TOU benefit was calculated from Dec 2014 to Jun 2015. The seven months' benefit received by customers on the Ilminster Avenue substation is shown in Table 21. The original electricity bill indicates the electricity bill if there was no PV and battery installation between Dec 2014 & Jun 2015. Both original and new electricity bills are calculated based on TOU tariffs, i.e. it is the product of load and TOU tariffs.

The average bill saving of the 11 houses are £52.10 in the seven months and the average bill saving per month is £7.43.

House No.	House load type	Original electricity bill (£)	Electricity bill with PV and battery (£)	Total benefit receiving (£)	Saving percentage (%)
6	Economy 7	981.4	934.5	46.9	4.8
7	Economy 7	818.5	768.5	50.1	6.1
13	Normal	212	173.3	38.7	18.3
15	High load	458.8	407.7	51	11.1
16	Normal	210	120.8	89.8	42.8
20	Normal	154.2	121.6	32.6	21.1
21	Normal	77.1	30	47.1	61.1
22	Normal	194.6	102	92.6	47.6
23	Normal	228	171.9	56	24.6
24	Normal	260.3	217	43.3	16.6
26	High load	351.1	326.5	24.6	7
Average	--	358.7	306.7	52.1	23.7

Table 21 Domestic customer TOU saving

L47	High load customers showed the least amount of saving using the hypothesised time of use tariff

L48	Different battery strategies impacted the customer savings.

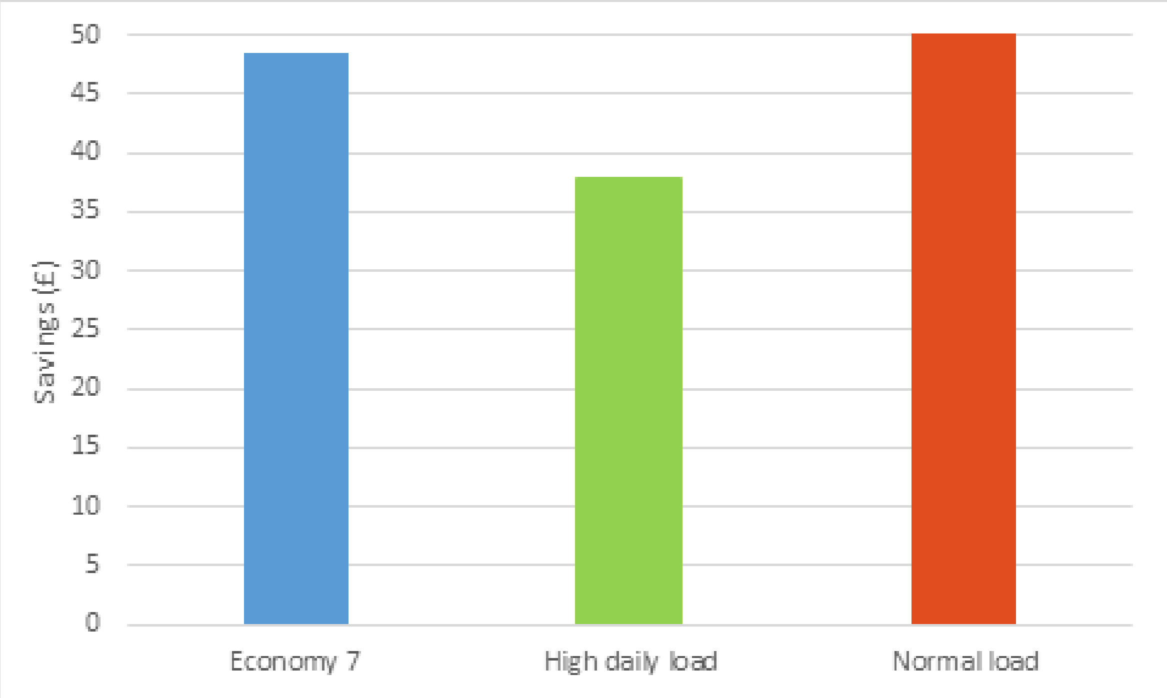
L49	PV output is a key mediating factor for the benefits of the battery storage

8.3.2 Benefits of three types of customers

The three types of customers: economy 7, high daily load and normal load, can be also differentiated in their electricity bill payments. The electricity bill of Economy 7 houses was highest: above £800. The bills of high daily load houses have higher than that of normal houses, which were above £350. The normal houses' electricity bills are generally below £300[8].

The average savings of the three types of customer in the project are shown in Figure 75. The saving results show that there is little saving differences between the Economy 7 and normal load customer types. The saving of high daily demand type customer is the lowest. But the lowest saving of high daily demand type is largely influenced by one customer: House 26. The reason for similar benefit levels could be caused by the generally similar battery operation strategies within the three types of customers.

Figure 75: Saving comparison between three types of customers



Source: Project Team

[8] The calculated bills are generally lower than the customers' real electricity bill paid to supplier. However, the information given by this calculated bill is meaningful.

8.3.2.1 Benefits of different time periods

As illustrated in the previous section, there were five different battery operation periods between December 2014 and June 2015 as shown in Table 22.

Strategy Periods	Dates	Number of days	Strategy type
1	5th Dec 2014 – 16th Dec 2014	11	Type 1
2	17th Dec 2014 – 15th Jan 2015	29	Type 2
3	16th Jan 2015 – 3rd Feb 2014	19	Type 1
4	4th Feb 2015 – 13th Apr 2015	66	Type 2
5	14th Apr 2015 – 30th Jun 2015	78	Type 1

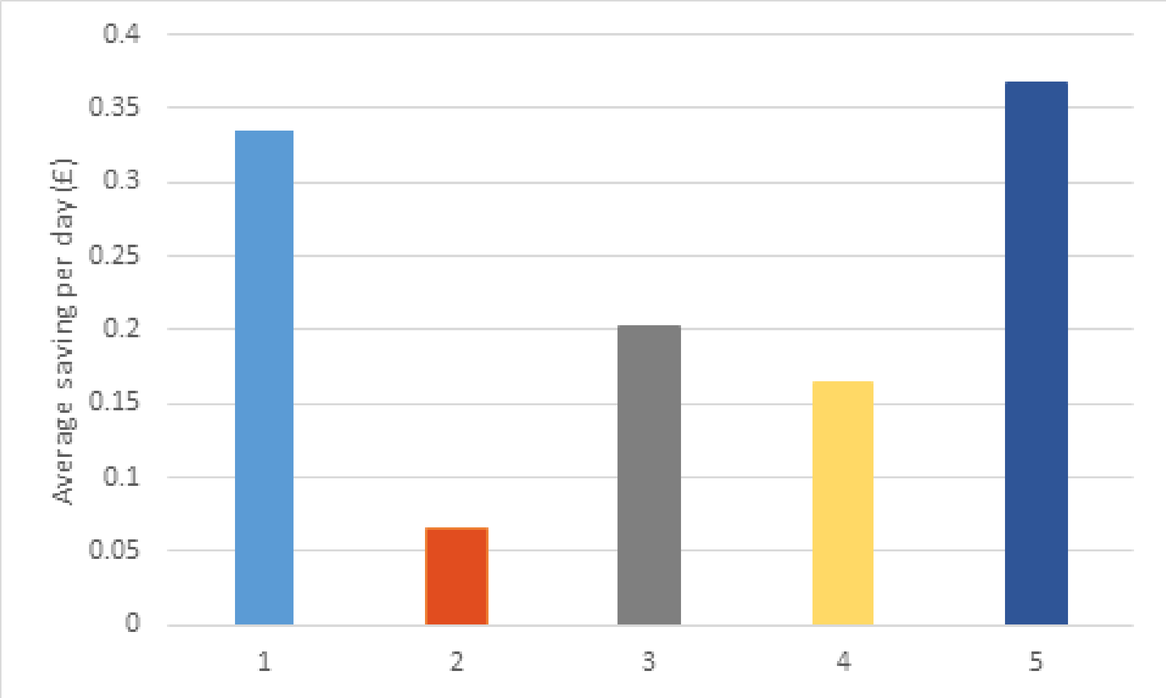
Table 22: Different battery operation strategies

In different periods, customers received different amounts of savings. Figure 76 gives the different savings per day under different time periods.

The results show that the battery operation strategies in periods 2 and 4 brought relatively less benefit to customers. As illustrated in Table 22, during periods 2 and 4, the battery operation strategy was the type 2 strategy, in which the battery is 1) charged from main grid during night (off-peak price) to support demand in the morning (shoulder price); 2) charged from PV (free) if it is sunny to support demand in the evening (peak price).

In the type 2 strategy, the electricity during the off-peak price time, was used in morning shoulder-price time, which is different from the type 1 strategy where the cheaper electricity was used in evening peak price time. There was less benefit when shifting demand from morning to night, since the price difference was smaller. Therefore, compared with the other operation strategy, the type 2 strategy did not take full advantage of price differences and led to less benefit. Accordingly, the benefit of period 2 and 4 was less.

Figure 76: Customer average saving in different operation strategies time



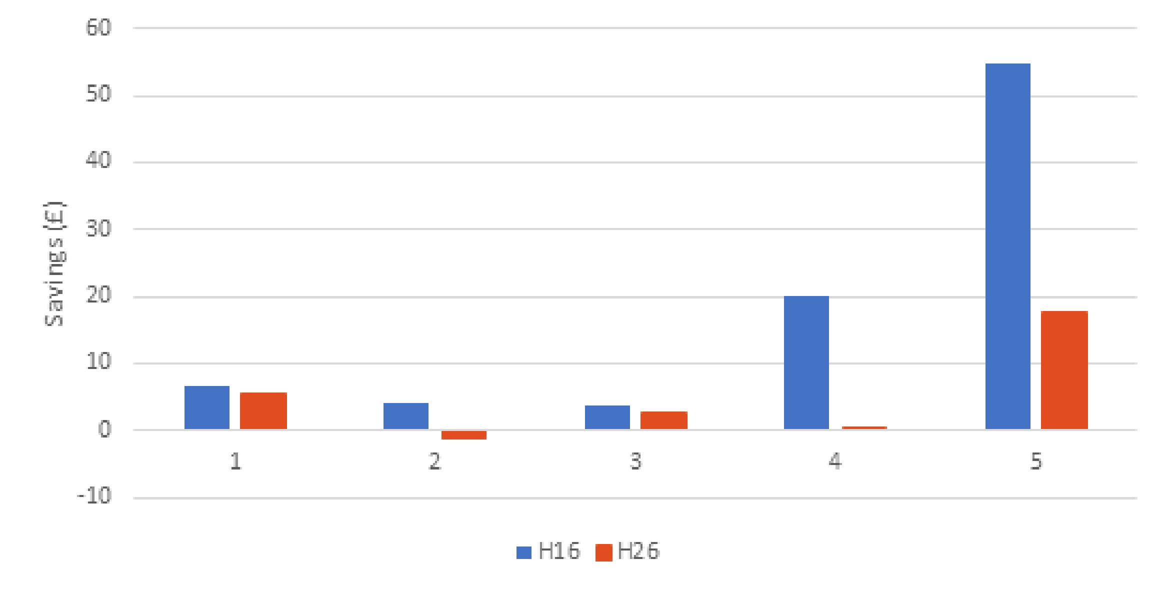
Source: Project Team

8.3.2.2 Different benefits between customers

The majority of customers received benefit of between £30-£55. Houses 16 and 22 received more benefit than the other houses: both were around £90. However, House 26 received the least benefit, £24.60 during the seven months.

Houses 16 and 26 were taken as examples to find out the reasons for differing levels of saving between houses. The total saving of House 16 and House 26 were broken into different time periods shown in Figure 77. It can be seen that the saving differences in period 4 and 5 are larger. The saving differences were analysed in period 4 and 5 in detail.

Figure 77: H16 and H26 total saving in different operation strategies time

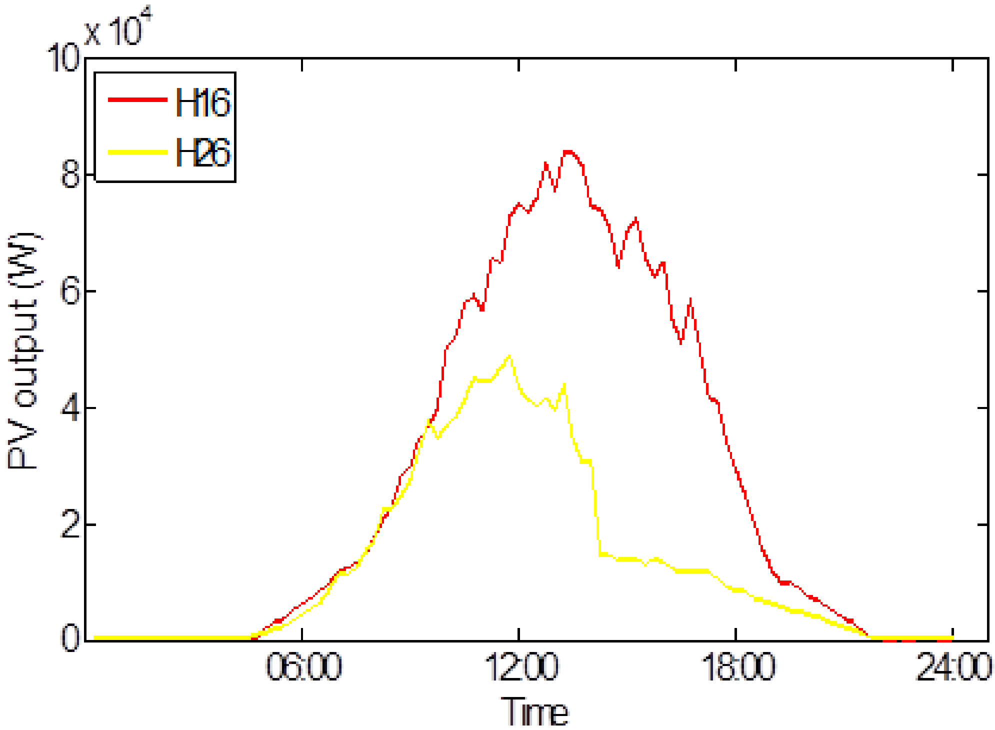


Source: Project Team

It is noticeable that House 26 has high daily demand and low PV output. The combination of these two factors in House 26 determined that its electricity bill savings were lower than that of House 16 in period 4 and 5. The reasons are detailed below.

Firstly, the total PV output of Houses 16 and 26 during period 4 and 5 were compared in Figure 78. The PV output in house 16 was nearly double of that in House 26. Therefore, House 16 received more benefit from demand reduction during the daytime. Additionally, there was a larger amount of free PV energy stored in the battery to reduce more peak demand during evening time, which brought more benefit in demand shifting as well. The first reason of the saving differences is the PV output differences.

Figure 78: H16 and H26 total PV output during period 4 and 5



Source: Project Team

The electricity bill comparison was conducted in different periods since the operation strategies were different. The total electricity bill savings through the day in period 4 are compared in Figure 79. The average SOCs in period 4 are compared in Figure 80. The differences of saving were significant in two time periods in the day 1) 8:00-21:15 and 2) 21:15 to 24:00.

Savings from battery discharge

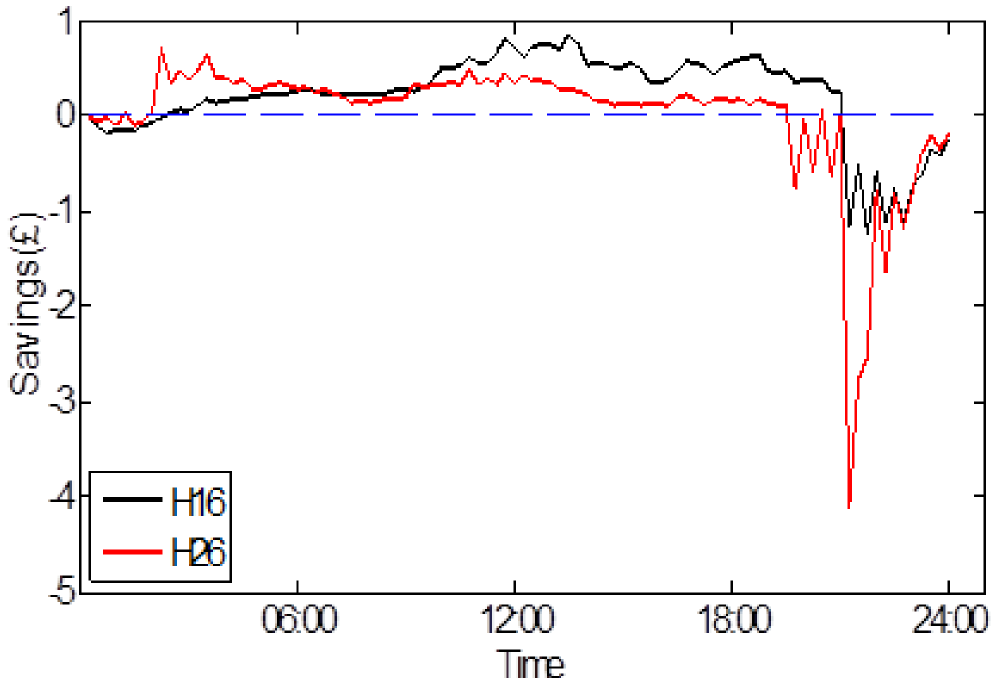
Iin house 26, the battery discharged more during peak price time but it did not bring more savings to House 26. As shown in Figure 79, the SOC of House 16 decreased about 18% between 15:00 to 21:15. In comparison, the SOC of House 26 decreased by more than 20% of SOC between 11:00 to 20:00. However, between 20:00 to 21:15, when the price was still high, the battery of House 26 had to charge from the main grid for safety reasons, which meant that the cost of charging reduced the savings from discharging.

Savings from PV output

The PV output in House 16 was larger than that in House 26, which meant that the saving was larger. As shown in the previous Figure 78, the PV output of House 16 is significantly higher than that of House 26. Between 14:00 to 20:00, the bill saving of House 16 came from both battery and PV output; but in House 26, the bill saving mainly came from the battery.

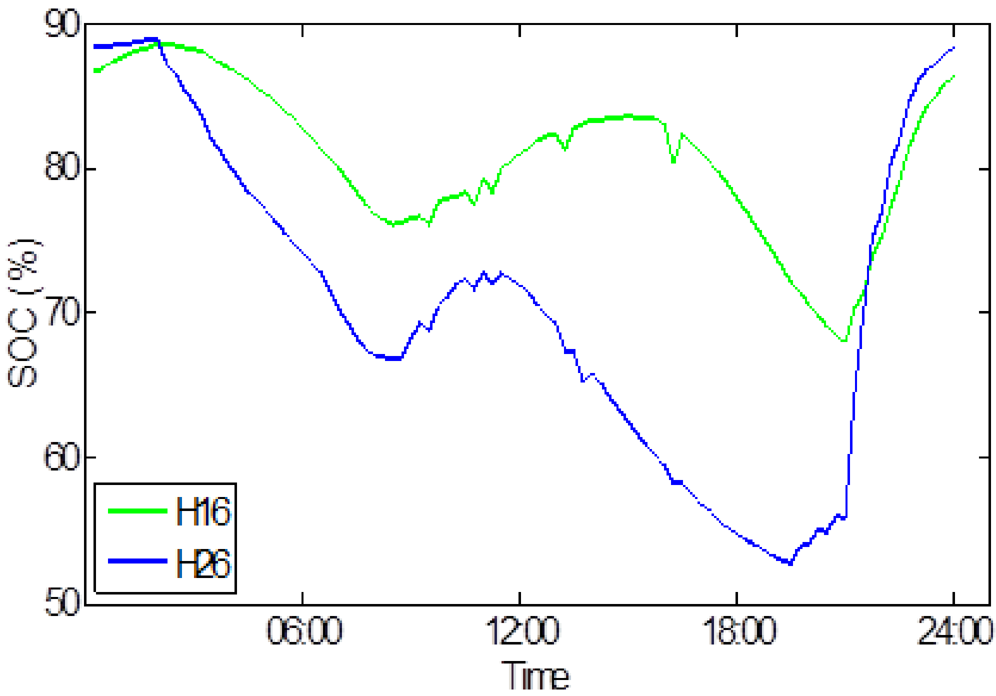
Between 21:15 to 24:00, electricity charged by the battery of House 16 costs less. The different amounts of charging energy were reflected in the changes of SOCs in the two houses. In House 16, the battery was charged from the main grid with 20-25% of SOC. However, the battery in house 26 had to charge 35-40% of SOC. Therefore, the different battery charging costs during night off-peak price time also determined final saving differences between the two houses.

Figure 79: H16 and H26 saving comparison in period 4



Source: Project Team

Figure 80: H16 and H26 average SOC comparison in period 4



Source: Project Team

The total electricity bill savings through the day in period 5 are compared in Figure 79. The average SOCs in period 5 are compared in Figure 80. The differences of saving are significant in two time periods within the day, these are 1) 0:00-6:00 and 2) 11:00 to 18:00.

Between 0:00-6:00, House 16 saves on their electricity costs, but House 26 pay additional electricity costs. In House 16, the battery had not used up its energy before midnight and therefore could keep dischargingto dawn. However, House 26 had high demand and the battery energy was used up before midnight and had to be charged from the main grid for safety reasons.

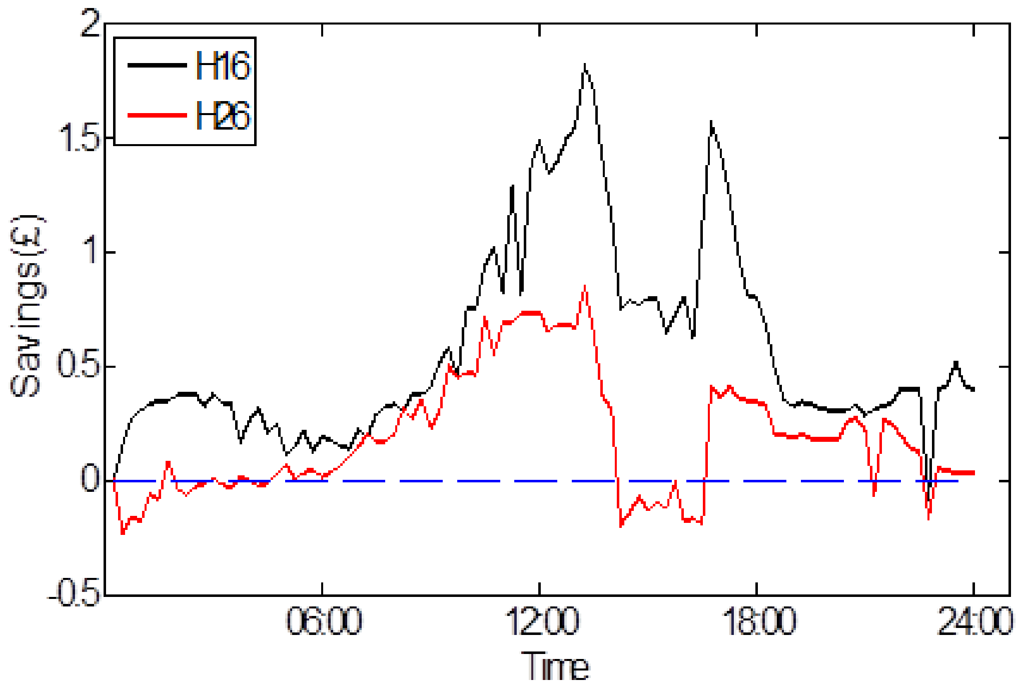
Between 11:00 to 18:00, House 16 saves electricity costs but House 26 has to pay additional electricity costs during 14:00-16:30 when the electricity is at an off-peak price. There are two triggers for the saving differences:

1) PV reduction is larger in House 16 especially in period 5 -- the spring and summer time. The magnitude of savings in House 16 followed a similar pattern of the PV output except for the time between 14:00-16:30 shown in figure 90 , which implies the savings mainly come from PV reduction, and

2) The battery in House 26 had to charge from the main grid. Normally, PV output charged the battery during the daytime. When it comes to off-peak price time at 14:00, the battery of House 16 was already at target SOC via PV and did not need to be charged from the main grid; but the battery of House 26 had to be charged from main grid to

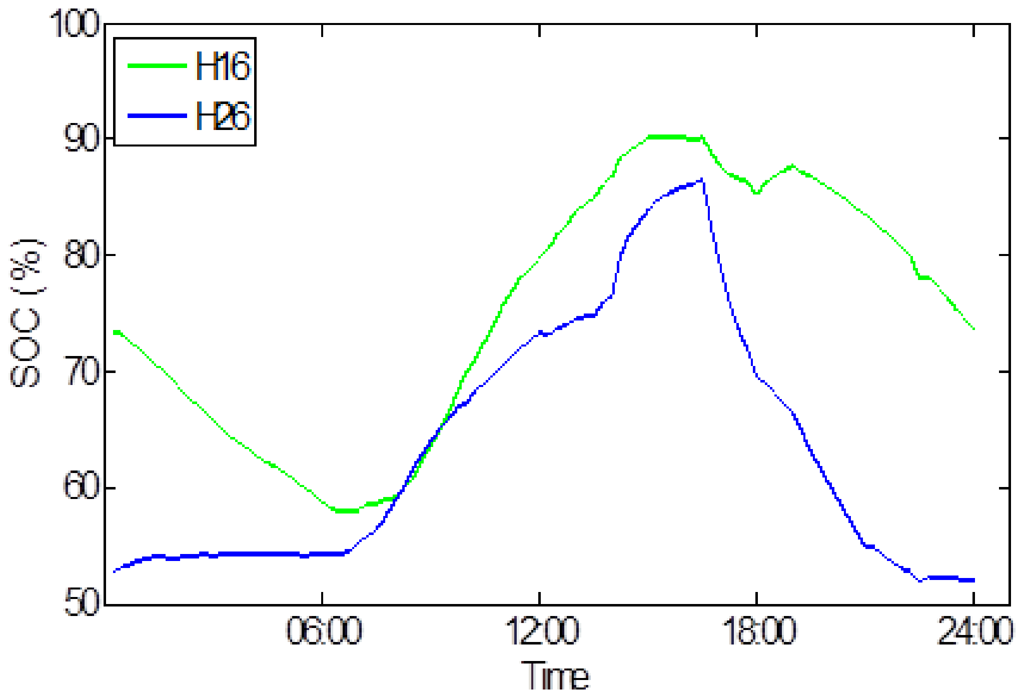
reach target SOC. When compared with House 16, a certain amount of the savings were mitigated by the costs during 14:00-16:30 in House 26.

Figure 81: H16 and H26 saving comparison in period 5



Source: Project Team

Figure 82: H16 and H26 average SOC comparison in period 5



Source: Project Team

8.3.3 Brentry primary school benefits

We have chosen to use Brentry Primary School as an example throughout this report.

In the schools, only the battery was taken into consideration to bring benefit instead of both PV and battery. The schools implemented the new EMS strategies at the end of November 2014. Therefore, the school's TOU benefit is calculated from Dec 2014 to May 2015. The six months benefit received by the school is shown in Table 23. Since both the weekday and weekend EMS strategies were different, the benefit of weekdays and weekends is listed in detail below. The average benefit receiving per month is £5.83.

Commercial	Original electricity bill (£)	Electricity bill with battery (£)	Total benefit receiving (£)	Saving percentage (%)
Brentry weekday	4048.9	4014.7	34.2	0.8%
Brentry weekend	630.4	622.8	7.6	1.2%
Brentry total	4679.3	4637.5	41.8	0.9%

Table 23: School benefits

SECTION 9

Customer Experience

9.1 Summary

As the customer views report (See Appendix) provides an in depth analysis of the learning arising from working with customers, in this section we provide an overview of the customer story, highlighting key learning points and signposting reports where greater depth can be found. We start with the Domestic properties, followed by the Office and concluding with the Schools.

9.1.1 Domestic

9.1.1.1 Recruitment

A detailed document describing the recruitment phases of the project can be found on lowcarbonuk and the WPD Innovation websites. In the following section we highlight the key lessons from this stage of the project.

Over 60 people were initially interested in the project. However, due to certain requirements on the properties (e.g. limitations on roof space) a number of interested householders had to be turned down . Due to these specific requirements, a new approach was taken which involved identifying houses that fitted the criteria and contacting the relevant householders through door-knocking and phone calls. This led to a different type of participant, who tended to not be as engaged in the project as those who originally actively sought to be part of the project.

L50	Different motivations for taking part will affect the level of householder engagement during the project.

To begin a branding focus group was run. This helped engage the Knowle West community with the project and allowed them to take ownership of the project through re-branding it with their own identity. Alongside this, easy-to-understand leaflets were produced and a drop-in workshop at KWMC was arranged for interested householders to attend. Feedback from the Knowle West residents after the workshop event indicated that some of them would have liked to attend, but they could not spare the time, and for some it would have been easier if located in a closer community hall.

L51	Rebranding a project with the community allows them to take ownership and feel affinity with the project.

L52	Drop-in sessions for the public work better if spread out geographically and people know that they will be kept short.

Figure 83: SoLa Bristol Drop in session

Source: Project Team

Discussions with KWMC social liaison specialists led to a number of recommendations for future projects.

9.1.1.2 Explaining the project

L53	Ensure all project partners understand the project and have a clear 2-minute explanation of it.

L54	Provide diagrams to explain the project and make time to read through the Q&As with participants; do not presume they will read them in their own time.

9.1.1.3 Communicating with householders

L55	Manage the expectations of the participants – be upfront and provide a single point of contact.

L56	People tend to prefer a one-to-one explanation, and if it is closer to home people are less likely to skip it owing to other demands on their time.

9.1.1.4 Eligibility

L57	Do in-depth eligibility checks prior to recruitment to help prevent disappointment and also allow for more targeted recruitment.

L58	Customers may have a better knowledge of their own system than the landlord. Discussions with householders may provide insights into potential issues, such as compatibility issues between a type of Key meter and the solar panels.

L59	If householders are not eligible to take part in a project, provide an alternative event that they can take part in so they do not feel excluded from the community group.

9.1.2 Phase One – Solar PV and Pre-Installation checks

Phase One of the project included household recruitment, assessment of the lofts, and Bristol City Council (BCC) installation of Solar PV on the roofs. While the installation of Solar PV was part of a previous initiative, it is important to understand the impact of Solar PV on our householders prior to the main SoLa Bristol Battery trials.

In-depth details about this stage can be found in the Customer Views Report 2015 and the June 2014 PPR. In the section below we summarise the key learning points that emerged.

9.1.2.1 Engagement & Communication

One of the biggest hurdles during this project has been recruiting and maintaining customer engagement, especially during the design phase of the project where to the householders it may appear that the project had stalled. Co-ordinating contractors and householders was also been a major task, ensuring that the correct people were on site at the right time and that everybody communicated effectively.

It was vitally important that KWMC were able to liaise with the householders and explain the installation process.

L60	The use of a trusted third party as a gateway helps projects run smoothly, minimising disruption to householders.

L61	Providing details to householders about the anticipated length of the install and the provisional dates encourages their continued involvement in a trial

It was repeatedly reported during the project that the use of local contractors had been widely appreciated by the householders, as often they would know a contractor, or at least recognize a familiar face. This added to the level of trust that householders had for the project. However, one risk of the project has been misunderstanding between SoLa Project maintenance and other BCC initiatives. More discussions between KWMC and BCC may have helped KWMC in their ability to offer guidance to tenants and differentiate between the project and BCC activities that occur outside of the project.

L62	Using local contractors can help build and keep public trust in a project.

L63	Be aware of overlapping projects, which the public might confuse with the project in hand, and take steps to avoid the projects being confused by the public.

9.1.2.2 Risks and future work

During this early stage of the project, a number of key learning points were identified that helped to inform project members about their future interactions with householders. In particular it was noted that the extent to which a householder was aware of their energy consumption varied considerably, with some able to describe their exact weekly costs and others having limited understanding. In addition, householder motivations for the project varied widely. Understanding these differences between households enabled project members to consider how they developed future project messages to support the householders during the project.

During Phase One, one of the householders chose to leave the project due to the installation requirements. In order to minimise future drop outs, householders were reminded of the installation requirements, such as changes to lighting, to ensure that they all remained informed of the project requirements.

L64	The extent to which householders are aware of their energy consumption varies.

L65	Understanding householders' motives for joining a project might be useful for maintaining people's involvement in a project, and for informing future recruitment or marketing.

L66	Participants will drop out of projects. Learning their reasons might help prevent other people leaving for the same reasons.

9.1.3 Tablet Interface

9.1.3.1 Design

Alongside the main SoLa project design, a smaller section of work was the tablet design. The main purpose of the tablet was to provide a tool that would give the householders details about their energy consumption in real time. To ensure the tablet was useful and easily understood by the participants a number of design workshops were held. Full details of the tablet design process can be found in the Tablet Overview report.

The key learning for the tablet design was the benefit of including householders in the design process. Not only did this lead to the wider Knowle West community feeling part of the SoLa Bristol Project, as noted above. It also ensured that the tablet only displayed data that the householders felt they would find relevant. In other words, the content was pre-screened for its acceptability to the householders in the trial.

L67	It is important to involve people from an early stage so they can feel ownership of the tool.

L68	Running focus groups provides opportunities to talk to the participants and provide additional insights into the project.

Figure 84: SoLa Bristol Tablet

Source: Project Team

A success in this project was basing the tablet design on work from previous KWMC projects. This provided a springboard of ideas for display and interactions, allowing more time to be spent on the specifics of the SoLa project.

L69	Search for existing materials that can be leveraged, to minimise repeating work and ‘reinventing the wheel’.

9.1.3.2 Roll out

The tablets were provided to each householder when their battery was installed and commissioned. As a number of householders did not have the Internet installed in their houses, it was decided that each tablet would be provided with a limited 3G-SIM card, to give the householders' access to the interface. The householders were trained on the tablet, and told that the 3G SIM was limited – meaning householders could only use it for checking the interface and needed to switch to their own personal Wi-Fi systems (where available) for doing general browsing.

Two key issues emerged with the use of the 3G SIM. Firstly, a number of householders accidentally went over their monthly limit (often due to their children using the tablet to watch YouTube videos). Secondly, due to large number of houses in the area and the number of personal networks generated by those living in the area, it proved difficult to obtain a reliable 3G signal in all of the properties. Consequently a number of householders were unable to access the interface on a regular basis. We would recommend future projects explore alternative methods for Internet access and include more testing time into the design phase.

L70	Not all homes have internet access and plans for householder technology trials must accommodate this.

L71	When mobile data is used to provide trial householders with connectivity, a mechanism should be considered to stop excessive data consumption from householders misusing the system.

L72	When relying on mobile data for a technology project, test network connectivity prior to roll out – and perhaps prior to recruitment.

9.1.3.3 Phase Two – Data Collection

The main phase of SoLa Bristol was the data collection stage, whereby the householders were asked to live normally in their house while the SoLa battery system worked in the background. It was important during this stage to maintain engagement with the householders, without being disruptive. To manage this, KWMC maintained regular contact with the householders, and the householders were all invited to take part in interviews and focus groups. The learning from this stage of the project can be found in the Customer Views Report, interim learning report 2014. In the following section we summarise the key areas that the customers raised during these interviews and focus groups.

9.1.3.4 Lighting

A major theme, which routinely emerged during conversations with the householders, was the LED lighting. Interestingly, there was no consensus with regard to the lights. Some householders reported that they well dull and felt 'in shadow', while others reported that the lights were over-bright and that they had bought lampshades to dim them. To offer the householders more control, WPD provided lighting adaptors that enabled two LED Lamps to connect to the light socket ; the householders were also provided with a range of cool and warm bulbs. From these options they were then able to change their own lighting systems to suit.

Figure 85: Inhouse adapter being installed

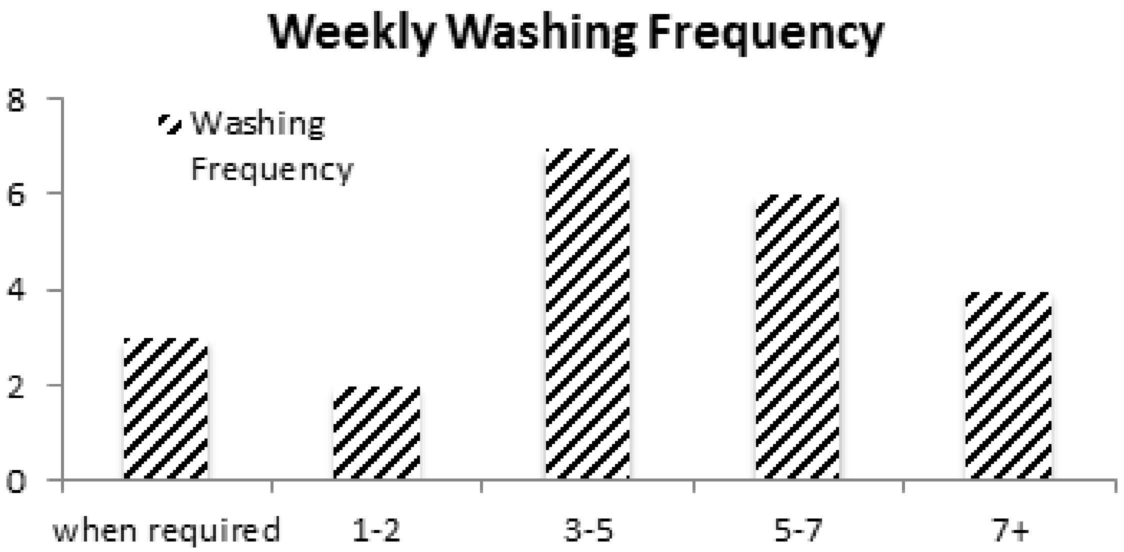
Source: Project Team

L73	Designing a flexible solution and enabling householders to adapt it to their personal tastes can provide a better experience for householders and so better participant retention.

9.1.3.5 Lifestyles

One of the most unexpected, but interesting, lessons emerged from discussions with the householders about their lifestyles. While the majority of the homes were 3-bed terraced houses, it is evident that they vary widely in the amount of energy consumed. Through discussions with the householders it became apparent that this variation is not only due to the number of tenants in each house, but their lifestyles. Particularly important here was people's laundry habits. While some householders did one or two loads a week, some of the houses did one or two loads every day. It is clear that this type of information can only be gained from careful information gathering from the householders. In particular, because the importance of washing behaviours was not known at the start of this project, it was only through the qualitative interviews that it became apparent.

Figure 86: Weekly Washing frequency



Source: Project Team

L74	Not all houses behave in the same way and assessing this variation will allow future projects better to accommodate this variety.

L75	Collecting qualitative (e.g., interview) data allows a project to assess unanticipated issues.

9.1.3.6 Finance

During the SoLa project the householders have seen a noticeable change in the amount of money they put on their pre-payment meters for electricity. Some saw bigger changes than others, and some households as much as halved their electricity costs. The largest saving came from the installation of the Solar PV, and for some the battery installation saved further money.

> "Probably saving, I don't know, thinking about it, probably about £2 a week, which doesn't sound a lot but when you work out over a course of quarter a year, it really does add up."

One householder reported that the battery saved her an extra £2 a week, noting that before the project she used to spend £10-£15 a week and since the Solar PV and the battery installation, it was down to £7 and she hardly ever required emergency credit. A number of the householders deliberately chose to continue adding the same amount on to their meter as before the trial. This meant that, while they did not see a saving in what they paid, they now found it rare to go into emergency credit and, moreover, used the credit in their meters as a way of saving, ready for winter.

For those who were on direct debit payment, savings were less clear as the householders were typically unaware of what they spent, and whether it had changed during the project life span.

L76	Some householders can notice, and be motivated by, even small financial savings.

L77	The consumption feedback inherent in a prepay meter can make any energy savings more easily visible to users.

L78	People on pre-payment meters respond differently when helped to save energy. Some take the extra money by putting less on the meter whereas others continue with their old payment routine and use the meter as a savings bank.

9.1.3.7 Energy Literacy

During the project it became apparent that the householders varied considerably in how they thought about energy. For some it is primarily a concern due to financial constraints, while others were concerned about minimising their impact on the natural environment. Often householders would form their own interpretations of the technology and use these lay-theories to manage their behaviour. For example, one householder commented that the light on their meter flashed more when they were using more energy whilst another attributed the same flashing light to the level of sunshine outside. A number of the householders felt confident in their ability to explain the project to the neighbours and were proud to be part of the project. Other householders reported that it was their children who pushed for 'greener' behaviour. A couple of householders reported they had changed their energy supplier for better deals, and they felt that this project had helped them feel more energy savvy.

L79	Energy literacy varies considerably, it is important that presumptions are not made about what people will understand about energy.

L80	Engaging with an in-home energy feedback system can increase householders' energy literacy.

9.1.3.8 Behaviour Change

All of the householders were interested in learning new methods for saving energy, such as reducing their use of the tumble drier, although a number of them felt that such behaviour change would not be possible and others felt they had already changed their behaviour as much as they could. One householder commented that she was now staggering her washing over multiple days so she could gain further benefit from her solar panels.

> “I tend to now, instead of doing two or three loads in one go, I notice if I do sort of one load because the tumble dryer is only going for like less time. If you do a little bit each day, it seems to save you more money than doing it all in one big go.”

L81	While householders may be keen to save money or energy, it may not be possible – or may at least be perceived as impossible – in all scenarios.

9.1.4 Outage Trials

During phase two of the project the battery system was evaluated in several ways, including an outage trial. Twenty houses took part in this three-day event. Each of the householders was contacted in advance to arrange a suitable 30-minute appointment. The houses were visited by the SoLa team and experienced their power outage for approximately 10 minutes. During this visit, system checks were made and a short outage survey was conducted, 19 of the 20 houses chose to take part in the survey. The full details can be found in the Householder Outage Report. In the section below we briefly summarise the key learning points that emerged during this test phase.

9.1.4.1 Behaviours

When asked about the types of devices they would normally be using during the day, responses varied substantially. Some householders reported using up to 5 different devices, while the majority thought they would normally have one or two items on. The television was the main item that people reported using during the day. This was followed by the washing machine. Only two people mentioned using the fridge/freezer, suggesting that often householders forget about background devices. When considering power cuts more people commented on the importance of keeping the fridge/freezer on to protect food.

L82	How householders use and view energy can be substantially different. It is important that houses are treated individually.

L83	Constant, background appliances such as fridges and freezers might not feature in people's minds when they think of the appliances running in their homes.

9.1.4.2 Blackouts and Power Outages

Some of the householders had experienced events similar to black outs during the project when the battery failed. While this was frustrating for the householders at the time, it was noted that a number of householders took it as an opportunity to get the family together in one room, leading to a feeling of 'blitz spirit'. In some instances householders had neglected to top up their meter, which led to their power going off but the lighting staying on. Those who experienced this often said that having the lights staying on was a valuable experience and it made it easier to deal with the power outage.

A number of the householders reported that they would be happy to experience planned outages if they knew in advance when they would occur and for how long. They were also happy to use reduced energy during the day if it would mean the lights would stay on during a power outage, indicating a desire to manage their behaviour mediated by the battery.

L84	Householders vary in how well they are able to cope with power outages. Future work may want to explore how behaviour could be changed during the day to 'save' energy for evening lighting.

9.1.4.3 Future Systems

When asked about the battery becoming a mainstream appliance, a number of the householders suggested that it was very valuable having it support the lighting in the event of a power cut. They also suggested a power cut might be less stressful if the system could keep other appliances running such as the fridge/freezer or entertainment systems.

L85	Householders valued the system that allowed the lighting system to remain on during power outages.

L86	Future battery systems may benefit from supporting additional devices.

9.1.5 Decommissioning

A full description of the decommissioning learning can be found in the customer views report. Here we summarise the key lessons that emerged.

9.1.5.1 Finance

Despite having had the battery system removed, none of the interviewed tenants had noted a dramatic change in costs for their electricity. Those that had noticed a small increase commented that it was also winter, so they expected costs to go up anyway. The householders were pleased that they would be keeping the solar PV and continue to see the financial gains from the panels.

9.1.5.2 Future research

Most of the householders reported that they would take part in a similar project again. When asked how the project could be improved, most felt that it had been a good experience but that minimising the delays in the project would have preferable. Similarly, if the tablets had been more reliable then the householders would have liked more interaction with their data.

9.1.5.3 Communication and Contractors

All the householders who were interviewed reported that the decommissioning process was smooth and straightforward. A number of householders described the value of using the same contractors that did the initial installation. The householders were happy with how their houses were restored, and some noted that the contractors had even fixed additional issues such as broken power sockets.

The communication from KWMC to the householders was excellent, with the householders happy with how the decommissioning was organised.

L87	Using the same contractors for each stage of a project can make the process smoother and easier for the householders.

9.1.6 Discussion

The previous section has highlighted some of the lessons that emerged during the SoLa project when interacting with the domestic customers. In order to avoid repetition this section is deliberately kept concise to provide an overview and signpost relevant documents that can be reviewed to provide further detail about the customer experience.

9.2 Office

In the following section we summarise the key themes that emerged during the engagement and installation of equipment in the Office. For an in-depth discussion please review the Customer Views report and the Interim Learning report 2014.

9.2.1 Recruitment and Installation

The recruitment of the office was delayed during the project due to changes in the organisation of Bristol City Council; their restructuring led to a reduction in available offices and an uncertainty about the office occupants. Despite this, an office was selected and the current occupants were contacted to engage them in the project.

L88	Planning to be flexible from the beginning allows a project to adapt to changes outside of project control.

Discussions with the office staff indicated that they had been waiting for solar panels for a long time and were eager for the project to begin, although they also had reservations and trust issues as they had previously experienced unsuccessful projects.

L89	Participants involved in more than one trial might not see them as separate. Recognize that frustrations from other projects could overflow into current projects.

Through discussions with the staff it became apparent that changing the IT systems would not be feasible due to IT requirements and the potential that the physical office layout might change during the year. Instead it was decided that the only change made to the offices was to replace the lights with DC LED lighting.

The installation of the office was planned to minimise disruption to the staff, with work taking place over the weekend and on Mondays when the office was shut to the public.

L90	Installation in workplaces has the advantage that there are clear times, knowable in advance, when the premises will be empty.

9.2.2 Office survey

During the project, researchers visited the office to interview the office staff and explore whether they had been affected by the SoLa system.

9.2.2.1 Personnel

The interviews were conducted 6 months after the battery installation and during this time a number of staff had relocated. Consequently some of the staff had only recently joined the office, meaning some were unaware of the project.

L91	The occupants of workplaces are particularly likely to come and go during a trial. The fluid nature of ‘residents’ can affect how much the office workers feel included in the project and might hinder efforts to track people’s experiences over time.

9.2.2.2 Lighting

As with the householders, there were mixed reviews to the lighting. Some felt that it was good and ‘like daylight’, while others found that the lights reflected off their keyboards and caused a glare. No single person in the office took control of the lights; the general assumption was that first in turned them on, and last out turned them off, and most of the office staff thought that this was probably the security guard. On a rare occasion, a staff member might switch a strip of lights off. However, as this would impact a number of people in the area it did not happen often. The office staff commented it would have been useful to control each light individually.

L92	Unlike in the home, there is no clear ‘ownership’ of the lighting arrangements in workplaces.

Despite some of the office workers complaining about glare, they have not attempted to adapt their office environment to improve their situation. For instance, turning the desk rows by 90 degrees may have reduced glare on the keyboards but nobody did this.

L93	Office workers do not feel in control of their workspaces. Additional engagement and consultation may help, but it is unlikely that every member of staff will be satisfied with any solution.

9.2.2.3 Discussion

The system showed minimal impact on the office staff. This is likely to be due to the changes of staff during the project, and the lack of control staff feel they have over their environment. It is not clear if there have been financial benefits, and while some staff expressed dislike of the lights, this is likely due to their size and layout rather than their LED DC qualities. This case study indicates it is possible to change the lighting system with minimal disruption to office staff.

9.3 Schools

In the following section we highlight the key learning that has emerged through SoLa Bristol working with schools. For full details please also see the Interim Learning report 2014 and the December 2014 PPR.

9.3.1 Recruitment

Members of Bristol City Council initially approached schools, using their existing relationships they contacted a range of head teachers, bursars and site managers to invite schools to take part in the SoLa Bristol Project. At this point, 12 schools registered an interest in taking part. While this number was smaller than anticipated, it was partly due to a number of the Bristol schools choosing to become academies and run independently of the council at around this time.

Delays in the design, and practicalities relating to the installation of the design, led to a further reduction in potential schools. Ultimately four primary schools were selected; KWMC also chose to take part as their building functions as an education establishment.

L94	When dealing with public organisations like schools, outside forces such as government initiatives may have an unforeseeable impact on the project.

L95	Delaying recruitment until the project start date is almost definite is a good strategy for corporate trials participants as well as householders.

A number of meetings took place with the schools to explore the potential of the system, how the school would benefit and the practicalities of installation. Early on in the project it was acknowledged that combining the battery storage with the schools Solar PV would be a time consuming and costly initiative that was unlikely to provide enough benefit and learning to justify the costs. Consequently a standalone battery system was designed.

Initial plans had indicated that each of the education establishments would convert an IT room to run DC lighting and PCs. However, again, the schools differed widely and this approach was not suitable. Instead, each school was provided with a bespoke system; in some cases this involved converting laptop trolleys to run from DC, while one school was able to change an entire computer room to run from DC.

These differences are typical of all schools and future projects should consider this when planning future projects.

L96	Schools are highly variable in their set-up and equipment. It may not be possible to provide a solution that suits all locations.

9.3.2 Communication and Timing

While BCC had an existing relationship with each of our schools, the member of staff that the project made contact with varied widely, and this led to different discussions and project focuses in the meetings. For instance, if the primary contact was the school bursar then the focus tended to be on the benefit to the school, and in particular the financial aspects of the trial, while if it was a teacher, the focus often shifted to how the project could benefit the students in terms of their energy literacy. It was also noted that often members of staff would need to consult with other members of the school body such as the head teacher or chair of governors before signing up to the project. While this is to be expected, it would have been useful had the relevant parties attended the initial meetings to gain their own understanding of the project.

L97	When recruiting organisations to a trial, tailoring the message to the interests or needs of each gatekeeper aids recruitment.

L98	It is important that all the necessary expertise is available at meetings with corporate trials participants so potential questions can be answered appropriately and accurately.

It can be hard to find a time that suits staff at the schools. During the day they are often teaching, and they often chose to work from home once the school day has finished. This limits their availability to immediately after school and during the lunch hour, and typically they can spare less than hour to discuss the project. It was vitally important that project members were flexible to ensure that relevant school staff could attend the meetings.

Time of year also affected the schools' availability, with certain times of the year busier than others. Any construction work needs to be done during school holidays, which often means it is occurring in parallel with other school improvement projects.

L99	Working with schools can be hard. Try to understand their multiple time constraints – both for the schools over the year and for the individual staff day to day – and be as flexible as possible to fit in with these.

L100	Plan projects to occur in the appropriate time of the school year, and provide adequate notice to the school so they can plan other summer works with your project in mind.

9.3.3 Education

To provide additional benefits to the school, an educational communications organization called Gallomanor was commissioned to produce a set of classroom engagement materials that could be used by the schools to support their curriculum. Detailed reports of the schools engagement materials can be found in the appendices section for the Gallomanor reports and the [SoLa Bristol – Decipher my Data case study].

In this section we briefly summarise the school intervention materials and their impact.

9.3.4 Science Debate Kit

The debate kit was designed to provide an introduction to the electricity industry. It provided background details and a debate activity that encourage the students to think about how the network could be reinforced in the future.

The debate kit was provided to over 800 interested teachers a further 687 were distributed to interested STEM contract holders. The debate kit was also available online and downloaded by 242 separate users. Example copies were also handed out at a range of public engagement events, including the Department for Education stand at BETT 2015.

Evaluation conducted by Gallomanor indicated that teachers were either using the kits or planning to use the kits in future lessons. A number of teachers were sharing the resources with colleagues and exploring different teaching methods. One surprising insight was the use of the debate kits in teacher training sessions, with feedback suggesting that the design and structure of the materials gave teachers confidence in their ability to run a debate within the classroom.

Generating and providing debate kits, as part of the SoLa Bristol project, has enabled WPD to provide energy education to a broad audience, expanding beyond the SoLa Bristol participants. Through engaging with Gallomanor, this part of the project has developed in parallel with the main SoLa Bristol project, showing that it is possible to combine energy literacy activities with engineering projects.

L101	Major engineering trials are a chance to engage with wider public education, and this can be planned from the beginning.

L102	A designated and experienced schools engagement partner is an excellent way to provide education to future energy consumers.

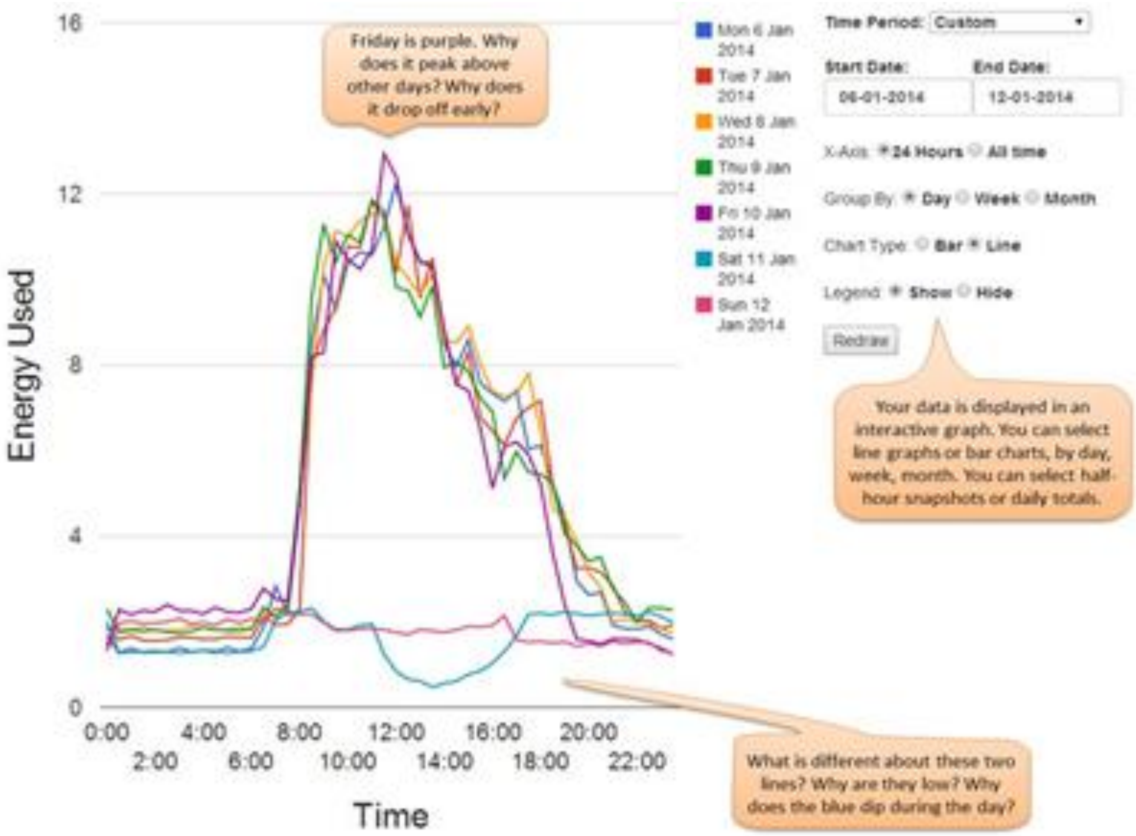
L103	Engagement with schools does not need to be a sustained piece of engagement. Producing a simple-to-use lesson resource may provide more long term value than repeated visits to schools and teachers.

9.3.4.1 Decipher my Data: Energy

The main SoLa school engagement materials developed by Gallomanor focussed on an online graphing tool, which enabled schools in the project to view their own energy data. The schools could explore the data in a range of ways, such as comparison of dates, school time only or weekdays compared to weekends. Schools were encouraged to use the tool in their lessons to explore energy and data handling topics. Teachers and students are able to record their findings using 'Lab logs' and interact with other schools using the site.

A full description of the website case study can be found in the Customer Views report.

Figure 87: Example from Decipher my Data



Source: Project Team

The key lesson that emerged from this work was the differences in how the schools approached the materials. While one school fully engaged with the website and reported how useful it was for teaching across all age ranges, another school felt that as they did not currently have any year 5/6 pupils it was too complex for their younger students.

The SoLa Bristol project has provided a test set of schools for the Decipher my Data: Energy and it is anticipated that schools across Bristol will be engaged and able to contribute to the website. Furthermore the website has been designed that roll out beyond Bristol would be possible, providing other Local Education Authorities and Councils were willing to provide access to their energy details.

L104	For all the benefits of engaging with schools, they will vary in how they engage with materials.

9.3.5 Discussion

It is clear that working with schools has provided different insights and lessons around the use of the SoLa system. In particular it has highlighted that not all schools are the same and that for a successful roll out a bespoke system needs to be designed, not only in terms of technical requirements, but also in the approaches required to engage with the school and provide a system that is mutually beneficial.

It is evident that schools need to be considered on a case-by-case basis, and consultation and discussion are vital for the project to work.

9.4 Conclusions

The previous sections have provided an insight into the customer learning that has emerged during the SoLa Bristol project. It is clear that customer experiences vary widely and future projects need to plan for multiple methods of engagement and communication.

While collaborating with customers can be time consuming, it is evident that it can provide valuable insights into how customers react and respond to technology. It can also provide additional information, which can be used to evaluate and interpret data, for example understanding the number of householders, and their typical behaviours may help to explain an unexpected energy consumption value.

Future projects should allocate time in their projects to spend engaging with customers and reflecting on the learning of previous projects that may help to inform their own projects and methodologies.

SECTION 10

Project Learning

In the following section we consolidate all the lessons that have emerged during the SoLa Bristol project. We combine the lessons reported in this final summary document, with lessons that have been reported in previous documents. In some instances we reword these original lessons to allow them to become transferable to future projects, in each case we document in which report the original lesson can be found to allow the reader to return to the source and understand the journey taken to produce the lesson.

Where lessons have been duplicated across reports, or are similar in message we have presented only one example.

Customer Communication	
Householder (H)	Working with domestic customers
Schools (S)	Working with schools
Corporate (C)	Working with offices
Engagement & Communication (E&C)	Activities that focus on engagement and communication
Project Design	
Project Process (PP)	How to have a smooth running project
Project Management (PM)	Managing the project
Engineering	
Engineering Practice (EP)	Specific engineering learning
Engineering Context (EC)	Ideas to help with engineering (e.g. regulation guidance)
Ofgem	
Ofgem (O)	Of particular interest to Ofgem

First we tabulate the lessons reported in this report.

10.1 Final Report Lessons

		Schools	Domestic	Corporate Engagement	Engagement & Communication	Project Process	Project Management	Engineering Practice	Engineering Context	Ofgem
L1	A clear specification, which identifies a lead for each aspect, will encourage ownership and allow for appropriate time and workload to be managed.						PM			
L2	Project contracts need to include an amount of flexibility for unexpected tasks that emerge during the project lifespan.						PM			
L3	Understanding the type of relationship between partners is vital for project success.						PM			
L4	Trust between partners is vital to allow the sharing of information and knowledge.						PM			
L5	Clear decisions need to be made with regard to knowledge sharing and the stage at which findings can be publically shared.						PM			
L6	Project regulations need to be clearly defined to prevent disruption to the project should a partner's focus or internal policies change.					PP	PM			
L7	It is important that all project members can explain the project and that understanding are not presumed.						PM			
L8	Project partners will have different backgrounds so time needs to be allocated for learning new areas to enable effective communication.					PP	PM			
L9	If the team is geographically dispersed it is important that members can be easily contacted via phone and email.					PP	PM			
L10	Projects benefit from clearly defined roles.						PM			
L11	Sharing tasks and expertise can reduce the risk of single failure points.						PM			

L12	Where possible a cross over period should be included to allow for job shadowing.					PM		
L13	Introduce new members to the team via email, with details of their job role.					PM		
L14	Ensure each member keeps clear documentation around decisions so new staff can understand the logic and continue to work in line with the project aims.				PP	PM		
L15	Project partners need to be responsible for knowledge sharing within their own company.				PP	PM		
L16	Key personnel need to be identified at the start of the project to ensure informed decisions can be made.				PP	PM		
L17	The inclusion of the knowledge managers in correspondence and project meetings can help document the project and support the sharing of knowledge internally.				PP	PM		
L18	Bid writers need to factor in additional time if a product is not 'off the shelf' or is being used in an atypical manner.					PM		
L19	Innovation is at the core of LCNI; an appropriate amount of time and space needs to be provided for a project to evolve.					PM		O
L20	Project members are often working on other projects simultaneously, honesty about timescales and availability can ensure a project is planned effectively to suit all partners.				PP			
L21	When applying for a change request it is important to evaluate the whole project and ensure other aspects continue while awaiting feedback				PP	PM		O
L23	Ensuring that house visits always occur in pairs minimizes risk to project members.	D			PP			
L24	Seek guidance from local community groups on how to present yourself when meeting new people and visiting their homes.	D		E&C	PP			
L25	Project members should be trained, not only on the technology that is being installed in the homes, but also how to talk to and engage with the homeowners. Sharing expertise can benefit the whole project.	D			PP	PM		

L26	It is important that there is a balance between innovations and existing methods, projects should be careful that they do not become overly complex.		PM			O
L26	Extra time needs to be included where regulations may need to be amended or guidance sought for the use of existing technology but in new ways.	PP	PM			O
L27	Outside factors may have an impact on the design of the project, where possible explore how this can provide additional learning and opportunity.	PP	PM			
L28	Extensive testing was undertaken to ensure systems complied with regulations. This testing phase also allowed tweaks and improvements to be made to the system.	PP			EC	
L29	While a working solution may be possible, it may not be approved due to regulations by other boards. It is important to consider external bodies when planning innovative projects.	PP			EC	O
L30	Early work exploring DC metering suggests that this could be a useful area to explore in the future.				EC	O
L31	Using the batteries in a non-traditional way led an overestimation of the state of charge.			EP		
L32	Battery problems could sometimes be alleviated through re-assignment of the set points to compensate.			EP		
L33	A 'backstop' device was produced to automatically disconnect the battery if the voltage dropped below a certain level.			EP		
L34	Introduction of a recharge cycle into the system, resulted in a reliable state of charge measure.			EP		
L35	Fixed price partner contracts limited the flexibility of the final system due to additional equipment costs.		PM			
L36	Partners taking part in similar trials with other projects may show reduced engagement following delivery of their [workstream].		PM			
L37	The house location and PV installation location significantly influence the output of PV output.			EP		

L38	Installation of two different batteries allowed for a comparison of two different battery manufacturers.				EP		
L39	The houses did not show the same load profile, instead the data suggested three distinct groups; standard load, high load and economy 7.				EP		O
L40	Communications or availability of the remote properties influenced the success of the trial.			PP	EP	EC	
L41	GPRS did not prove to be a reliable communications method between the nodes in the trial network.				EP		
L42	Household demand changes were masked on the phase demand, most likely due to the small proportion of trial properties on the feeder.				EP		
L43	Domestic load profile uncertainty is primarily caused by differing energy consumption behaviour and householder habits.				EP		O
L44	Load profiles of normal homes usually have a high evening peak and a relatively lower peak in the daytime.				EP		
L45	In high load homes, there are high demand in the daytime instead of a high demand peak in the evening and a relatively lower peak in the midday.				EP		
L46	Economy 7 houses will show a peak from mid-night to 7am, after this they will either mimic a high load or a standard load house, dependent upon the householder behaviour.				EP		
L47	High load customers showed the least amount of saving using the hypothesised time of use tariff.				EP		O
L48	Different battery strategies impacted the customer savings.				EP		
L49	PV output is a key mediating factor for the benefits of the battery storage				EP		O
L50	Different motivations for taking part will affect the level of householder engagement during the project.	D	E&C				
L51	Rebranding a project with the community allows them to take ownership and feel a great affinity with the project.	D	E&C				

L52	Drop-in sessions for the public work better if spread out geographically and people know that they will be kept short.		D		E&C	PP				
L53	Ensure all project partners understand the project and have a clear 2-minute explanation of it.				E&C	PP	PM			
L54	Provide diagrams to explain the project and make time to read through the Q&As with participants; do not presume they will read them in their own time.	S	D	C		PP				
L55	Manage the expectations of the participants – be upfront and provide a single point of contact.	S	D	C		PP	PM			
L56	People tend to prefer a one-to-one explanation, and if it is closer to home people are less likely to skip it owing to other demands on their time.		D		E&C	PP				
L57	Do in-depth eligibility checks prior to recruitment, this will help prevent disappointment and also allow for more targeted recruitment.		D			PP	PM	EP		
L58	Customers may have a better knowledge of their own system than the landlord. Discussions with householders may provide insights into potential issues, such as compatibility issues between a type of Key meter and the solar panels.		D			PP			EC	
L59	If householders are not eligible to take part in a project, provide an alternative event that they can take part in so they do not feel excluded from the community group.		D			PP				
L60	The use of a trusted third party as a gateway helps projects run smoothly, minimising disruption to householders.		D			PP	PM			
L61	Providing details to householders about the anticipated length of the install and the provisional dates encourages their continued involvement in a trial.		D			PP				
L62	Using local contractors can help build and keep public trust in a project.		D			PP		EP		
L63	Be aware of overlapping projects, which the public might confuse with the project in hand, and take steps to avoid the projects being confused by the public.		D			PP				
L64	The extent to which householders are aware of		D							O

	their energy consumption varies.					
L65	Understanding householders' motives for joining a project might be useful for maintaining people's involvement in a project, and for informing future recruitment or marketing.	D	PP			
L66	Participants will drop out of projects. Learning their reasons might help prevent other people leaving for the same reasons.	D	PP			
L67	It is important to involve people from an early stage so they can feel ownership of the tool.	D	PP			
L68	Running focus groups provides opportunities to talk to the participants and provide additional insights into the project.	D	PP			
L69	Search for existing materials that can be leveraged, to minimise repeating work and 'reinventing the wheel'.	D	PP			
L70	Not all homes have internet access and plans for householder technology trials must accommodate this.	D	PP		EC	O
L71	When mobile data is used to provide trial householders with connectivity, a mechanism should be considered to stop excessive data consumption from householders misusing the system.	D	PP			
L72	When relying on mobile data for a technology project, test network connectivity prior to roll out – and perhaps prior to recruitment.		PP			
L73	Designing a flexible solution and enabling householders to adapt it to their personal tastes can provide a better experience for householders and so better participant retention.	D	PP		EC	
L74	Not all houses behave in the same way and assessing this variation will allow future projects better to accommodate this variety.	D	PP		EC	O
L75	Collecting qualitative (e.g., interview) data allows a project to assess unanticipated issues.		PP	PM	EC	O
L76	Some householders can notice, and be motivated by, even small financial savings.	D				
L77	The consumption feedback inherent in a prepay meter can make any energy savings more easily visible to users.	D				O

L78	People on pre-payment meters respond differently when helped to save energy. Some take the extra money by putting less on the meter whereas others continue with their old payment routine and use the meter as a savings bank.	D				O
L79	Energy literacy varies considerably, it is important that presumptions are not made about what people will understand about energy.	D	PP			O
L80	Engaging with an in-home energy feedback system can increase householders' energy literacy.	D				O
L81	While householders may be keen to save money or energy, it may not be possible – or may at least be perceived as impossible – in all scenarios.	D				
L82	How householders use and view energy can be substantially different. It is important that houses are treated individually.	D			EC	
L83	Constant, background appliances such as fridges and freezers might not feature in people's minds when they think of the appliances running in their homes.	D			EC	
L84	Householders vary in how well they are able to cope with power outages. Future work may want to explore how behaviour could be changed during the day to 'save' energy for evening lighting.	D			EC	O
L85	Householders valued the system that allowed the lighting system to remain on during power outages.	D			EC	O
L86	Future battery systems may benefit from supporting additional devices.			EP		O
L87	Using the same contractors throughout the project can make the process smoother and easier for the householders.	D	PP			
L88	Planning to be flexible from the beginning allows a project to adapt to changes outside of project control.	D	PP			
L89	Participants involved in more than one trial might not see them as separate. Recognize that frustrations from other projects could overflow into current projects.		PP			

L90	Installation in workplaces has the advantage that there are clear times, knowable in advance, when the premises will be empty.		C		PP			
L91	The occupants of workplaces are particularly likely to come and go during a trial. The fluid nature of 'residents' can affect how much the office workers feel included in the project and might hinder efforts to track people's experiences over time.		C					
L92	Unlike in the home, there is no clear 'ownership' of the lighting arrangements in workplaces.		C					
L93	Office workers do not feel in control of their workspaces. Additional engagement and consultation may help, but it is unlikely that every member of staff will be satisfied with any solution.		C		PP			
L94	When dealing with public organizations like schools, outside forces such as government initiatives may have an unforeseeable impact on the project.	S			PP			O
L95	Delaying recruitment until the project start date is almost definite is a good strategy for corporate trials participants as well as householders.				PP			
L96	Schools are highly variable in their set-up and equipment. It may not be possible to provide a solution that suits all locations.	S			PP		EP	
L97	When recruiting organizations to a trial, tailoring the message to the interests or needs of each gatekeeper, aids recruitment.	S	C	E&C	PP			
L98	It is important that all the necessary expertise is available at meetings with corporate trials participants so potential questions can be answered appropriately and accurately.	S	C	E&C	PP			
L99	Working with schools can be hard. Try to understand their multiple time constraints – both for the schools over the year and for the individual staff day to day – and be as flexible as possible to fit in with these.	S			PP			
L100	Plan projects to occur in the appropriate time of the school year, and provide adequate notice to the school so they can plan other summer works with your project in mind.	S			PP	PM		
L101	Major engineering trials are a chance to engage with wider public education, and this can be				PP			O

	planned from the beginning.									
L102	A designated and experienced schools engagement partner is an excellent way to provide education to future energy consumers.	S				PP				
L103	Engagement with schools does not need to be a sustained piece of engagement. Producing a simple-to-use lesson resource may provide more long term value than repeated visits to schools and teachers.	S				PP				
L104	For all the benefits of engaging with schools, they will vary in how they engage with materials.	S				PP				
L105	EMS strategies should be designed individually for each types of customers, such as, normal homes, high load properties and economy 7 homes and even for specific customers.							EP		O

Table 24 All project learning

10.2 Project Management Learning

The knowledge workstream of SoLa Bristol was managed for WPD by the University of Bath, as having previously worked with WPD on the LV Templates project, the knowledge management approach requirement for SoLa Bristol was deemed to be much the same; in particular we continued to use a number of approaches ranging from the formal reports, and meeting notes to interviews, observations and ethnographic techniques.

A full description of our methodology can be reviewed in the LV Templates close down report[9]. Below we summarise our methods and comment on key techniques.

Knowledge can be stored in a multitude of ways, varying widely in its structure, organisation and accessibility. Some information can appear so obvious it is unclear how we ever did not know it, while other knowledge can take multiple trial and error attempts before the procedure is fully understood. Knowledge can be documented in formal ways such as instruction manuals, or it can be informal and tacit, such as an underlying understanding that allows you to make an intuitive guess to solve a problem. Experts are often seen to have a large amount of informal knowledge, which can be hard to explain and transfer to others.

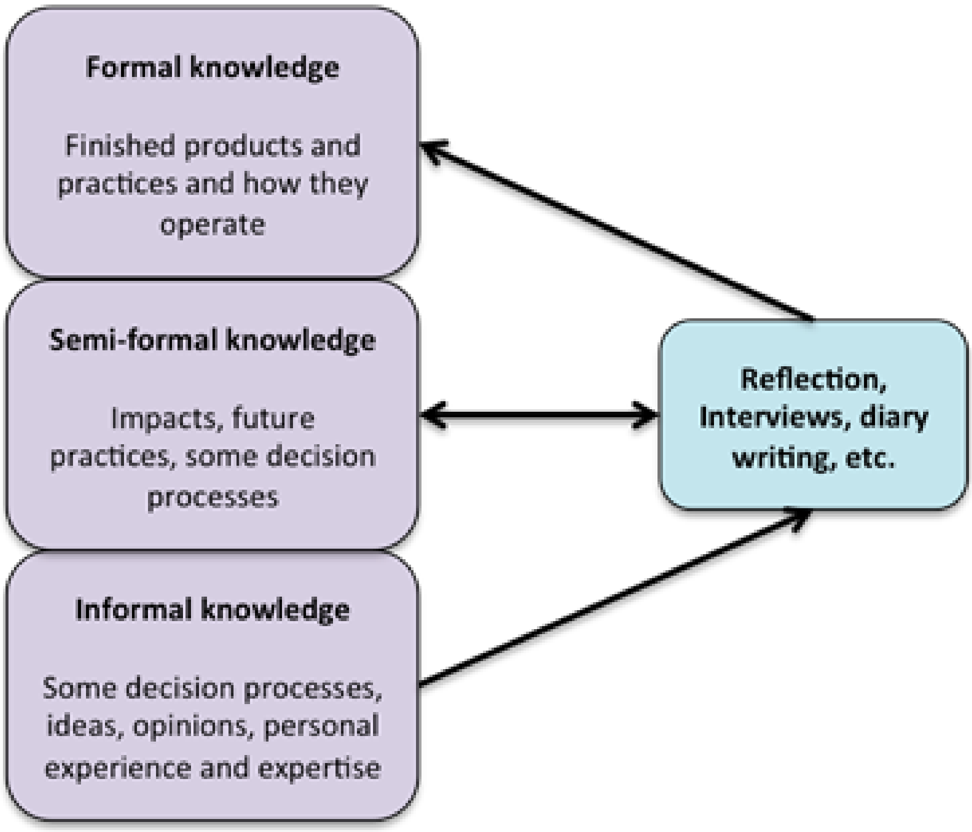
Typically the formal report has been the best method for reporting and sharing knowledge generated in engineering organisations such as DNOs. There are clear

[9] http://www.westernpowerinnovation.co.uk/Document-library/2013/LVNT-Appendix-A-Knowledge-Management.aspx

advantages to this as it allows for a clear description of the knowledge to be documented and maintained in a medium that is accessible. However, reports often focus on the successful methodology or result and may fail to report the numerous methods trialled prior to the successful methodology. They also often neglect to include rationales for decisions. Because reports present firm conclusions, rather than the messier 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.

During the LV Templates project we faced similar issues so we developed a methodology than enabled us to use a variety of knowledge mediums, the diagram (Figure 87 below) shows the three key forms of knowledge and how they might interact and co-produce new forms of knowledge. We continued with this successful methodology in this SoLa Bristol project, taking it a step further by embedding the knowledge manager within the project.

Figure 87 Project knowledge methodology



Source: Project Team

In addition to knowledge sources there are also different types of knowledge produced, in particular 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. Learnings of this kind can be valuable for future 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. We refer to these two types of knowledge 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 regarding learning from LCNI projects – 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 recognised 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"

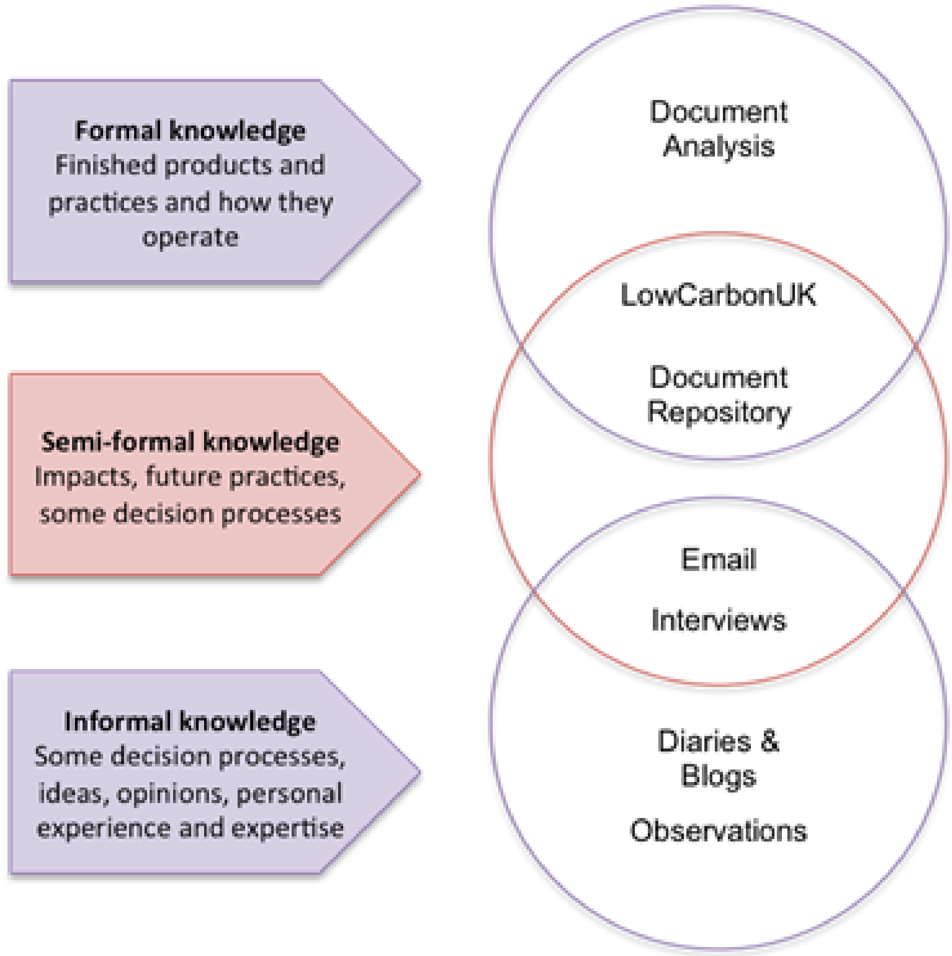
In summary, then, our knowledge capture and dissemination processes, to gather and share new information from LCNF projects, were shaped by three key ideas:

- New information can range from the formal to the informal
- New information can specifically be sought, or can arise incidentally as research takes place
- New information can be about engineering, customer engagement or about the management of research projects

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

The diagram below (Figure 88) shows examples of some of our knowledge capture methods and how they relate to the knowledge types.

Figure 88: Example of capture methods



Source: Project Team

Through using a variety of capture methods we are able to produce an in depth understanding of the knowledge and learning that is generated during this project. Of particular use was having the knowledge managers embedded within the project, through attending all project meetings, interacting with project partners and participants gave an ethnographically informed understanding of the project, its process and the learning generated during its lifespan.

In the following sections we first provide an overview of the project lifespan through document analysis, we then highlight the major learning themes that have emerged during this project, documenting key learning points for future projects.

10.3 Report Analysis

The University of Bath has compiled documentation of the learning and knowledge generated during SoLa Bristol. Using a range of techniques they extracted a number of key lessons that can be used to inform future projects. This method has already been successfully demonstrated with the conclusion of the LV project whereby relevant learning has been incorporated into new projects such as SoLa Bristol.

In addition to technical based learning and learning generated from engaging with customers, it is also important that we recorded knowledge gained from managing the project. By accurately reporting issues we faced, and methods we tried, our learning can help inform future projects in their design and implementation. Detailed project management lessons are reported in this section. But first we summarise the project themes and discuss how the project shifts focus during its lifecycle.

10.3.1 Document Analysis

An integral aspect of the LCNI projects is the 6 monthly reporting which allows the projects to reflect on their progress, and share their learning throughout the project life cycle. These reports provide an insight into the progress of the project and the issues that were faced. During the LV Templates project learning report, it was noted that these reports, when summarised into a word cloud, give a fast and effective way to see the content and underlying focus of each of the reports. Word clouds involve presenting the most common words from documents in a graphical format, with the size of each word representing how often it appeared in the original document.

In this next section we produce word clouds for each of the 7 Project Progress reports for SoLa Bristol. By presenting these in chronological order the evolution of the project can be seen, as the project moves through the various phases of planning, installation and analysis.

This provides a fast and efficient way for a viewer to see the tone and content of a larger, more complex document. It can be seen that throughout the project that reporting and recording has been an integral aspect, while the emphasis of the householders fluctuates depending on the project stage. Due to the extended project phases, installation remains a key aspect right up until December 2014 report indicating how integral the installations have been to the project. These shifts in focus are also apparent in the project timeline [see Section 3], which clearly highlights the range of types of activities, which occur during the project lifecycle.

10.3.1.1 June 2012

It can be seen that there are lot of aspects to the project, however customers, *network* and *installation* are the key focuses. It is important to note that while *Bristol* is the largest word, this is to be expected, as it is not only part of the project name, SoLa Bristol, it is also the geographic location for the project.

Figure 89 Word cloud June 2012

Source: Project Team

10.3.1.2 Dec 2012

The *SoLa* name emerges for the first time in this report. Again the diversity of the project is clear with *schools*, *domestic* and *office* all featuring. As in the earlier report, *design*, *equipment* and *installations* are still of major focus.

Figure 90: Word cloud December 2012

Source: Project Team

10.3.1.3 June 2013

PV, *charging* and *battery* are key aspects at this time, indicating a shift in the project. *Installation* is still a major aspect but it has diversified to include *converter*, *network* and *charging* indicating a more technical focus to the project. *Ecohome*, despite being visible in earlier reports has a larger focus in this report, presumably due to the learning generated from the early installations.

Figure 91: Word cloud June 2013

Source: Project Team

10.3.1.4 Dec 2013

Property, *progress* and *reports* become more prevalent, as do the terms of *reporting*, *data* and *communications*. This highlights the importance of documenting during this stage. Despite this shift, it is clear that installations are continuing with *installation*, *equipment*, *network*, *battery* and *substation* still apparent in the word cloud.

Figure 92: Word Cloud December 2013

Source: Project Team

10.3.1.5 June 2014

As in the Dec 13 word cloud the prevalence of *report* is still apparent, however in this summary we see *householders* as the major focus, with *householders* and *customer* both holding large positions in the cloud. We also see *customer*, *BCC* and *KWMC* feature, indicating a shift towards customer engagement and communication.

Figure 93: Word cloud June 2014

Source: Project Team

10.3.1.6 Dec 2014

Report, *progress* and *risks* are the main focus in the Dec 2014 report. The installations are now complete so minimal contact is required with the householders allowing the team to concentrate on data and analysis. *Issues* and *risks* emerge, indicating that there is continual support for the participants in the project.

Figure 94: Word cloud December 2014

Source: Project Team

10.3.1.7 June 2015

We see *charge, state* and *target* emerge as new key concepts. This highlights the focus on meeting the project SDRCs and conducting the outage tests. Reviewing the use of the batteries is the major focus at this stage of the project.

Figure 95: Word cloud June 2015

Source: Project Team

10.3.1.8 Dec 2015

In this final word cloud we again see a shift in focus, with decommissioning and completed appearing as new themes. Report has the largest presence indicating a focus at the stage of the project on writing up the findings and sharing knowledge.

Fig 96 Word Cloud Dec 15

Source: Project Team

10.3.2 Discussion

It can be seen from the word clouds that the project has gone through a number of key phases, including technical design, customer engagement, testing and analysis with clear changes in perspective. In the next section we discuss the project management learnings that have arisen during this extensive project.

10.4 Project Management Lessons

In the following section we discuss the key themes that have emerged during this project. These were revealed following extensive analysis of project reports, meetings and in depth consultations with project members. We summarise the key themes and provide key learning points to help future projects run efficiently and effectively.

10.4.1 LV Learning

In order to establish continuity from previous LCNI projects we first turn to the learning from the LV Templates project and highlight some of the key learning points that have been used during this project, and continue to offer guidance.

LV ID	Learning Point	Update
LVL41	There is great value in planning, at an early	We agree with this point, our experiences while

LV ID	Learning Point	Update
	stage, to use recognized standards wherever possible but particularly for IT, data storage and communications.	working to obtain new standards have again highlighted the benefits of using existing standards.
LVL43	Having a named person responsible for data management can be valuable to a research project. This person should ideally be involved at the bidding stage.	Including knowledge managers early in the project has allowed an in depth understanding to be formed.
LVL45	It may be necessary to combine different areas of expertise to solve a problem. It is important that this integration is effective, to ensure the outputs are both valid and useful.	Combining social science with technical engineering has provided a broad overview allowing challenges to be considered from a wide range of angles.
LVL47	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.	Inclusion of knowledge managers allowed for the easy translation of complex ideas to a wide variety or audiences.
LVL57	Using an intermediary can help when communicating with the public.	Inclusion of KWMC has been fundamental to the success of this project. Acting as community liaison they have maintained engagement with project participants throughout.
LVL64	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	Project reports have been widely disseminated using existing WPD outlets.
LVL74	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.	Knowing how to work with different suppliers makes for a smoother project.
LVL75	Universities have less ability to be flexible around work content and timescales than other parties, especially as usually senior specialist staff can be engaged in teaching commitments.	A flexible approach was taken during this project, providing deadline details early so project work can be planned into the academic time scales.

Table 25- Key learning from LVNT

It is clear that the LCNI projects are not only providing important technical learning, but also useful project management learning which can be used in a wide variety of settings and future projects. The learning from LV templates has directly influenced the management of SoLa Bristol; in the next section we detail the new learning that has emerged during the SoLa Bristol project lifecycle.

10.4.2 SoLa Bristol Learning

10.4.2.1 Multi-partner projects

An integral aspect of innovation projects is the inclusion of those outside of the typical business, to support the project and to introduce new methodologies and ideas to the project. However there are inherent risks in working with different industries and businesses that may approach the project in a different manner, and have different priorities or systems for tackling a large-scale project.

In particular during the SoLa project we have learnt a lot about the importance of providing a clear specification at the start of the project and ensuring that each part of the project has a 'project owner' associated with it. This reduces the risk of project tasks being overlooked. Through encouraging ownership, tasks can be planned into the project time line better and have appropriate time and workload allocated.

L1	A clear specification, which identifies a lead for each aspect, will encourage ownership and allow for appropriate time and workload to be managed.

However while it is important to be clear about job roles and tasks, in projects such as these it is likely that new, and unexpected, tasks will emerge during the project. It is important that all partners have a certain amount of flexibility in their contracts to respond to these new tasks and be open to working above and beyond their initial job description.

The differences between industry and academia have, like in previous LCNI projects, been identified and as in LV we highlight the importance of defining if an agreement is a supplier relationship or a 'shared agreement'.

L2	Project contracts need to include an amount of flexibility for unexpected tasks that emerge during the project lifespan.

L3	Understanding the type of relationship between partners is vital for project success.

As in a number of industries it is often the case that learning reports are produced which provide final guidelines based on the final working technique and providing a clear "how to" guide for repeating the process. However, few reports include details of learning instances arising from experiments that failed. These types of learning are inherently important as while they may not help the reader to repeat the process, they may provide unexpected learning, or provide an insight into a new methodology. At the very least they will provide information that negates the need to repeat the experiment.

A fundamental difference between academia and industry is how information is shared and managed. Those who work within academia are fortunate as they are able, and encouraged, to share learning and data with those outside of the field in order to develop and progress the research area. However, industry is reliant on producing bespoke and 'sellable' ideas that can be used to sustain the company. As a consequence it can be hard to find a compromise on projects such as these for sharing information without putting industry partners at risk. It is important that these boundaries are clearly identified and acknowledged at the start of the project, and that industry partners are willing to be flexible around their agreements and share details that allow the project to be repeatable.

L4	Trust between partners is vital to allow the sharing of information and knowledge.

L5	Clear decisions need to be made with regard to knowledge sharing and the stage at which findings can be publically shared.

10.4.2.2 Project Partners

If partners are concerned about aspects of the project these should be raised as early as possible, and minimised to reduce the impact on other aspects of the project. Regulations need to be defined at the start of the project that prevents a single partner from restricting key project activities due to internal change in their policies.

L6	Project regulations need to be clearly defined to prevent disruption to the project should a partner's focus or internal policies change.

While LCNI projects are focusing heavily on the engineering solutions it is vitally important that other aspects of the project, such as participant engagement and knowledge management are not overlooked or stalled due to engineering issues. All project partners need to show respect for the expertise of others and be considerate about the implications of their own changes on others.

Similarly partners should feel confident to ask for explanations about unfamiliar aspects of the project. Partners should not presume understanding as often project partners are coming from substantially different backgrounds. This is of particular importance for project members who are public facing, as they need to have a level of project understanding that enables them to communicate not only with the other project partners, but also with the public partners such as the householders.

L7	It is important that all project members can explain the project and that understanding are not presumed.

L8	Project partners will have different backgrounds so time needs to be allocated for learning new areas to enable effective communication.

10.4.2.3 Geography

The current tendering process for projects means that the best company for the task gets the job, however this can result in a geographically dispersed team. If this occurs it is important that the project members work hard to mitigate any issues. Willingness to travel is important as is ensuring that team members can be easily contacted.

Regular phone calls and emails can minimise the need for face to face meetings, however when these do occur, time should be managed to ensure the best use of time for those who have travelled large distances.

L9	If the team is geographically dispersed it is important that members can be easily contacted via phone and email.

10.4.2.4 Personnel

Working on a large multi discipline project requires a large number of people with very different job roles. It is vitally important that these roles are clearly defined at the start of the project. While there are a variety of tasks being undertaken to complete the project, it is inherently useful if all project members are aware of the roles of others to minimise misunderstandings around tasks.

It was noted during project interviews that it can be useful to have a cross over in tasks as this not only provides support to project members it also reduces the chance of 'single failure points'. It is also important that sub-contractors do not rely on a single person as this can cause unexpected delays.

L10	Projects benefit from clearly defined roles.

L11	Sharing tasks and expertise can reduce the risk of single failure points.

L11	Sharing tasks and expertise can reduce the risk of single failure points.

In a long-term project such as this it is to be anticipated that there will be job changes and new project members joining partway through the project. As this cannot be prevented it is important that it is acknowledged and planned for in order to minimise disruption. We suggest that the following guidelines are considered:

L12	Where possible a cross over period should be included to allow for job shadowing.

L13	Introduce new members to the team via email, with details of their job role.

L14	Ensure each member keeps clear documentation around decisions so new staff can understand the logic and continue to work in line with the project aims.

Where project partners are aware they are likely to go through restructuring during the project life span it would be useful for them to raise this as a risk prior to the start of the project to allow for planning to minimize disruption. Similarly if a partner is multifaceted and likely to require approval from a number of departments prior to decisions, these people should be involved from the project start, and encouraged to develop an understanding of the project.

L15	Project partners need to be responsible for knowledge sharing within their own company.

L16	Key personnel need to be identified at the start of the project to ensure informed decisions can be made.

Working with knowledge managers from the start of the project has benefited SoLa Bristol. Through including the knowledge managers in a wide variety of project meetings and correspondence this has provided an overarching understanding of the project. The knowledge managers have also supported communication between project partners.

L17	The inclusion of the knowledge managers in correspondence and project meetings can help document the project and support the sharing of knowledge internally.

10.4.2.5 Bidding, Ofgem and Change requests

A key learning that has emerged in previous LCNI projects is the importance of building additional contingency time into the project. And in particular additional design phase time when a project will be using products that require additional certification or change of use.

It is important that those who write the project bid are aware of the differences between obtaining an 'off the shelf' solution, and a bespoke design which will require more testing and time allocated to it in the project plan.

L18	Bid writers need to factor in additional time if a product is not 'off the shelf' or is being used in an atypical manner.

In order for LCNI projects to be innovative they need to have the freedom to move outside of the typical methodologies, however they are then at risk of failure due to time, cost and regulatory limitations. Despite these risks a large amount of learning can be obtained from trying something new. It is important that high level partners such as Ofgem are aware that innovation cannot be predicted or tied down to a timescale; therefore it is important that a certain amount of leeway is provided to allow the project to grow and evolve to suit, without fear of repercussions for delays or change of direction.

L19	Innovation is at the core of LCNI; an appropriate amount of time and space needs to be provided for a project to evolve.

All partners need to be honest and upfront about their timescales and delays and be considerate of the, sometimes unexpected, impact this may have on other project partners. All partners need to be flexible and willing to change methods to respond to the evolving project to ensure that useful learning can emerge, while minimising the risk to the public partners.

L20	Project members are often working on other projects simultaneously, honesty about timescales and availability can ensure a project is planned effectively to suit all partners.

L21	When applying for a change request it is important to evaluate the whole project and ensure other aspects continue while awaiting feedback.

10.4.2.6 Customer Engagement

Working with KWMC has highlighted the clear benefit of having an embedded trusted partner in the project. Their ability to advise the project, liaise with customers and provide engagement expertise has enabled the project to run smoothly, even during times of disruption and delay.

It is suggested that future projects take this a step further with regular correspondence to the customers ensuring that they are aware of the wider project and of all the partners involved.

During SoLa Bristol, it was noted that entering a house alone was a potential safety risk, consequently a policy was introduced that ensure project members never visited a home alone, and all appointments were made through KWMC. Future projects need to consider the risks of working within homes and consider plans to minimise risk.

L22	Ensuring that house visits always occur in pairs minimizes risk to project members.

L23	Seek guidance from local community groups on how to present yourself when meeting new people and visiting their homes.

L24	Project members should be trained, not only on the technology that is being installed in the homes, but also how to talk to and engage with the homeowners. Sharing expertise can benefit the whole project.

10.4.2.7 Innovation

Innovation is integral to the LCNI projects, however it is important that innovation is matched with tried and tested methods to ensure that the project can still function if the innovation fails, causes delays or responds unexpectedly. For example in SoLa Bristol the original bid suggested the use of a DCDC convertor; early communications suggested that regulations and supporting documentation would be easy to obtain. However, this was not the case resulting in changes to the technical design. Consequently the project was unforeseeably delayed, not due to technical problems but the bureaucratic regulations surrounding it.

Similarly the ability to connect the SoLa system to the school PV system was evaluated and deemed too time consuming and costly to be worthwhile to the project.

L25	It is important that there is a balance between innovations and existing methods, projects should be careful that they do not become overly complex.

L26	Extra time needs to be included where regulations may need to be amended or guidance sought for the use of existing technology but in new ways.

10.4.2.8 Unanticipated Issues

Changes in government policies surrounding education led to an unexpected impact on the project with a number of the city council primary schools choosing to become academies, as a consequence they severed their ties with the council resulting in a smaller pool of schools to engage with and take part in the project.

Internal restructuring of the Council also led to a reduction in available offices to use as part of the project. This period of unknown led to delays in recruiting the office. Furthermore the office staff were relocated during the project which impacted the ability to monitor the behavioural impact of the project.

A number of tenants moved house during the project, while this is to be expected with a project of this length, this again changed the focus of the social learning.

While all of these issues were unexpected and impacted the project, they are perfect examples of why it is important that projects such as these are conducted in the real world with real people, rather than testing technology in labs.

L27	Outside factors may have an impact on the design of the project, where possible explore how this can provide additional learning and opportunity.

10.4.2.9 Discussion

It is clear from the previous section that the SoLa Bristol has generated a wide range of project management lessons that could be applied to future LCNI projects, and more generally across industry.

A full list of the lessons learnt can be found in this section.

10.5 Previously Reported Lessons

Customer Communication	
Householder (H)	Working with domestic customers
Schools (S)	Working with schools
Corporate (C)	Working with offices
Engagement & Communication (E&C)	Activities that focus on engagement and communication
Project Design	
Project Process (PP)	How to have a smooth running project
Project Management (PM)	Managing the project
Engineering	
Engineering Practice (EP)	Specific engineering learning
Engineering Context (EC)	Ideas to help with engineering (e.g. regulation guidance)
Ofgem	
Ofgem (O)	Of particular interest to Ofgem

		Schools	Domestic	Corporate Engagement	Engagement & Communication	Project Process	Project Management	Engineering Practice	Engineering Context	Ofgem
Learning March 2013										
L1	It can be useful to engage with the public at an early stage, allowing the participants to become part of the project by developing the project identity.		D			PP				
L2	Recruitment on paper may seem easier than in real life due to factors outside of your control. Be prepared and outsource for support if needed.				E&C	PP				
L3	Factors such as weather can impact on workshops and events, it is important to make the events as accessible as possible.				E&C	PP				
L4	It is important to maintain contact with the participants, and to ensure everybody feels involved.				E&C	PP				
L5	Using leaflets can help to disseminate information but it is important to check that people fully understand the project by talking to them.				E&C	PP				
L6	It is important that technical explanations are translated into easy to understand language but make sure it is still correct.				E&C					
L8	Working with participants may highlight things of interest that had not been predicted, for instance viewing energy savings in terms of nappies. If participants are to use a tool it is important that they feel it has value.		D		E&C					
PPR June 2013										
L1	The production of an installation guide helped train the electricians and provide clear details of protocol.						PM		EC	
L2	Pre-surveys save time and allow for the consideration of additional factors such as outside lights, and atypical wiring.					PP		EP		
L3	When working with new equipment, allow additional time for overcoming potential issues.							EP		

L4	Ensure spare equipment is kept easily accessible.						EP		
L5	Where possible pre-program equipment to reduce tasks during the installation						EP		
L6	The FAT must appropriately replicate the environment the equipment is being installed in to provide greater certainty the equipment will perform as intended.						EP	EC	
L7	The use of advanced DC power supplies was not an appropriate equivalent for Solar PV panels.						EP		
L8	The effort and risk in developing a new piece of equipment or modifying an existing piece of equipment should not be under estimated.						EP		
Learning Report December 2014									
L2	Hold recruitment events at different times of the day to ensure a variety of people can attend.	D		E&C					
L3	Once a participant is recruited, the project needs to progress ASAP. Consider delaying recruitment until the start date can definitely be known.	D			PP	PM			
L4	If the project is delayed, then communication about this with the public is vital.			E&C	PP	PM			
L5	Explaining the nature of the issue can help the participants to understand why there is a delay.			E&C					
L7	The safety of the project team is paramount. Ensure there are guidelines in place for visiting customer homes.				PP	PM			O
L9	Customers appreciate communication but are not always forthcoming themselves. Ensure they are contacted periodically to provide their input on the project.			E&C					
L10	Participants need a safe environment where they feel they can ask questions or query issues.			E&C					
L11	The extent to which energy is understood varies considerably across the population. Work closely with your participants - perhaps using members of community to pre-screen literature - to ensure messages are pitched at the right level.			E&C	PP				
L12	Not everybody is interested in energy saving. Finding a way to make it interesting or relevant can help to involve a larger range of householders.			E&C	PP				

L13	User experience is an important part of the project. Focus groups provide an opportunity for householders to discuss queries that they may not deem important enough to ring the project members about.	E&C	PP				
L14	It is important for householders to feel safe when installations are occurring, the use of local trusted workers can help with this.	E&C	PP				
L15	The benefits offered to customers by a research project might not be used - or appreciated - by all of the participants.	E&C					
L17	People might not all be happy with the same in-home display system. Consider options in which the same information can be presented in multiple ways, such as on a dedicated in-home display and on a phone app.	E&C					
L19	During a trial in people's homes, responding quickly to issues is important - as is being aware of extenuating factors which may impact how a householder experiences a disruption.	E&C	PP				
L20	Like with householders, delays between initial recruitment and the project beginning led to school participants withdrawing from the project. Again, consider delaying recruitment in future projects until the start date is almost definite.	E&C	PP	PM			
L27	Always be ready for unexpected changes that may impact how a project progresses.		PP				
L28	Often, those on the ground have a better understanding of the workplace dynamic and can provide greater detail about ideal times for visiting and making changes.	E&C	PP				
L31	Time constraints and financial costs may impact how the project proceeds. Refocusing the project to answer specific questions may make better use of resources whilst still allowing the project's key aims to be met.	E&C	PP				
L32	Using hypothetical data can provide a useful way of exploring novel ideas without excessive cost. However, it is essential to document the process and any assumptions made.		PP			EC	O

L33	New technology does not have all the solutions. Using tried and tested systems for parts of a project that are not meant to be innovative can remove unnecessary risks and allow a project properly to focus on the parts that are intended to be novel.					EC
L34	Ensuring contractors are familiar with the project and are invested in the outcomes can help the process run smoothly.		PP			
L35	In some situations partners need to remember that the project is comprised of people with different expertise and what may seem clear to you, may not be to someone without the same level of technical skills.			PM		
L36	Ensuring that there are clear systems and protocol in place means partners are free to concentrate on their area of expertise.			PM		
L38	Creating a shared open space between partners can help form a trusting relationship.			PM		
L39	Early project meetings should seek explicitly to make clear everybody's expectations and needs, so potential issues can be identified early.			PM		
L40	Different methodologies can be employed for collecting customer feedback. It is unlikely that just one method would be sufficient, as each offers benefits.		PP			
L41	Methods that require time or effort from trial participants may work better at different times of year and in different situations. Consider barriers that might prevent participants from fully engaging.	E&C		PM		
SDRC 9.5 Report 2014						
L1	Regular checking of equipment can provide an opportunity to identify potential issues and amendments to be made.					EC
L2	Early analysis can indicate where settings can be changed to optimise performance.					EC
L3	Changing the charge profile of the batteries can influence the extent to which savings occur. These can be managed to benefit the householders or the grid.					EC
L4	Understanding errors is important. Looking at additional information can help interpret the data					EC

L5	Analysis of the data suggests that the systems charge at two different times.	EP	
L6	The battery state of charge can change more than anticipated.	EP	
L7	Data can be unexpected so it is important to check everything.		EC
L8	As this is a trial the extent to which it can be seen to impact the system may be minimal. It is important to consider this when analysing and extrapolating the results.		EC
L9	It can be hard to manage the granularity of data to ensure you see changes, while ensuring that you are not recording noise.		EC
	Remaining aware of the granularity, amending settings and supplementing with additional data can help us to understand the output data.		EC
L10	Households have varying characteristics; different settings are needed to ensure the battery stays charged in all scenarios.	EP	
L11	When systems are based on estimations it is expected that some houses will fall outside of this range and consequently the systems may fail.		EC
L12	You cannot always rely on data from the houses.		EC
L13	Changing the settings can help to normalise extreme cases.		EC
L14	Outside factors such as the weather can have an impact on the system. Using historic weather data can help with the data analysis.	EP	
L15	If data is collected locally, disruption to the householders should be minimised by copying the data when visiting the householders for other events.		EC
L16	A large amount of data can be generated during these types of project. Automation can help. Care and attention are needed to ensure the files stay correctly labelled and connected to metadata.		EC
L17	It is important to review the data capture and ensure that relevant data is collected. In some cases it may not be possible to collect all forms of data, in these instances a decision needs to be made about the best approach.		EC

L18	Economy 7 houses can provide interesting learning.		EP		
L19	Unexpected inclusion of economy 7 meant that the settings were not appropriate for all the houses in the project		EP		
L20	Seasons may affect how the householders use energy.		EP		
L21	Minimising the impact on the customers is important.			EC	
L22	The impact of the social circumstances of the householders is currently unclear and may provide an insight into the extent that batteries will minimise the PV impact on the network.			EC	
L23	Understanding the householders can be just as important as collecting the meter data for understanding the load on the houses.			EC	O
L24	Houses cannot be expected to perform as well as those based in theory. Reminding householders that the project is research and development can help minimise disappointment and frustration around system changes.			EC	
L25	In some instances system failures may have been due to householder input rather than problems with the settings.		EP		
	Discussions with householders can provide insight into the likelihood of problems being due to payment rather than the system.		EP		
L26	Not all houses will respond in the same way. Each house should be considered on a case by case basis.		EP	EC	
L27	Typical load profiles differ not only between the customers, but also within the customers on a day-by-day basis.		EP		
L28	A staggered install, while time consuming can allow for changes to be made as the systems are installed, minimising the disruption to the householder and making the system more effective.	PM	EP		
L29	Schools use the system differently to houses. Changes need to be made during the holiday period.		EP		
L30	Amending the school settings sometimes had unexpected consequences to the comms system.		EP		

L31	Without context it can be hard to understand why a system fails. Information gathering is an important aspect of troubleshooting.						EP	EC	
L32	It can be useful to visit the substations to understand the logic behind unexpected settings noted in the documentation.						EP		
L33	Do not underestimate the value of real world data. It can provide guidance to theory informed systems and decisions.				PP		EP		O
L34	Consider and plan system updates to minimise disruption to the householders. Hypothesising and trial running can help test settings prior to the live update.				PP		EP		
L35	It is important to continually review the data to see if settings can be refined.							EC	
L36	To prevent disruption to customers it is important to add a failsafe to prevent system failure.							EC	
L37	Tariff design in theory can have many more options than that which can be introduced in reality. Ensure that constraints are discussed and designs include the restrictions to gain the most benefit.							EC	
L38	There can be different ways to collect the same data, it is important to explore options and choose the optimum method for the scenario.				PP			EC	
L39	It is important to test out options and review the responses. Flexibility is key.				PP			EC	
Customer Views Report 2015									
L7	Members of the public given a new technology might find different and unexpected ways to use it. Seek to learn about these to inform future work.	D			PP		EP		
L8	Individual differences may mean the project benefits manifest in different ways. Being responsive to householders may help them change their behaviour to the most benefit for their own personal situation.	D							
L9	Participants can form their own theories and explanations when using unfamiliar technologies. It is important people are provided with accurate and accessible information to ensure they can gain the greatest benefit from the system.	D							O
L10	Householder energy literacy might influence	D							O

	perceptions of new in-home technologies.								
L11	Using existing connections can help with the recruitment of interested participants.	D			PP				
L14	Installation of Solar PV led to a drop in bills for prepayment participants.						EP		O
L15	Taking part in the project led to behaviour changes. Therefore, monetary savings may not be due to the equipment alone.						EP		O
L16	Honesty about delays, and access to the project manager, can make participants more forgiving of delays and foster greater affinity with the project.	D				P M			
L17	The attitude and behaviour of the people who actually work in participants' homes can have a big impact on their perceptions of the whole trial.	D							O
L18	Houses, while similar in design and size, have a number of individual differences; it is vital that houses are assessed individually prior to generic installations.	D			PP		EP		
L19	Providing clear details to the participants about the installation will improve relationships, especially where disruption is likely or the householder will need to clear rooms.	D							
L20	Including test homes in the project provides an opportunity to develop a clear and thorough methodology for future roll out.	D			PP		EP		O
L21	There exists an appetite amongst some householders to engage with new technologies better to understand their energy use	D							O
L22	Do not make assumptions about people's homes. Houses, even when of similar style, age and size, can vary dramatically in their occupancy and use patterns.	D							O
L23	Lighting is the most visible form of electricity and householders have strong opinions on it. It is hard to please everybody with lighting, so flexibility and options are important.	D			PP				O
L24	Householders will invent solutions to their problems. These may not have been anticipated in the original plans, and may have an impact on how true behaviour, or network benefits, match predictions.	D						EC	

L25	Remember that, while the house is part of the project, it is a home to the householder. They will make changes to their homes, which may have an impact upon the wider project.	D				EC	
L26	A non-residential test-bed home is valuable for technical troubleshooting and checks to be made without disrupting householders.	D	PP		EP	EC	
L27	People's perceptions of lighting are variable and subtle. What is perceived to work in one house or room may not be perceived the same way in another.	D			EP		
L28	Because light bulbs are a central way for people to engage with their energy system, responding quickly to breakages will maintain a friendly relationship with householders.	D	PP				
L29	Householders are adaptable. While frustrated by blackouts, they can often see positives in such unexpected events.	D	PP				O
L30	A project does not just rely on project members, but also on wider connections. Providing relevant training and support is vital for a project to run smoothly.		PP	PM			
L31	Any trial run in people's homes will inevitably overlap with other activities. Wider project awareness, and providing information channels, helps when issues arise.	D	PP	PM			
L32	Installing local storage in people's homes did not lead to householders noticing a salient financial saving.				EP		O
L33	Many prepayment householders do not change their financial behaviour in response to a household energy reduction and continue to add the same amount to the meter.	D					O
L34	Householders will respond differently to changes in energy costs. Some will use it as an opportunity immediately to divert money elsewhere while others will use their prepayment meters as a method of saving money.	D					O
L35	Houses with direct debits were less connected to the financial costs of energy. They are unable to report the costs associated with their actions, or if they saw a difference in consumption from a change in the home.	D				EC	O

L36	Behaviours such as laundry are incredibly variable from one home to another. These differences are not always predictable and can have a fundamental effect on consumption and the experience of energy.	D						EC	
L37	Laundry habits may provide a useful focal point for future research if this was to be extended beyond supporting the lighting system.	D						EC	O
L38	The people who consume the most energy in laundry might be the group who would need the most support to change the time of their consumption.	D						EC	
L39	Householders are interested in, and engaged by, displays showing savings and details relating to money.	D							O
L40	Providing an in-home display works for some people, but others prefer to access the same information through their phones. People unfamiliar with mobile devices might need particular support to learn in-home displays.	D					EP		O
L41	USB sockets are widely used by householders when these are provided. These were most useful when located in a central area of the house.	D					EP		
L42	Not everyone will change behaviour and make use of new tools. This information should be included in future scenario modeling, as we cannot expect householders to behave in a 'logical' manner.	D						EC	
L43	Asking the householders where equipment such as USB sockets should be located will increase the likelihood of the householders using them.	D						EC	
L44	Until people have experienced new household equipment, their guesses about where they need it located might be wrong. Seek to inform householders about other householder's successes and problems with equipment placement.	D			PP			EC	
L45	It is important that power outages are reported so that the circumstances surrounding them can be fully understood.	D					EP		
L46	Families are generally resilient and able to adapt to temporary problems like lack of lighting.	D							
L47	Having the lights stay on during a power outage is reported as being beneficial.	D						EC	

L48	There appears to be an appetite for a system that keeps non-lighting appliances on during an outage, but homes vary in which appliance(s) they would wish to maintain.	D			EC	O
L49	Householders are willing to change their behaviour if it made successfully coping with a power outage more likely.	D			EC	O
L50	Householders in cities are often unfamiliar with power cuts and often are not prepared for them.	D				O
L51	If forewarned, householders are understanding of power cuts and able to adapt.	D			EC	O
L52	Seasonal timing of equipment installation or decommissioning may mask any changes in financial cost.	D		PP		
L53	Although not all will take advantage, householders might be better engaged with a project if there are opportunities to meet with other project participants and learn more about the project.	D				
L54	Movements towards more flexible working mean it may be more appropriate to engineer static factors such as lighting for low-carbon, rather than equipment.		C		EC	O
L55	Decision makers who provide access to a workplace for a trial are probably not the people who engage with the trial day to day. The motivations of the two groups will differ and end-users' behaviour might not be as anticipated.		C		EC	
L56	Frustrations from other project delays may overflow into current projects, creating frustration that must be managed.		C	PP		
L58	Offices are dynamic and change depending on who is within them; projects need to be adaptable and considerate of these changes.		C	PP		
L59	Future trials in corporate settings would benefit from collaborating with staff early to create links between decision makers and end users.		C	PP		
L61	Although open-plan office lighting is inevitably shared, lighting is a subjective experience and unlikely to be viewed in the same way by all office staff.		C		EC	
L62	Office workers dislike any lack of control over lighting.		C			

L63	Workers in open-plan offices are unlikely to be happy with any single lighting outcome.		C			
L64	Office workers are likely to be more accepting of a lighting system if it is there when they first arrive in an office than if the same system is later installed.		C			
L65	Consultation about work requirements can help those affected by a workplace trial feel more involved.		C			
L66	Despite widespread dissatisfaction with their environment, people in a shared workplace might make no attempt to institute even simple changes.		C			
L67	Workplace technology trials should recognize the fundamental difference between those who make workplace decisions and those who are affected by them.		C	PP		
L68	When contacting a corporate body about trials, being clear about project requirements helps all required people be included from the outset.		C	PP		
L69	Bodies such as schools require more advance notice than most businesses to get all the appropriate people to attend a meeting.	S		PP		
L70	When dealing with schools in trials, follow up meetings with written confirmation of decisions rather than relying on informal memory.	S		PP		
L71	To include schools in trials, it is necessary to generate school-specific literature rather than repurpose recruitment literature from other groups.	S		PP		
L72	Using a single point of contact when dealing with schools helps create a clear line of communication and minimises confusion.	S		PP		
L73	When coordinating contractors on school projects, a degree of autonomy should be provided to enable contractors to contact the schools directly.	S		PP		
L74	Schools, perhaps even more than householders, vary tremendously and will probably need a bespoke system in any trial.	S		PP	EC	
L75	When working with schools, remember their primary focus is to educate. Providing additional support in this area may make a school more inclined to take part.	S		PP		O

L76	Schools may have different motivations for taking part in the project, and recruitment strategies may need to reflect these variations – for instance, by promoting multiple benefits from involvement.	S				PP				
L77	Energy literacy could be a key area for the future; inclusion of real project data can help schools gain more value from a project such as this.	S								O
L78	Teachers are open to additional support for teaching electricity, collaborating closely with teachers may help the development of suitable resources.	S								

Table 26- All project learning

SECTION 11

Future Works

11.1 Next Areas of research

This section reflects on what has been learnt and what some suggested next steps could be. In some instances we are already discussing how some of these could be taken forward.

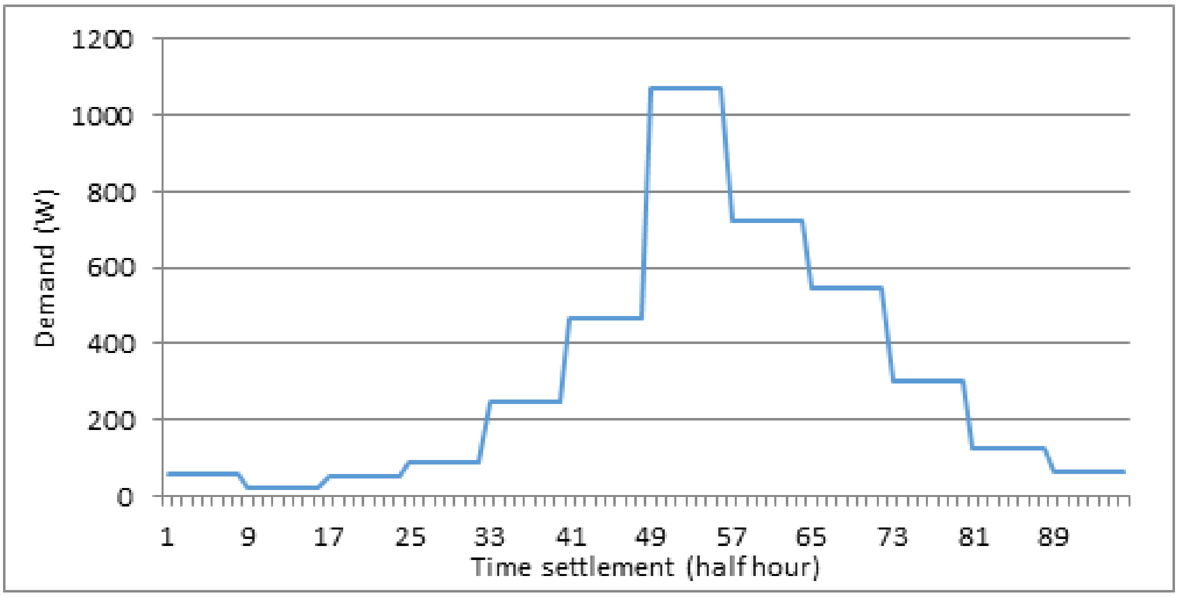
11.1.1 Load Profiles and EMS

In the project, the in-home battery was controlled by EMS strategy designed by Siemens to provide demand shifting capability. The strategy was a logic-based control triggered by real-time measured parameters, including PV output, demand and tariff rate. For the engaged 26 domestic customers, the basic strategy settings were identical. Only small adjustments were implemented for specific customers for reliability and safety reasons. However, according to the results from TOU benefit section, the customers' bill savings were different particularly when their demand patterns were extremely different. This result suggests that the EMS strategies could be designed individually for each type of customers, such as, normal homes, high load properties and Economy 7 homes and even for specific customers.

The measured data of domestic customers in SoLa Bristol shows that there is high uncertainty in domestic customers' demand. The major challenge for an EMS design for a domestic customer is the volatility of load profiles. One of the most effective methods to eliminate the volatility and noise is transferring the household demand into frequency domain. Figure 97 and 98 represents the de-noised load profiles of a high daily demand home and a normal demand home.

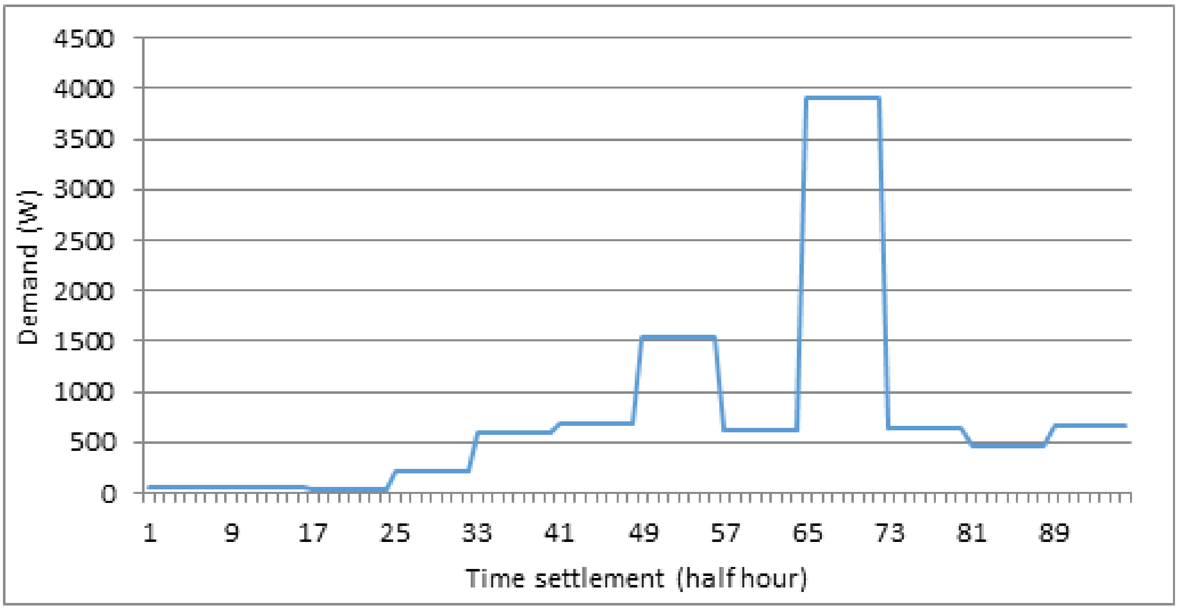
As demonstrated, the de-noised data, which is the stable component in uncertain demand, reserves the general pattern of original load profile and thus keep the majority of information in load profiles. The future research will use these stable components of customers' demand in the EMS design.

Figure 97: De-noised load profile of a high daily demand home



Source: Project Team

Figure 98: De-noised load profile of a normal demand home



Source: Project Team

L105	EMS strategies should be designed individually for each types of customers, such as, normal homes, high load properties and economy 7 homes and even for specific customers

11.2 Post Project developments

The majority of trial equipment is now housed at the Department of Electronic & Electrical Engineering, University of Bath. They will provide a unique platform for teaching, research and collaboration, forming the core part of the university's strategic direction in smart grids, particularly for developing new methods of connecting high density low carbon technologies to the existing network through energy shifting over time and space.

The key plan for this equipment is to reconfigure them into a laboratory hardware-in-the-loop platform to study and research into the interplays between consumers, technologies and the grid. This will allow the following smart grid related teaching, research and collaborative activities to be conducted which is otherwise not possible:

11.2.1 Teaching

For Undergraduates and MSc students to understand the key elements in Smart Grids and the challenges and opportunities in system design and integration between energy, power, electronics and communications.

Some of the learnings and innovations that students could develop from the platform are:

1. Local DC network configuration and alternative energy management system strategies to increase renewable uptakes and utilisation, reduce network congestion, and enhance supply security during interruptions
2. Increasing energy efficiencies for supplying DC demand from local DC system and onsite PV instead of inefficient AC/DC conversions,
3. Tariffs designs for mobilising consumer demand reduction and shifting, reducing consumer energy bills, changing energy behaviour, and minimising the impact to the grid constraints,
4. Big data processing to detect features and threats for consumes and the grids, develop innovative technical and commercial solutions to minimise the impact to the grid from customer/communities' low carbon technologies.

Each component in the system can be designed as an individual project for our BEng, MEng and MSc students.

11.2.2 Research

The platform essentially act as an Emulator and a Demonstrator for modelling the effects of low carbon technologies on networks (power and voltage), developing and testing new strategies for demand side responses (DSR), developing and testing new methods for uncertainty quantification and mitigation of PVs and loads, and emulating the impact to the ecosystem of consumers, communities and the supply network.

This enables new research into:

- Assessing new threats to the system as a result of low carbon deployment at customer, community premises from a combination of grid monitoring and smart metering.
- Developing energy management system (demand side response strategies) and local DC networks under different network conditions and for differing customer energy behaviour and low carbon technologies.
- Developing local energy markets, tariff structure, and business models for the existing and new energy service providers.
- Impact assessment to customer, communities and the grid from introducing new technologies, energy management systems, new market arrangements, new tariff structure, new business model, and their combinations.

11.2.3 Collaboration

There is virtually no such real-world equipment available in a University setting. In particular, this equipment has been tried and tested in practice and with significant data being collected since 2012. The set-up of hardware-in-the-loop platform can closely emulate a practical setting, and become a trusted development and testing facility for academics and industry alike.

This platform will help Bath to further our collaboration with the industry, ensure the learning from SoLa Bristol trial is embedded within the university platform. Critically, this will ensure that the innovation from the University environment can be directly used in practice.

The platform will act as a vehicle for further academic collaboration; it provides the facilities to test effects to the grids and customers from partners' cutting edge developments. This will improve our external visibility and strengthen our collaborations with national and international leading researchers, particularly through joint publications and grants.

11.2.3.1 Commercial System

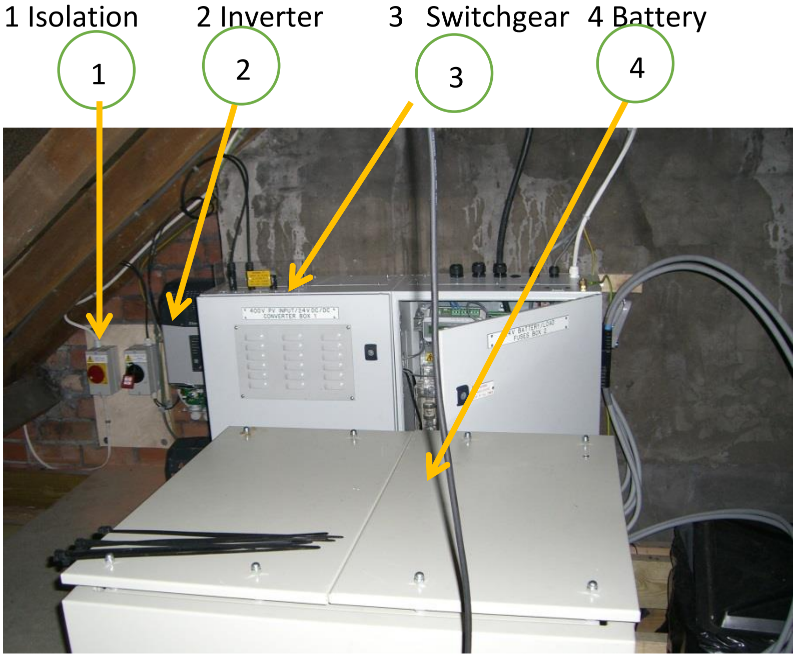
A typical these 3 Phase energy storage system (10kW) is shown in Fig below. It imports/exports ac and saves/delivers DC power to the DC microgrid supporting DC lighting and DC-PCs. These have integrated Metering and GSM/WiFi communications capability. There are no connection points for PV array within this system.

11.2.3.2 School Installation

These units are designed for outdoor installation, comprising of Battery storage (22kWh, 24V, 940Ah) left cabinet and Inverter/chargers in the right cabinet.

The domestic system as installed onsite is shown below. Physically this is to be located within the Lab, as it is not weather proof for outdoor installation. The system comprises of five units which are shown in Figure below.

1 Isolation 2 Inverter 3 Switchgear 4 Battery 5 Consumer Unit



Domestic Loft installation

Hallway installation

In the Lab a combination of floor and wall mountings would require (WxDxH) 1Mtr x 1 Mtr x 1.5Mtr per student station. It is proposed that two student stations are equipped within the Lab. This is to encourage competition amongst students to achieve comparative performance.

11.2.3.3 Sub-Station System

These were self-contained units requiring 1Mtr x 1Mtr x 300cm space (and can be seen in Figure 8 and 9 earlier in this report). These are wall mountable within building. These units also have Communication capability using GSM/LAN/RS232. Proposed usage is through simulated power and power quality (Sensor simulation emulating grid behaviour).

11.3 Areas for development

11.3.1 Regulation change

11.3.1.1 Time of use tariff

In the UK, the benefit for customers adopting low carbon technologies is shrinking in the current commercial framework. The customers' PV subsidies will significantly reduce from the 1 January 2016 and may keep reducing in the future. The Department of Energy and Climate Change (DECC) proposed a new Feed-in-Tariff (FIT) rate with an 87% reduction for solar PV installations. Therefore, there is less financial incentive for customers to take part in renewable deployments.

Additionally, there is little incentive from the market for domestic customers to shift energy over time. Domestic customers are deemed to be too small to access the wholesale energy market, and their electricity tariff is pre-determined into two categories: 1) Standard Electricity, i.e. flat rate electricity, which is adopted by 86% of domestic customers; 2) Economy 7 tariff, if customers use electricity to heat the electric storage heaters or hot water tanks for space and water heating. Therefore, if customers have battery storage, they cannot take advantage from shifting energy over time.

Therefore, as shown in the SoLa Bristol project, opening the energy market to customers and introducing a new pricing scheme, such as Time of Use Tariff (TOU tariff), is important for not only customers but also DNOs to take advantage of opportunities afforded by the increased take up of low carbon technologies. For customers, the TOU tariff could provide benefit if they shift the energy usage from peak price time to trough price time or high PV output time. For DNOs, the customers' energy behaviour change brought by TOU tariff through different locations and over time could mitigate the adverse impact of PV connection and reduce network peak demand and defer network investment. This is a key commercial instrument for renewable generation to stay competitive in a subsidy-free environment.

11.3.1.2 Ownership of the battery storage

The SoLa Bristol tested a new ownership strategy for battery storage – joint ownership between customers and DNOs. The result proved that with the battery storage, DNOs could access additional support where there is network congestion. In the future, DNOs may not be the best and only party to own a battery. The emerging third parties, such as Energy Service Company, could provide new opportunities to balance the benefit of both DNOs and customers.

Future scenarios might be: 1) Customers own the ownership of battery solely; 2) DNO and customers share the ownership of battery storage; 3) Third parties and customers can share the ownership of battery storage; 4) Third parties owners the battery entirely . Table 27 shows the comparison of the three scenarios in terms of cost to the customers, risk for network support, and financial benefit to customer and other parties.

Ownership	Cost to customers	Risk for network support	Operation complexity	Financial benefit to customer and other parties
Customers	High	High	Low	High to customers Uncertain to other parties
DNOs and customers	Low/medium	Low	Medium	Medium to customers High to DNOs
TPIs and customers	Low/medium	Medium	High	Medium/high to customers High to third parties High to DNOs

Table 27: Comparison of the 3 scenarios

As shown in the table, each scenario has its advantages and disadvantages.

- Customer owns the battery

Advantages: high financial benefit to customers; the operation of battery is easy;

Disadvantages: high cost to customers; capability to support network is not tapped for the benefit for DNO, and ultimately to customers; high risk that the operation of battery worsen network condition if the battery charges at network peak demand time.

- DNO and customers shared ownership

Advantages: reduced the cost to customers; guaranteed the battery capability to support network and high financial benefit to DNOs;

Disadvantages: lower financial benefit to customers; needs of advanced communication and implementation devices for battery operation between customer and DNO.

- Third parties and customers shared ownership

Advantages: reduced the cost to customers; guaranteed the battery capability to support network; balanced financial benefit to both customers and DNOs;

Disadvantages: needs of new regulation and operation mechanism to third parties; needs of advanced communication and implementation devices for battery operation between customer, third parties and DNO.

11.3.2 Scaling it up

The immediate focus for a DNO is network investment deferral, however, considering future scenarios, where high levels of PV and storage systems become integral part of the distribution network, factors such as quality and security of supply become equally important factors.

Additionally, benefits to the consumer and the environment hold as true, though not directly a DNO's benefit, it does impact on corporate social responsibility of a DNO.

In view of emerging specifications and codes of practices, equipment vendors need to provide effort for seamless interworking, for their respective equipment located at the Sub-station and the User Premises. This is a progressive task and is expected to be an ongoing one.

11.3.2.1 The network investment deferral in different network utilisation levels

The trial network was lightly utilised with peak demand accounting for only 42% of its capacity. In the lightly utilised network, the demand reduction and shifting in SoLa Bristol could only bring minor investment deferral. However, when the network is heavily utilised, the network investment deferral was significant. It was assumed that the average output power from single battery to network was 0.3kW. Table 28 shows the network investment deferral if the SoLa Bristol solution was used in an 85% utilised network. The deferred year is inversely proportional to the network utilisation.

As can be seen from the table a number of key findings are:

- The EMS system of 11 houses at a substation can defer transformer investment for four months. With the penetration of EMS increased to 30% and 50%, the deferral will be 2 years and 3.2 years respectively.
- The EMS system of 3 houses at feeder 1 can defer feeder investment for one month. With the penetration of EMS increased to 30% and 50%, the deferral will be 2 years and 3.3 years respectively.
- The EMS systems of 8 houses at feeder 2 can defer network investment for four months. With the penetration of EMS increased to 30% and 50%, the deferral will be 2 years and 3.4 years respectively.

	Current penetration (4.3%)	30% penetration	50% penetration
Transformer	£277.2	£1756.5	£2864
Feeder 1	£61.9	£1951.8	£3224
Feeder 2	£620.5	£2842	£4743.9
Total	**£959.6**	**£6550.3**	**£10831.9**

Table 28: Network investment deferral

SECTION 12

Conclusions

The main conclusions from the SoLa Bristol project are as follows:

- Smart tariff- As mentioned previously there are positives and negatives to tariffing we found. This is of course a supplier area for more detailed consideration. However, there are some customers for whom it is very clearly of benefit as their behaviour can be influenced through pricing.
- DC Network- Reaction to the light output from the DC LED lights was very subjective, with some participants liking them and others not. Advances in this technology since the project outset have been considerable, and further studies into the effect of these could be useful. The real advantage is during a power outage, with all customers realising the benefit of 'keeping the lights on'. One of the key unexpected learnings is that, as a large number of the participants were on a prepayment key meter, when the credit ran out they still had the DC lighting and USB facilities from the battery.
- Storage- whilst the storage devices worked and worked broadly in line with expectation we feel that there is some work to do to make this kind of mode of market operation successful and attractive to DNOs. There are of course some installation related limitations to this type of solution which of course further impacts on any potential large scale installation programme. More work needs to be done to explore how technological advances could be brought to this particular solution for more wide scale use. On the customer side there is a real link between the customer demand profile and the benefit of the storage device. If the load during the day is constantly high, then the charge in the battery at peak evening time is low. Consequently this does not allow the ability to discharge, to maximise the use of the ToU tariff. In the worst case, if the State of Charge is very low, failsafes will be instigated to force charge at peak times. The concern is that if this type of solution is to be rolled out, then installation companies need to fully understand their customers demand and lifestyle profiles in order to maximise the benefits. One point to consider is that a choice between financial benefit and the power outage back-up needs to be considered, as to have both at all times of the day is not possible. To maximise the financial benefit you must at times discharge the battery to quite a low State of Charge. At this time outage back up would not be possible.
- Customer feedback – there is plenty of evidence within this report that shows that the key to these projects is efficient and ongoing stakeholder engagement. As is always the case you learn this through trial and error. Projects and initiatives such as these have to be predicated on clear benefit as well. Currently we are of the view that the benefits of this project don't rest, in the main, with DNOs but could do with Suppliers and perhaps communities.

Future Work- as can be seen with this report there are a number of key areas where we feel further work and analysis could be undertaken. We intend to explore these further over the coming months to see how the learning from SoLa Bristol can be exploited further.

We do feel that further work between the Regulator, DNO's and Suppliers is key to moving this particular project further forward. To this aim, WPD are actively involved with the IET in a working group looking at Energy storage in domestic properties.

They have also contributed to the IET Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings, published in 2015.

Appendices

A Publications

Customer Views report

Customer Views Report.pdf

Gallomanor Report

Electricity-Distribution-Debate-Kit-PDF.pdf

Electricity-DK-Evaluation-FINAL.pdf

SoLa Bristol – Decipher my Data Ca

Western Power Distribution (East Midlands) plc
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Western Power Distribution (West Midlands) plc
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Western Power Distribution (South West) plc
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