SOLAR STREETS

Final Report
June 2021

Bath & West Community Energy
Generating local energy

Acknowledgements

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Other key contractors, Moixa and TH White played vitally important roles in project delivery in supplying and installing solar PV and battery storage systems across the 16 households.

Finally, a big thank you to all the project participants across Maple Grove and Bloomfield Avenue in Bath for their involvement, their patience as the project unfolded in a way that wasn't quite as planned and their commitment to supporting our transition towards net zero.

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1 Executive Summary

Headline Findings

1. The Solar Streets project demonstrated the potential for householders to shift up to 20% of their electricity demand away from peak times of the day, during the evenings and first thing in the morning.
2. However, the capital costs of the solar PV and battery installations will need to fall by over a third in order to make it viable for BWCE to roll the project out beyond the initial grant funded pilot.

The Solar Streets project examined the role of community action in delivering domestic solar PV and battery storage and promoting ways of reducing electricity use during times of peak demand. This kind of response by household consumers will be critical to our ability to utilise very high levels of intermittent renewable electricity on our grid as well as reducing our reliance in the short term on fossil fuel peak generating plant and the need for some (but not all) expensive grid upgrades.

A feasibility study tested the economic, technical, regulatory and social conditions within which community models for generating local value within electricity markets might be viable. This study was undertaken by Carbon Coop and has reported separately[1].

This feasibility study was used to underpin a practical pilot, designed to test the degree to which a collective community approach can be successful in encouraging electricity demand management at a neighbourhood level. The pilot integrated the use of domestic solar PV, battery storage and a simulated Time of Use electricity tariff (ToUT).

The pilot was enabled with grant funding from the Friends Provident Foundation and Power to Change and was part of the Western Power Distribution, Open LV programme[2]. Through the Open LV programme, collective electricity demand was monitored at the substation level and was displayed via a software app that was made available to households, alongside data from local solar PV systems and battery storage. Substation data was broken down by separate feeders enabling the pilot to target two streets in particular.

The provision of data at neighbourhood level was used to encourage a collective rather than just an individual response to electricity demand via community engagement, a series of one off 'How Low Can You Go' (HLCYG) days and a short demand shifting campaign. This campaign also tested different approaches to optimising battery operation, including maximising PV storage and simulating a Time of Use Tariff (ToUT).

The Solar Streets pilot was designed to identify the role and added value that community energy can offer in promoting demand management. In particular the pilot considered the impact of increasing the use of domestic solar PV, battery storage and demand management and the viability of potential business models that might support community energy groups to engage in this area of activity.

[1] Bath and West Solar Streets Feasibility Study, Carbon Co-op, August 2018, Aylott, Atkinson, Melville
[2] See https://openlv.net for more information

1.1 Summary of key results and conclusions

1. 20% of households in the target neighbourhood were enabled to install battery storage, either in conjunction with new solar PV or alongside existing solar PV systems.
2. Recognising the pilot was located in an area with known interest and was only able to carry out focussed short term interventions, the pilot demonstrated an ability to:
   - increase energy awareness;
   - encourage up to 16% demand reduction during one off days;
   - encourage up to 6% demand reduction during short extended campaigns;
   - encourage up to 20% peak demand reduction during short extended campaigns;
   - demonstrated the efficacy of text messaging as a prompt for action.
3. These results suggest that behavioural approaches to demand shifting can be effective. However, the pilot has been unable as yet to test whether any of these behaviours have been embedded and will last the test of time.
4. Given householders referred to the value of being involved in a specific project as a highly motivating factor, action may well drop away when the project is no longer active.
5. This raises the importance of automating demand response where possible and appropriate. Though this in turn raises the question as to how to retain a level of consumer control necessary to build trust, consent and participation.
6. Nearly as many participants referenced factors relating to collective action, as referenced saving money as a strong motivation to take action. This does in part reflect the demographics of the area; however, it does also illustrate the appetite for collective action at a community level.
7. The pilot flags a danger that, given weather forecasts are never 100% accurate, optimising battery charging to follow cheaper tariffs can increase carbon emissions associated with the host property by charging batteries from the grid when in fact they could have been charged by on-site solar.
8. The replication/roll out of this project within a community energy model is not currently viable following the close of the Feed in Tariff and the current high cost of domestic battery storage in particular.
9. Capital costs will need to fall by over a third to a half for a combined solar/battery system, and income from flexibility markets increase by a factor of somewhere between 2 and 10, before either community ownership of assets or wide scale take up by householders becomes financially attractive or sustainable.
10. From a community energy perspective, additional issues such as simplifying complex contractual relationships, reducing transaction costs and enabling smart technology to automatically control <u>some</u> aspects of demand shifting, will underpin viable delivery models.
11. The experience and knowledge gained from this project has directly led to BWCE securing new funding from Power to Change and the EU to develop a community led demand side response programme that promotes smart technology, through a partnership with Stemy Energy, rather than relying purely on behaviour change.

1.2 Recommendations – government/regulators/wider energy sector

12. Promote the importance of demand shifting via government and the energy industry – with a particular focus on carbon reduction as well as financial benefit.

13. Support local intermediaries, like community energy groups, to create a neighbourhood focus that can increase awareness and build motivation to act on demand side response by demonstrating that 'people like me' are taking action
14. Utilise innovation funds to proactively seek local community partners to test and further demonstrate value through increased take up and small consumer engagement with demand side response.
15. Create flexibility markets that value carbon reduction, not just the avoided cost of network upgrades, as well as the higher transaction costs involved in engaging and retaining small consumer demand side response.
16. Create flexibility markets that are simple enough to engage and retain small consumer buy in and that retain levels of consumer control around the level and timing of flexibility offered in order to avoid consumer override of automated systems.
17. Provide long term subsidy schemes to support the electrification of heating and transport and deliver whole house retrofit to reduce heat loss and increase affordable warmth.

1.3 Recommendations – community energy sector

18. Household behaviour can be a powerful mechanism for driving change, but long term, consistent shifts in demand are likely to require some level of automation to embed change.
19. Given the importance of control to community energy, ensuring that automation is implemented in a way that empowers rather than disempowers could be a key strength of a community aggregation offer.
20. When designing community projects, care needs to be taken around ensuring that supply chains are as secure and strong as possible before engaging potential participants. Enthusiasm generated and lost due to project delays is difficult to regain.
21. Consumer motivations in this area are complex. It may be helpful to build in market research and audience targeting into project design and delivery that focuses on consumer openness to change, e.g. pioneer, early adopter etc as well as environmental and social motivations and technical and logistical constraints.
22. Recognise the barriers to engaging with demand side response faced by low income and vulnerable households and look to mitigate where possible, for example by working with social housing providers as intermediaries.

1.4 Recommendations – further research

23. Further research could help develop understanding with regards to:
    - the impact of solar ownership on motivations for shifting demand. In particular, whether community ownership of local solar PV systems has a similar impact on household demand as indicated by some research on individual ownership of household solar PV;
    - develop an effective and practical hierarchy that maximises demand shifting before battery storage at a domestic level in order to minimise resource impacts of the currently predominant Lithium ion battery storage technology;
    - how to engage low income and vulnerable households in demand side response.

2 Introduction

The Solar Streets pilot was a local community energy initiative running across Maple Grove and the south side of Bloomfield Avenue in Bath and was managed by Bath & West Community Energy, (BWCE).

Peak electricity demand, usually between 4-8pm for domestic consumers, places the greatest stress on the electricity grid and requires the most expensive and carbon intensive electricity generation to satisfy. There is also a significant mismatch between the time of generation from renewable sources like solar and the time of this peak demand, undermining the UK's ability to significantly roll out renewables further. Reducing peak demand will therefore:

1. reduce carbon emissions;
2. reduce the cost of supplying electricity;
3. make it easier to increase the proportion of our electricity that can come from intermittent renewable energy sources in the future.

The issues associated with meeting peak demand will be exacerbated as reliance on centralised power generation is reduced, and we see an increasing contribution from small scale intermittent renewables together with growing electricity demand, through the uptake of electric vehicles, for example.

The electricity market is also rapidly changing with an increasing emphasis on engaging domestic consumers in trying to make the grid smarter, more flexible and more efficient.

Combined, these factors could make the role of community energy groups more important as the focus shifts to looking at localised energy markets to supply 'grid services', such as storage and altering demand patterns to provide flexibility to grid operators.

Active community energy groups could be well-placed to draw domestic consumers wary of new technology, smart control and sharing data into new markets by building on the trust and credibility earnt through local presence, governance and accountability.

However, community energy groups need effective and financially sustainable business models to deliver a household level response to localised grid services.

The Solar Streets pilot tested the conditions within which financially viable community models might be available to address the issues outlined above, in two key areas:

1. community ownership of assets such as domestic solar PV and battery storage; and,
2. community engagement and collective action around electricity demand management.

Community ownership will enable the pilot to deliver local benefits through recycling surpluses locally as well as testing the ability to optimise system use to benefit local needs such as minimising peak demand, rather than only benefiting individual households through reduced electricity bills.

The pilot assessed what any future roll out would need to be able to achieve in order to operate without grant aid.

Key outcomes for the project as a whole included:

1. identification of the role and added value that community energy can offer in delivering domestic solar PV and storage and in local electricity markets more widely;
2. development of the potential business strategies open to BWCE and other community energy groups to engage in this area of activity;
3. increasing the use of domestic solar PV, battery storage and demand management in participating households within the pilot area.

3 Carbon Coop Feasibility Study Outcome

This feasibility study[3] evaluated the technical and market viability of solar PV plus battery storage systems to be deployed as part of the Solar Streets pilot. This evaluation helped BWCE refine its approach to offering solar PV plus battery storage within this pilot.

Carbon Coop developed three different 'use case', scenarios that map directly on to different income streams:

1. self-consumption – enabling the householder to maximise benefit from solar PV generated on their roof both in terms of cost saving and carbon saving;
2. maximising community benefit via community aggregation with local balancing tariff – effectively 'moving the meter' from an individual home scale to the sub-station;
3. maximising income from the sale of local flexibility to grid energy system actors such as Western Power Distribution (WPD).

Although self-consumption can be delivered under current market conditions, collective balancing is not possible due to regulatory barriers and markets for local flexibility are still in development. The study undertook further modelling to understand the conditions for viability under these different use cases. This modelling confirmed that the battery costs in particular are still too high to deliver market viability under current conditions for the installation of solar PV and battery storage.

The study also compared five different brands of battery, four of which, Tesla, Moixa, Powervault and Sonnen have consumer friendly offerings whilst the fifth, LG Chem RESU battery with a Victron inverter, is a more bespoke option. The resulting analysis compared:

1. value for money in terms of the battery's raw cost per kWh;
2. interoperability for use in grid programmes;
3. capacity (kWh) and low power input/output (kW);
4. dimensions and possible household installation location;
5. ease of procurement and required level of liaison with installers.

On completion in August 2018, the feasibility study enabled BWCE to target potential battery manufacturers and prepare an effective ITT and procurement process. BWCE received 3 quotes from Sonnen, Powervault and Moixa. Moixa was selected on the basis of the quality of their

[3] Bath and West Solar Streets Feasibility Study, Carbon Co-op, August 2018, Aylott, Atkinson, Melville

response, price, the quality of the data portal accessible by householders and at a community level (by BWCE) and their plans around grid services. Moixa also provided a combined solar and battery supply offer which was preferable, providing one point of contact.

The feasibility study findings also shaped how BWCE recruited householders to the Solar Streets project with a major focus on use case 1 above, maximising self-consumption. The regulatory barriers prevented the full exploration of use-case scenario 2 above as part of the pilot.

Whilst the pilot did not directly engage with WPD's local flexibility market and so couldn't offer income from shifting demand, (use case 3 above), the battery provider Moixa committed to providing £50 per year, per battery. Whilst this offers some income, it is limited and not linked to performance.

Importantly however, the pilot did test the appetite of domestic consumers to consider demand management and reducing peak demand. This interest would create fertile ground in which to operate a more automated approach to demand side response that could generate income through entering local flexibility markets.

4 Partner Selection for the Pilot: PV Installers and Battery Providers

The original solar PV installer, contracted by Moixa as part of their response to our tender, was for various reasons replaced by TH White, a local contractor BWCE has worked with before.

This created some delays, as we had to repeat some of the surveys before we could confirm the involvement of individual householders. Following new roof surveys for PV installations, revised installation plans and costs were submitted by TH White and approved by BWCE. It was the intention for as many of the PV installations to be registered for the Feed-in Tariff (FIT) before the scheme closed on the 31st March 2019. However, only four installations were completed in accordance with FIT eligibility requirements. This was partly due to the requirements to undertake a second survey by the appointed installer TH White, but also because of the lengthy process involved in obtaining mortgage lender approval for the lease of the roof space to allow BWCE to install the PV array where a mortgage was outstanding.

5 Substation Data and Use of Software

The monitoring equipment was installed in the sub-stations in August 2018. However, identifying the feeders to monitor was not straightforward. Initially BWCE had selected 2 feeders to focus on, that covered Maple Grove and the south side of Bloomfield Avenue. This was around 80 households in total, plus a pub. When WPD were installing the monitoring equipment it became clear that one of the feeders had been changed to also include 25 additional properties (in Elm Place) that were in fact listed, so not easy to install solar on, plus several additional fairly large commercial properties.

The two feeders in the area therefore covered the following:

- Maple Grove – this includes all of Maple Grove plus numbers 62 to 82 Bloomfield Avenue.

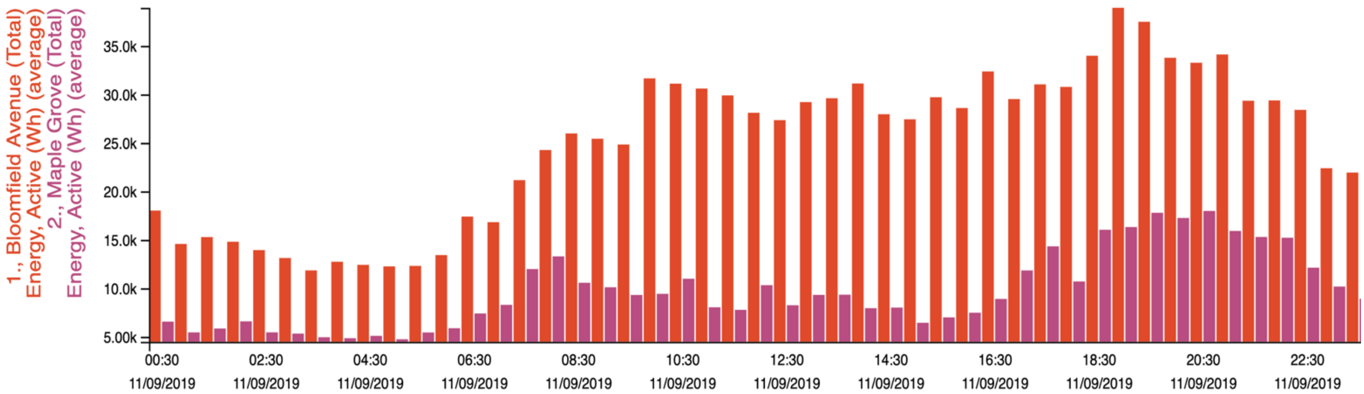
- Bloomfield Avenue – this includes 1 to 32 Bloomfield Avenue plus 1 to 54 Elm Place (many of which are listed) and three commercial properties on Wellsway.

The pilot benefited from two software portals designed to analyse data from the local neighbourhood via WPD's monitoring equipment and data from just the solar and battery systems via a portal provided by Moixa.

5.1 Neighbourhood Portal

The Centre for Sustainable Energy worked with WPD as part of the wider Open LV programme to develop a software portal that would enable Open LV participants to access data about electricity demand at the sub-station level and disaggregated by individual feeders, as illustrated in Figure 1.

Figure 1: Total Electricity Demand at the Substation (Wh) During Typical Day



The demand profiles illustrate the significantly higher 24 hour profile on the Bloomfield Avenue feeder that reflects the additional commercial properties that obscure the domestic consumption. The Maple Grove feeder provides an easier focus with demand related purely to Maple Grove and a few houses on Bloomfield Avenue.

This information was very helpful in focussing residents minds on the impact of electricity demand in their neighbourhood. The data also enabled us to monitor the impact of collective actions on local demand. Though this was more effective for residents connected to the Maple Grove feeder.

Problems with consistent access to the data also curtailed some of the community actions planned and reduced the scale of data analysis that was possible; Covid-19 prevented engineers from accessing the sub-stations to repair or update the technology to improve data collection.

5.2 Solar and Battery Data Portal

As part of the pilot, Moixa gave access to BWCE to their GridShare Portal to see the performance of the solar/battery systems in real time, either by feeder or collectively. Figures 2 – 4 below show the screen shots from the Moixa dashboard, with Figure 2 showing the live power flow between the household, their battery and the grid; whilst Figure 3 shows the power flow across a 24-hour period; and, Figure 4 shows the sources of, and the destinations for, the power flows between the PV, battery, grid and household consumption.

Figure 2: Moixa Dashboard: Live Power Flow

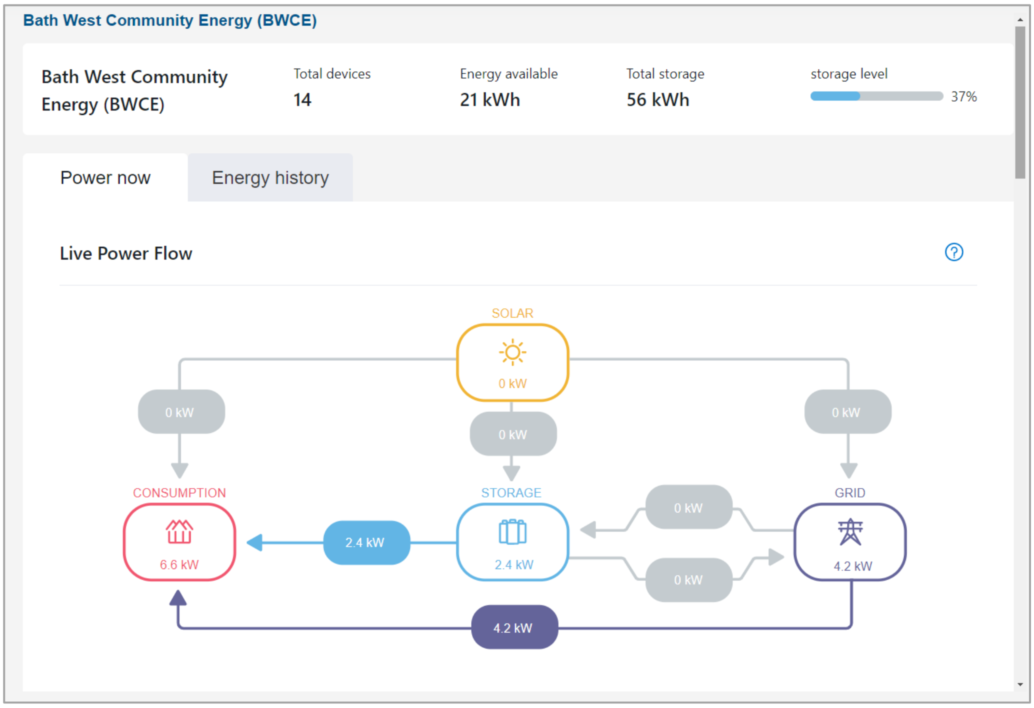


Figure 3: Moixa Dashboard: Power Flow Across a 24 Hour Period

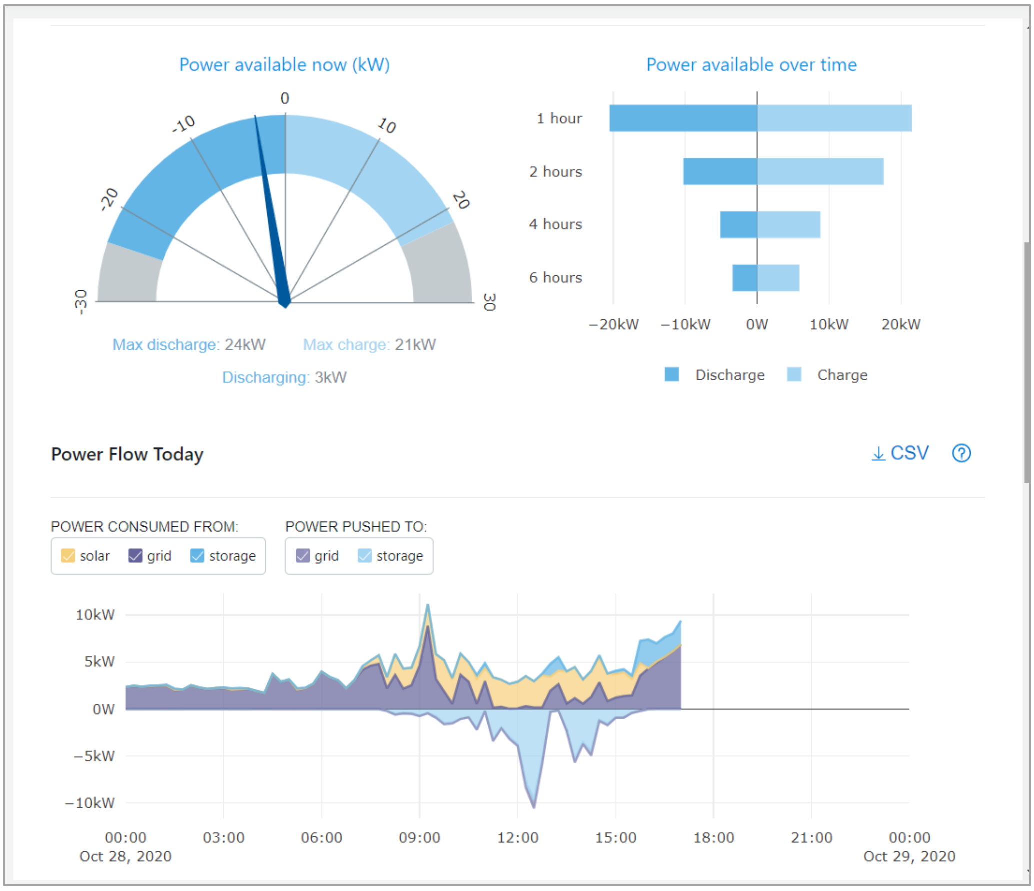
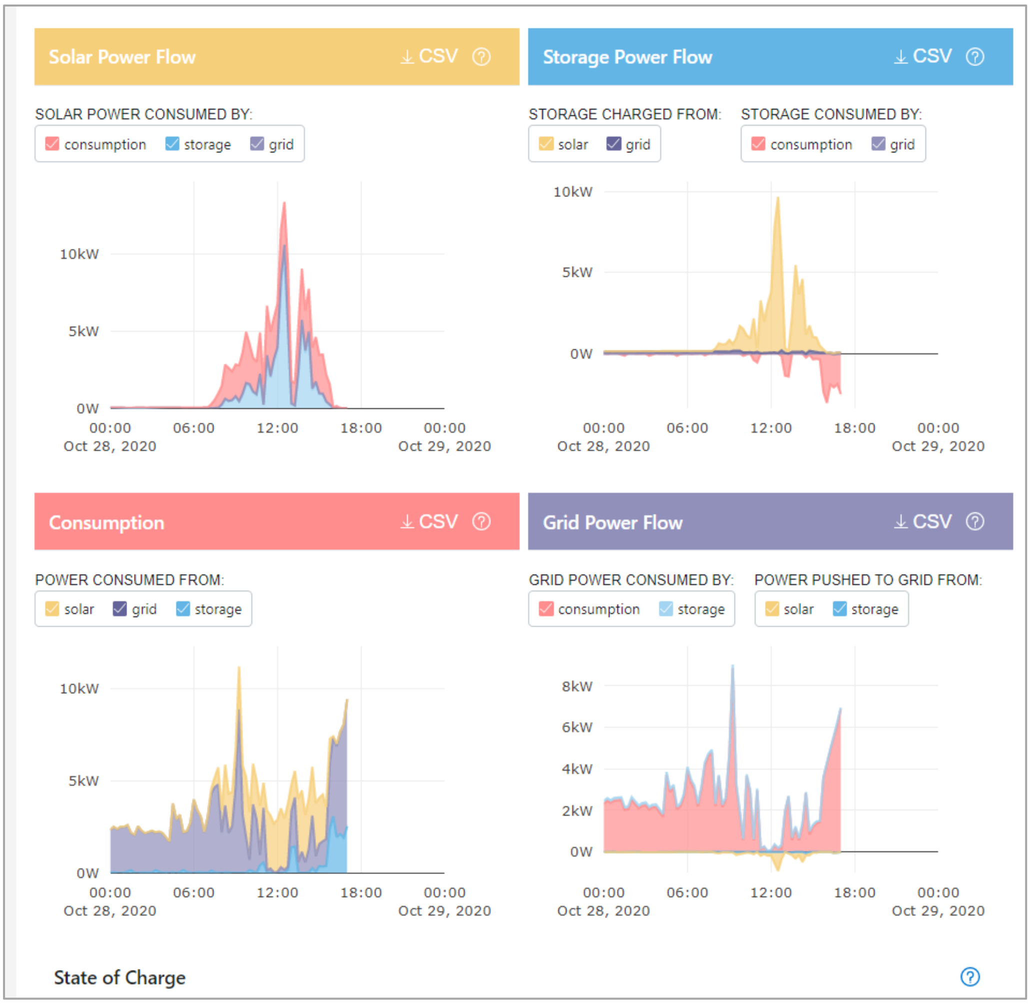


Figure 4: Moixa Dashboard: Power Flow Between PV, Battery, Grid and Household Consumption



6 Community Consultation and Recruitment

The geographical area originally selected for the pilot was due to its relatively high proportion of households that were either BWCE members and/or had solar PV already installed, which indicated that the area was:

1. suitable for further solar PV installations;
2. had people with available capital to support investment in new equipment;
3. might have a number of people who were prepared to act as local champions to support participation in the pilot;
4. be interested in having a battery installed. (Indeed, 70% of the existing solar PV households signed up for a battery installation, with the ones not installing due to technical reasons e.g. size of solar system or absence of permanent internet connection).

The availability of mains gas for water heating and space heating was a known factor which limited the demand management of electrically powered immersion heaters or storage/space heaters, though some households did use immersion heaters as back up during the summer.

Other factors which would be considered when targeting areas in the future might also include:

1. the average age of local people - a high proportion of older/retired couples concerned about long term investments in their property and with relatively low energy use can limit engagement and impact. However, older/retired couples may have capital to invest in new technology and are less likely to have an outstanding mortgage which eliminates the need for mortgage lender approval for the householder to enter into a lease;
2. penetration of electric vehicles - no electric vehicle use removes the opportunity to use this type of high energy consuming technology for demand shifting exercises;
3. solar PV installation costs - mixed, non-standard build types within the neighbourhood can generate high and sometimes prohibitive scaffolding costs.

However, the approach to identifying, engaging and supporting local champions had on the whole been very successful. There was a core group of around 10 people that consistently came to meetings and engaged with the project, promoting the offer to their neighbours, providing feedback to us on materials, approaches and communications locally during the initial publicity and recruitment phase.   Table 1 below shows the initial recruitment activities.

Table 1: Promotional Campaign Pre-PV and Battery Installation July 2018 – February 2019

Communication Type	Date	Where/What	Number of Attendees, Recipients or Responders
Meetings / drop-in sessions	31st July 2018	House meeting	Active engagement with 15-20% of target 80 households
	3rd October 2018	House meeting	
	9th November 2018	Public meeting 1	
	21st November 2018	Public meeting 2	
	11th December 2018	Drop-in session 1 (Bear pub)	
	12th February 2019	Meeting with Moixa / TH White / householders	
Publicity & Information	Oct/Nov 2018	Project leaflet 1 delivered to 110 households (some twice)	Target 80 households visited at least once
	Dec 2018 / Jan 2019	Project leaflet 2 delivered to all houses that we had been unable to make contact with previously	Spoke with 53 households; 36 email addresses provided; 21 Expression of Interest forms received
	Aug to Nov 2018	Householder briefing, Expression of Interest and Solar/battery briefing prepared and distributed	-
Household surveys	28th - 29th Nov 2018	Solar PV and Battery survey	12
	11th Dec 2018	Solar PV and Battery survey	6
	7th January 2019	Solar PV and Battery survey	4
	15th & 18th February 2019	EPC survey	7
Contract arrangements	January & February 2019	Costings and legal documents circulated	18

Even in a neighbourhood that seems to have strong community networks there was a reticence amongst some to talk to neighbours about something that was a bit unusual, like this. There were concerns about politicising local conversations and personal confidence about knocking on other people's doors. But with support, either from BWCE or from pairing up with others that were more confident, the impact of these issues was reduced.

Several people became engaged with the project as a result of conversations with their neighbours and local conversations have clearly been instrumental in promoting positive views about the project.

Once the installation programme got underway, there was further communication with both the participating householders and those from the wider catchment area that did not have, or were not planning to have, solar PV or a battery installed. Table 2 shows the communication during the resulting installation period.

Table 2: Communication During the Installation Period March – September 2019

Communication Type	Date	Where/What	Number of Attendees, Recipients or Responders
Meetings / drop-in sessions	8th May 2019	Public meeting	Active engagement with up to 10% target households
	22nd May 2019	Action Team meeting	
	24th June 2019	Drop-in session 2 (Bear pub)	
Publicity & Information	April 2019	Newsletter delivered to households	110
	May 2019	Web pages set up	-
Household surveys	May 2019	Baseline behavioural survey of households	26% of target households

Participants were prepared to accept problems that arose during the project on the grounds that it is a pilot. This demonstrates a high level of commitment to the project, which was related to both a desire to do something about climate change and the fact that BWCE was a known and trusted organisation with a good track record.

However, clearly the wider engagement process would have had more impact if the project had started with everything ready to go. The delays (see Section 7) with the installations meant that it was hard to keep levels of enthusiasm going through the project and it was inevitable that conversations between neighbours may well have contributed to the dip in enthusiasm across the wider neighbourhood. Nonetheless, 21 householders (over 20% of the targeted area) completed the baseline survey in May 2019, at which point only five of the solar PV systems had been installed and none of the batteries, and included householders who were not part of the installation programme.

Table 3 below shows the communication with householders post the installation period.

Table 3: Communication Post Installation Period October 2019 - September 2020

Communication Type	Date	Where/What	Number of Attendees, Recipients or Responders
Meetings / drop-in sessions	22nd October 2019	Meeting between Moixa / householders	10% of target households
Publicity & Information	Nov 2019	Newsletter delivered to households	110
House-hold surveys	Mar 2020	ToUT simulation survey	10% of target households
	Aug/Sep 2020	End of project survey	23% of target households
Demand side response	29th Nov 2019	HLCYG day 1	Unknown
	31st Jan 2020	HLCYG day 2	
	28th Feb 2020	HLCYG day 3	
	9th – 15th March 2020	ToUT Week 1	
	23rd – 29th March 2020	ToUT Week 2	

The final communication activity was the end of project survey in September 2020, to which 18 responded.

7 Launch of the Pilot

BWCE's original target was to have 25 properties with solar and battery systems and as many as possible new PV installations registered for the soon-to-be-closed Feed-in Tariff (FIT), 31st March 2019. By the completion of the installation period (October 2019) there were 16 participating properties, each with a battery installed and nine with a roof top PV array installed (seven households had an existing PV array).

The reasons for the lower than targeted take up of the solar PV and battery systems include:

1. technical and/or financial viability reasons for not being able to install in the property of a number of interested households;
2. the listed status of the additional domestic properties that were added to one of the sub-station feeders;

3. the legal complications of the arrangement between householder/Moixa/BWCE, putting off otherwise interested households;
4. an intention to move home within the next few years for two of the households who would otherwise have been involved;
5. a view that batteries were rapidly evolving as a technology and a subsequent preference to wait before installing.

Despite the lower than target uptake, these 16 properties equate to 20% of the original subset of 80 households and still well above the 10% minimum for materiality flagged by Carbon Coop in the initial feasibility study.

The feeder serving Maple Grove only serves domestic properties and of these, nearly 20% have solar PV and battery systems. The feeder serving Bloomfield Avenue also serves three commercial properties (Carphone Warehouse, Majestic Wine, The Bear pub). Despite repeated attempts to engage with these properties, it was not possible to install a simple clamp to monitor on-site electrical consumption. Therefore, it was not possible to account for their consumption in the feeder data set which made it much harder to monitor the role of PV and battery on the domestic properties on that feeder.

Following recruitment of households to participate in the pilot, there were a number of factors which delayed the commencement of the installation of the solar PV and batteries and to actually establish the pilot.

7.1 Preparation of Legal Contracts

The biggest impact on delay to the pilot launch was caused by the negotiation of the legal documentation. The legal documentation developed was complex and innovative in that it provided for a three-way arrangement between Moixa, the householder and BWCE. We had to therefore draft three key agreements:

1. a supply/install and O&M contract between BWCE and Moixa;
2. a grid services agreement between Moixa and the householder;
3. either a lease between BWCE and the householder (where the householder had installed both solar and battery) or a licence (where the householder just had a battery installed).

The documents interlinked and cross referenced where necessary. The negotiations with Moixa were detailed and lengthy due to the innovation involved in making it work with the involvement of a third party i.e. BWCE, that owned the assets, rather than the usual arrangement where the householder owned the solar and battery system.

In addition, BWCE opted for a contractual arrangement with the householder where the householder paid a one off 'use of system' charge which gave them the right to free electricity from the solar PV for the life of the system. This was easier to establish and administer than selling the electricity from the system at a discount to the householder, which would have been the alternative. It did however require additional legal work to establish and refine the lease/licence development.

7.2 Mortgage Lender Approval

On properties where there was an outstanding mortgage, it was necessary to obtain the mortgage lender's approval for the householder to enter into a lease of their roof space with BWCE to allow for the installation of the BWCE-owned solar PV array. The Council of Mortgage Lenders (an industry body representing mortgage lenders in the United Kingdom, which consisted of banks, building societies and specialist lenders and represented 95% of mortgage lending in the UK) was subsumed into a new body called UK Finance in July 2017. Despite several attempts to work with UK Finance to agree a standardised approach to obtaining mortgage lender approval for domestic roof-top leases, it was necessary to liaise with each mortgage lender individually to obtain the consent. This process was time-consuming as different mortgage lenders had different requirements before consent could be provided. However, once mortgage lender approval had been received, obtaining household signature of the lease was straightforward.

7.3 Change of Installer

The original solar PV installer, contracted by Moixa as part of their response to our tender, provided sub-standard technical survey results and expensive installation quotes so was replaced by TH White, a local contractor BWCE has worked with before. Roof-top surveys needed to be repeated before we could confirm the involvement of individual householders and clearly this added considerable delays. Following new roof surveys for PV installations, revised installation plans and costs were submitted by TH White and approved by BWCE.

7.4 Availability of Moixa Batteries

There was a considerable delay to the installation of the Moixa batteries. The installations should have started in mid-April but did not get underway until mid-Summer and were not complete until the end of October 2019. There were several reasons for this six-month delay, including:

1. the introduction of new G99 type-testing for the larger 4.8kWh batteries (Moixa V4) from the end of April 2019 which meant that TH White was required to re-submit a grid connection application to the local DNO, WPD, for approval. The approval process from WPD took several months as was not fully complete until the end of August 2019;
2. due to the closure of the Feed-in Tariff (FIT) scheme, Moixa had been overwhelmed by orders for both the smaller 3.0kWh battery (the V3) and the larger 4.8kWh battery in early 2019 and as such, were unable to promptly supply the batteries to BWCE as originally agreed, by April;
3. a fault had been identified by the manufacturer of a new component in the V4 battery that caused a short-circuit, which in turn caused a short-circuit in the inverter triggering the battery alarm. Moixa were reluctant to ship further V4 batteries until they had been 'soak-tested' in the laboratory for a significant period of time to ensure the alarm issue had been resolved.

7.5 Time of Use Tariff

BWCE had arranged an agreement with Our Power that as part of our partnership with them (we had a local energy tariff that we had just started promoting) they would offer a Time of Use Tariff (ToUT) to local households. However, our partnership with them dissolved when they went into administration in January 2019. We have had to take a step back in terms of energy supplier partnership to review more widely what we want to achieve and what kind of partnership we should be looking for. As a result, we have not had a ToUT to offer locally. This has had an impact on our ability to offer actual financial benefit to participating householders from the demand management/demand shifting campaign. However, with support from Moixa, the project was able to simulate a ToUT with those householders with solar and battery systems, as part of the demand side response modelling exercise.

8 Solar PV and Battery Installations

8.1 BWCE Offer to Households for Solar PV and Battery

Following receipt of grant funding, BWCE covered the installation costs of the domestic solar PV and domestic battery storage, and in doing so, owns all the equipment. Costs ranged between £7,000 - £9,500 for a complete system and between £3,000 - £3,750 for battery only systems. The costs of the solar systems were higher than anticipated due to multiple access issues and higher scaffolding costs.

Rather than charge householders for the electricity the solar system generated, which would have involved setting up complex power purchase arrangements with each household, BWCE offered households the opportunity to instead pay a one-off use of system charge of between £350 – approx. £1,800 which depended on the:

1. size of the system to be installed;
2. whether there were non-standard requirements, such as more extensive scaffolding;
3. whether the household already had solar PV or not.

This one-off use of system fee entitled households to receive free electricity from the solar panels for the whole lifetime of the system. The amount of electricity generated by the solar panels that will be used in the home (and therefore reducing electricity bills) will be increased by the operation of the battery. A typical 3kW solar system and 4.8kWh battery might reduce electricity bills by around £390 per year from year 6 onwards, assuming annual electricity demand of 4,000kWh. Householders are also required to pay a contribution of £35/year towards the maintenance fees for the system.

BWCE receives all external income from the equipment including the Feed-in Tariff (FIT) subsidy for generation from the solar panels that were eligible for it. Income from Moixa for operating the batteries will be shared 50:50 between householder and BWCE.

Table 5 below shows the key details of the offers made by BWCE to the participating households.

Table 4: Summary of Participants' Offer Details

	Total Solar Capacity (kW)	Average solar yield (kWh/kW/yr)	Total Battery Capacity (kWh)	Total Capital Cost (inc VAT)	Householder one-off use of system charge	Average Pay-back in years	Average 5th year saving
Solar & Battery Households	30.9	751	37.8	£73,238	£13,421	5.3	£98
Battery Only (existing solar)	19.35	792	28.2	£24,060	£2,677	4.7	£110
Totals	50.25	767	66	£97,298	£16,098	5.2	£101

Average solar yields were reduced by several properties having shading issues. The average payback periods relate the time to repay the one-off use of system charge rather than the whole capital cost. For the solar and battery households this average was higher than 5 because of one property that paid a higher proportion of the capital costs due to the requirements of their property's management company

8.2 BWCE Commitments

As part of the Offer and in preparation for the installation, BWCE:

1. provided a 20-year lease enabling BWCE to utilise the air space above the household's roof and to connect the system to the household's electricity supply;
2. ensured that the lease is compatible with the Council for Mortgage Lenders requirements for solar roof leases;
3. secured consent from mortgage providers where appropriate;
4. insured the systems against liability for any damage caused to the property or injury to any person, which may have occurred during or arose from the installation or operation of the equipment (no claims have been lodged to date);
5. agreed to cover costs associated with the repair of the systems, including replacement of invertors and battery cells, unless caused by the actions of the householder (some initial replacements were made due to faulty equipment i.e. an inverter and were covered by manufacturers' warranties);
6. agreed to provide a point of contact for the householder to raise any issues regarding the operation of the system (but post battery installation, Moixa has been the first port of call for householders querying any issues).

To provide reassurance to the householders, BWCE also agreed to long-term commitments to:

7. remove and replace the solar systems if absolutely necessary to facilitate repairs to the roof and not charge for any loss of FIT income for up to 3 consecutive weeks or 6 weeks in any 12 month period;
8. cover 50% of the cost of removal and replacement, not including scaffolding costs;
9. remove the systems after 20 years, if requested to do so by the householder, at no cost to the householder.

It was the intention for as many of the PV installations to be registered for the Feed-in Tariff (FIT) before the scheme closed on the 31st March 2019. However, only four of the nine installations were completed in accordance with FIT eligibility requirements by this date so the remaining five PV arrays installed after the 31st March were therefore not eligible for the FIT.

As of the end of October 2019, 16 batteries and nine pv arrays were successfully installed as per Table 6 below. The battery only systems are installed in homes with pre-existing solar PV.

Table 5: Solar PV and Battery Installations

Participant Number	Battery size (kWh)	PV size (kWp)	PV Installed (kWp)
1	4.8	3.6	3.6
2	4.8	3.9	3.9
3	4.8	3.0	3.0
4	4.8	1.4	
5	4.8	4.0	

6	4.8	3.9	3.9
7	4.8	3.5	
8	4.8	3.9	3.9
9	4.8	3.0	
10	4.8	3.0	3.0
11	3.0	3.0	3.0
12	3.0	3.3	3.3
13	3.0	3.9	3.9
14	3.0	2.1	
15	3.0	3.0	
16	3.0	2.1	
Total	**66**	**50.6**	**31.5**
Bloomfield Avenue	3 x 4.8 kWh	9.0	
	4 x 3.0 kWh	12.3	
	Total PV kWp	**21.3**	
Maple Grove	7 x 4.8kWh	24.2	
	2 x 3.0 kWh	5.1	
	Total PV kWp	**29.3**	

There were some initial post-commissioning issues with some of the solar PV arrays and batteries which required on-site visits by the installer (with remote input and guidance from Moixa as appropriate) and some battery bedding-in issues that were resolved remotely by Moixa, with input from the householder as required.

8.3 Batteries Operating in Balancing Mode

All the installed batteries were initially set-up in 'Balance Mode'. This means that the batteries were configured to minimise the quantity of energy consumed by the household from the grid. The battery therefore begins charging when PV generation exceeds household consumption, and it will discharge when household consumption exceeds PV generation. Householders were informed that the battery will not charge if its state of charge (SOC) is 100% (i.e. the battery is full) and it will not discharge if its SOC is 20% or lower (i.e. the battery is deemed 'empty'; this is to increase the life expectancy of the battery modules). Where the household has a flat tariff, this battery Balance Mode will minimise the electricity cost from the grid.

8.4 Batteries operating in Optimisation Mode

In Optimisation Mode the battery responds to a Time of Use Tariff (ToUT), so enabling households to take advantage of this dynamic tariff to minimise energy import when electricity is most expensive. So it can be financially beneficial to charge the battery from the grid during periods of cheaper prices to ensure it can provide maximum discharge value during the expensive period. To be clear, the PV generation is regarded by the battery as having 'no cost', so the battery should always charge using excess PV if it is available. To ensure the potential savings under a ToUT are maximised, the household's historic consumption and PV generation data is used alongside weather predictions to compute the optimal behaviour of the battery. This heavily relies on the accuracy of the weather forecast in order to continue to maximise the value of the solar.

9 Community Action: Electricity Demand Reduction and Demand Shifting

BWCE wanted to test two demand side response mechanisms and model the outcomes. These were:

1. demand reduction; and,
2. demand shifting.

9.1 Demand Reduction: How Low Can You Go?

The first of the demand side response (DSR) activities targeted all the participants in the Solar Streets project, including the 16 participants with PV and battery and involved promoting an overall reduction in electricity demand through one off 'How Low Can You Go' (HLCYG) days.

The purpose of these HLCYG days was not to generate long term behaviour change, as that was not considered achievable within a project like this, but to focus householders' attention on the quantity of electricity they consumed and to raise awareness of how they could reduce demand in the future. Selecting a repeated one day focus offered an approach that was considered achievable in terms of householder engagement but also manageable in terms of the resources of this project to provide support.

The plan was to have one HLCYG day per month for four months, going into Spring and be able to monitor the impact from increased performance of the solar systems.

The intention was to also gauge the extent to which engagement with the issues could be generated through a local campaign as a precursor to running an extended campaign later in the year.

However, this plan was disrupted by severe data collection problems with the sub-station monitoring equipment. First there was a fault in the equipment that prevented data capture in December 2019 and most of January 2020, reducing the analysis that was achievable during HLCYG day at the end of January 2020. The whole system then went down in mid-February 2020, and whilst new equipment was promised, this wasn't installed until much later in the year (due to Covid-19 restrictions) with the revised software not coming online until October 2020.

As a result, only two HLCYG days were possible where data could be harvested and analysed and more detailed analysis of demand shifting and demand reduction during the summer was not possible.

As an alternative to the extended campaign that would have relied on the sub-station monitoring data to monitor impact, an approach was adopted that focussed on just those households with solar PV and battery systems as data could be collected via the Moixa data portal.

9.1.1 What were we comparing against?

A core group of households were involved in discussions around what would be good to demonstrate impact that would motivate them. It was agreed that the project should provide comparisons between the electricity demand profile on the target HLCYG day and:

1. average total electricity demand per day and the average daily electricity demand profile across the same month in the current year and in the same month in the previous year.

2. total electricity demand and the daily electricity demand profile on the same day in the previous year

Whilst it was recognised that comparing with the exact same day in the previous year was of limited value, it was agreed to provide that information as an additional check, alongside the potentially more useful comparison with average consumption across the relevant months.

Data on electricity demand at the sub-station was collected from the monitoring equipment installed by WPD. The impact of the solar and battery systems was extracted from aggregated data for all the systems supplied by Moixa and taken off the data recorded at the substation to approximate collective electricity demand, before the systems (including both new and existing solar PV) were installed.

9.1.2 Results from the First HLCYG Day on 29th November 2019

Headline findings include:

1. Whilst it's difficult when comparing with averages to make any definitive comments or associate any specific causal link between action and impact, the data implies that there had been a reduction in electricity demand of around 5% during the 29th November on the Maple Grove feeder.
2. The impact of the battery and solar systems may provide around 50% of the Maple Grove reduction, suggesting that the balance may be made up from the actions of households during the 29th November 2019.
3. There is no evidence of any additional reduction in demand on the Bloomfield Avenue feeder on the same day. It is clear from a comparison of energy demand across the two feeders that the Bloomfield Ave feeder is heavily impacted by demand from the three commercial premises.
4. Despite trying to make contact with the commercial properties to install a CT clamp in order to eliminate their consumption data from the Bloomfield feeder, this did not happen so it was difficult to clearly see the impact of domestic behaviour on overall demand.

The results shown in figure 5 imply that for Maple Grove the HLCYG day on 29th November did have a below average electricity demand during the day, when compared to the average figures for the whole month in both 2018 and 2019.

Whilst there is a more significant reduction when compared to November 29th 2018, this comparison is in some ways arbitrary as there are unlikely to be electricity uses that are specific to this actual day. The fact that 29th November 2018 is above the average for the whole month suggests it may also be something of an outlier.

So, the more relevant comparison may be with the average for the whole month, showing a reduction of just over 5% compared to the November average in both 2019 and 2018.

Figure 5: Comparing kWh/day average for November and for 29th November for 2018 and 2019

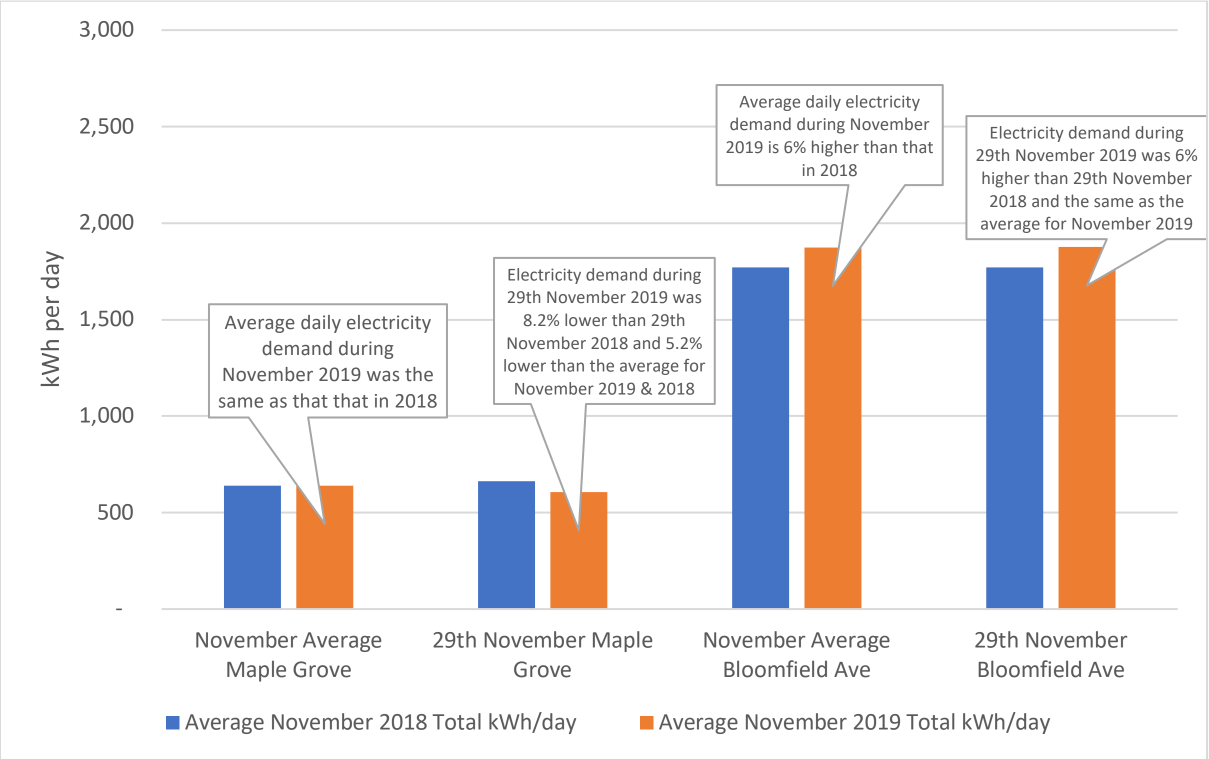
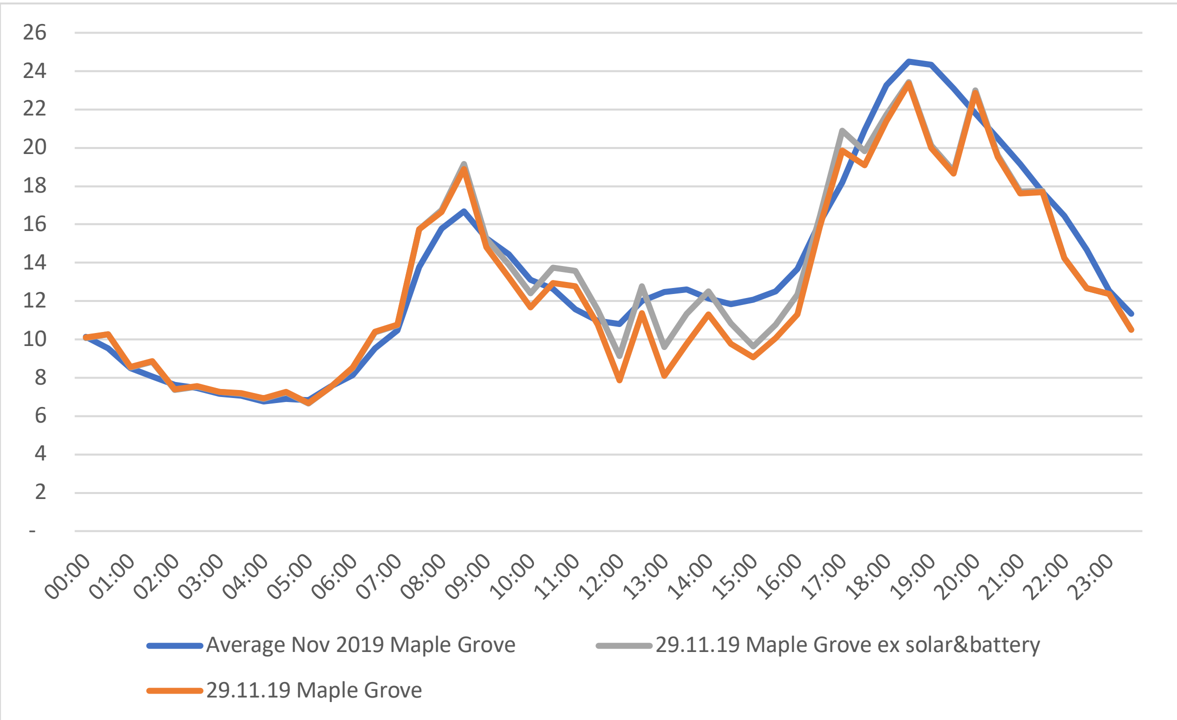


Figure 6 below suggests that while there is a higher demand on 29th November 2019 compared with the average for the month, this is more than made up for by the reduction during the middle of the day and during the evening peak.

<u>Figure 6: Comparing November 29th 2019 electricity demand profile with average daily demand profile during November 2019 for the Maple Grove feeder</u>



The impact of the solar and battery systems is around 50% of this reduction. The impact of the solar and battery systems lasts until the early evening. The sun is not strong enough this time of year to produce enough electricity to fully charge the batteries and enable the battery to then supply electricity back into the home for very long.

For Bloomfield Avenue, demand in November 2019 was 6% higher than that in November 2018, for both the monthly average and for the day on the 29th. There is also no discernible difference when comparing data on 29th November 2019 with the November 2019 average or when comparing 29th November 2018 with the November 2018 average.

Because of the significant non-domestic electricity demand on the Bloomfield Avenue feeder (including the Bear pub, Majestic Wine Warehouse and the Carphone Warehouse) any reductions in domestic electricity demand will be harder to see and are likely to be swamped by the increase year on year. For example, the impact of the solar and battery installs on Bloomfield Avenue are likely to have had a less than 1% impact.

9.1.3 Results from the Second HLCYG Day on 31st January 2020

Unfortunately, there was a malfunction in the monitoring equipment at the feeder which meant that only limited data had been monitored during January. It was therefore not possible to provide a comparison with the January 2020 average for the Maple Grove data.

In addition, it was discovered that there was no data for January 2019 from the Bloomfield Road feeder with which to make a comparison. Therefore, analysis was only possible of a more limited data set for the Maple Grove feeder.

Figures 7 and 8 below show that the Maple Grove feeder data indicates that on 31st January total electricity demand was:

1. 17% lower than the monthly average for January 2019;
2. 21% lower than 31st January 2019;
3. 3% of the reduction was due to the presence of PV and battery.

It was not possible to compare the 31st January figure with the average daily electricity demand across the whole month or compare the January 2020 average with the January 2019 average. However, the average daily demand in October, November, December 2019 and in February 2020 (until data collection stopped on February 17th) was very similar to the average daily demand during the same months in the previous year. This suggests that it is perhaps not unreasonable to assume that it was also similar in January as well.

If that is the case, the data suggests that there was a significant increase in the level of reduction during this second HLCYG day, on the Maple Grove feeder. In addition, the contribution coming from the solar PV and battery systems was minimal at around 3%, as opposed to 50% of the reduction during the November HLCYG day.

Figure 7: Comparing kWh/day average for January and for 31st January for 2019 and 2020 for the Maple Grove feeder

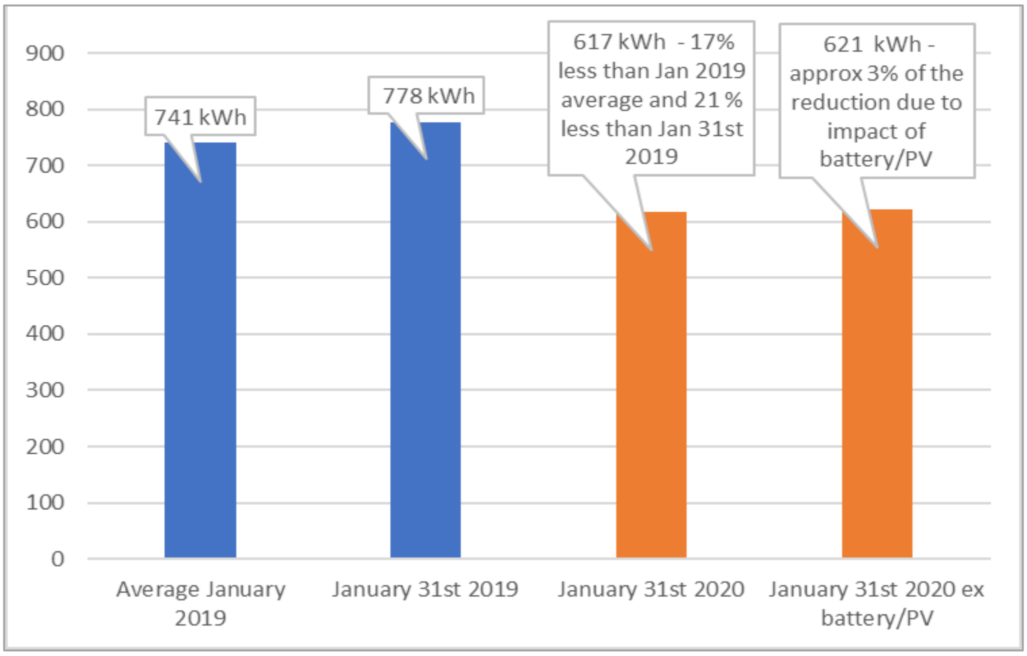


Figure 8: Comparing 31st January 2019 and 31st January 2020 (with and without battery/pv) electricity demand profile with average daily demand profile during January 2019 for the Maple Grove feeder

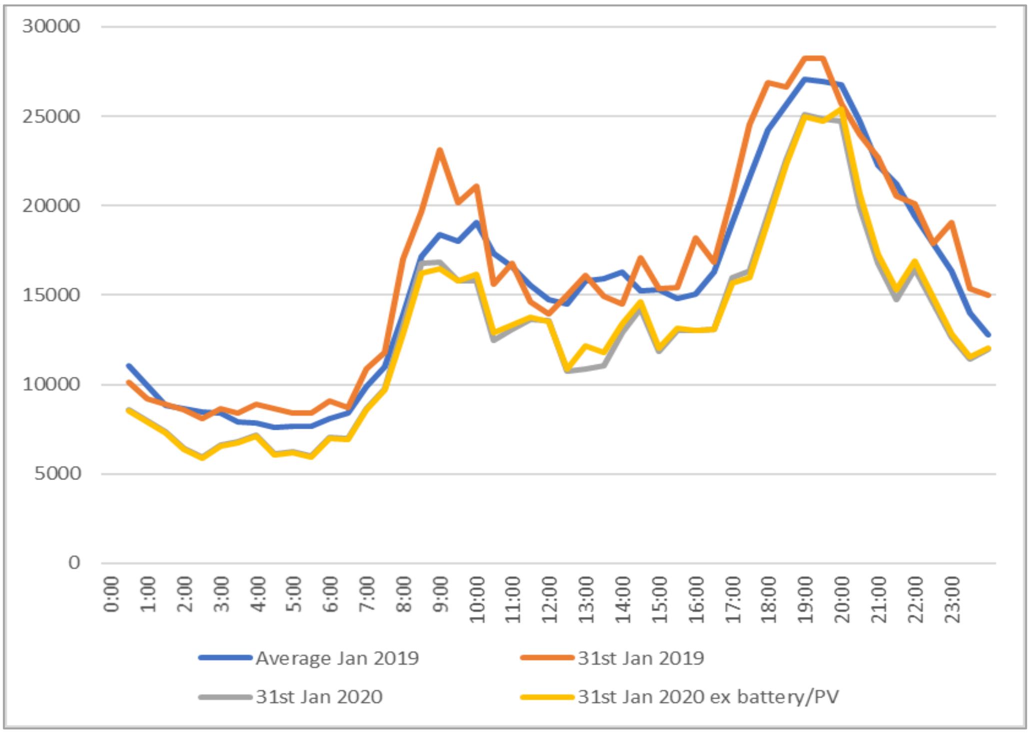


Figure 8 shows the small impact of the solar PV around 1.00pm with some battery discharge in the evening. This low impact is not surprising given the time of year, but emphasises the much increased behavioural impact implied by the analysis.

9.1.4 Results from the Third HLCYG Day on 28th February 2020

Just before sending the email prompt to all householders for the third HLCYG day on 28th February, BWCE was notified that the LV-Cap units installed in the substations stopped producing data on 17th February. This meant that there was no substation data available via the community web application from 17th February onwards and neither would there be until the replacement monitoring solution, VisNet, was installed. At the time, BWCE was informed that there was no timescale for when this would happen.

Despite this, BWCE decided to notify the Solar Streets participants of the third HLCYG day on the 28th February, whilst also informing them that were problems with the monitoring equipment at the sub-station so that there would be no data analysis following this HLCYG day. BWCE went ahead with this HLCYG day because we felt that it would be good to keep the momentum going of encouraging Solar Streets residents to reduce electricity demand and would feed into the focus on the demand shifting exercise outlined below.

9.2 Demand Shifting: Simulated Time of Use Tariff (ToUT)

The second of the demand side response (DSR) activity involved modelling the impact of a demand shifting campaign using a simulated Time of Use Tariff (ToUT) as the prompt. This activity focussed on the 16 households with PV and battery, where the batteries could be configured to respond to the simulated ToUT. To do this, Moixa ran simulated trials using a bespoke ToUT (but based on the Octopus Agile Tariff) for the 16 individual customers with V4 and V3 Moixa batteries to demonstrate the potential positive and/or negative effects ToUTs may have with each household and their PV and battery systems. The hypothesis was that simulating a ToUT would lead to reduced household energy bills and potentially interest in tariff switching.

9.2.1 What were we comparing against?

To create a baseline against which the effects of a simulated ToUT can be compared, Moixa collected detailed, real-time customer data (solar production, energy usage, battery state or charge, etc.) during February, whilst the battery was in Balancing Mode, maximising the self consumption of solar electricity. See section 8.3 for a description of battery operation in balancing mode.

At this stage, the 16 householders were unaware of the pending ToUT simulation exercise planned for the two one-week periods in March. This was to ensure that electricity consumption behaviour was not altered in response to the pending demand shifting campaign. All 16 households were invited to submit their current electricity tariffs to be used to calculate the cost of electricity consumption during February's baseline monitoring period and to enable cost savings to be made when the households underwent simulated ToUT modelling in March. Where householders did not supply their current tariff, Moixa used the 'Solar Streets Tariff', which was calculated as an average of the tariffs that were submitted by participating households (see Table 9 below).

Table 6: Current Flat Rate Householder Tariffs and Solar Streets Tariff

Participant Number	Current House Flat Rate Tariff (p/kWh)	'Solar Streets Tariff' (p/kWh)
1	-	16.95
2	-	16.95
3	-	16.95
4	19.31	
5	19.31	

6	12.81	
7	-	16.95
8	17.50	
9	-	16.95
10	-	16.95
11	-	16.95
12	-	16.95
13	14.70	
14	-	16.95
15	19.98	
16	14.97	

In addition to capturing the baseline data and modelling demand shifting, Moixa specifically noted the household consumption on the third HLCYG day on Friday 28th February. As with the first HLCYG day in November, it had been planned that this demand reduction exercise would involve comparing the household electricity demand data on the 28th February 2020 with the sub-station feeder data on the 28th February 2019, and, with the monthly average daily demand data for both February 2020 and 2019. However, because the LV-Cap units installed in the substations stopped producing data on 17th February it was not possible to undertake this comparison exercise.

9.2.2 Data gathering and communication with the 16 households

At the beginning of March 2020, BWCE informed all the 16 PV and battery residents of the proposed two one-week ToUT simulation periods in March (9th – 15th inclusive and 23rd – 29th inclusive). It was agreed that two one-week periods would, with an intervening one week break, be less intrusive. BWCE also notified the 16 residents of:

1. details of why BWCE was undertaking a ToUT simulation exercise;
2. details of the ToUT being modelled and the use of the Solar Streets Tariff in the absence of an actual tariff;
3. how the householders will be reminded by BWCE that the ToUT exercise is 'live' i.e. by email;
4. ways to make the most of the ToUT e.g. using the time switch on electrical appliances such as washing machines.

During these two weeks, all V4 batteries were switched remotely by Moixa to 'Optimisation Mode' to ensure that the battery charging maximises the use of electricity at cheapest times. See section 8.4 above for a description of battery operation in optimisation mode.

To ensure the potential savings under a ToUT are maximised, the household's historic consumption and PV generation data is used alongside weather predictions to compute the optimal behaviour of the battery.

During the first week of ToUT simulation, Moixa collected electricity consumption, PV generation and battery operational data per household based on running a ToUT optimised plan. BWCE sent timely email reminders to householders that they were shortly due to enter a higher tariff band under the simulated ToUT exercise as a prompt to alter or shift their electricity demand behaviour.

During the intervening week (16th – 22nd inclusive) no ToUT was simulated and householders were notified accordingly.

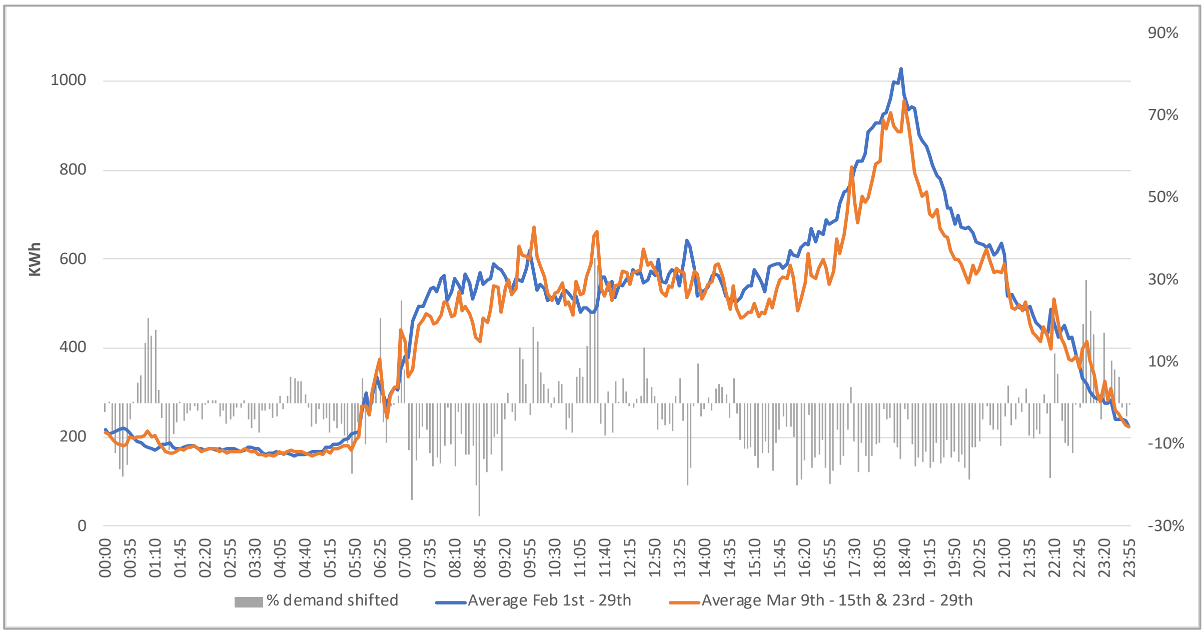
During the second week of ToUT simulation, Moixa again collected electricity consumption, PV generation and battery operational data per household based on running a ToUT optimised plan. Again, BWCE sent timely reminders to householders, but those that opted in received them by text or WhatsApp message, as a more immediate communication medium.

Using the data gathered, Moixa calculated the cost savings and CO_2 savings per household:
- by comparing business-as-usual demand behaviour during February using their current tariff;
- by comparing their demand shifting behaviour during the two weeks in March using the ToUT.

9.2.3 Headline Results

The key results are shown in Figures 9-11 and Table 10 below and include:
1. Figure 9 clearly shows the noticeable shifts in demand from the typical peak periods i.e. 0700 – 0930 and 1630 – 2200 where there was a reduction in demand of 12% and 10% respectively;

Figure 9: Impact of Demand Shifting Due to the ToUT Simulation: Comparing with both weeks in March



2. interestingly, the shift in demand commenced at 1430 when the householder was sent the alert by BWCE, illustrating the willingness to take action, although not necessarily at the correct time. Householders were told that the peak tariff period would start at 1600;
3. overall, there was a roughly 5% reduction in total demand across the average day in the two weeks in March when compared to the average day in February;
4. when comparing the reduction across the two weeks in March (see Figures 10 and 11 below) the first week showed a 4% reduction in total demand on the average day, when compared

to the average February day and the second week showed a 6% reduction in total demand on the average day;

Figure 10: Impact of Demand Shifting due to the ToUT Simulation: Comparing with 1st week in March

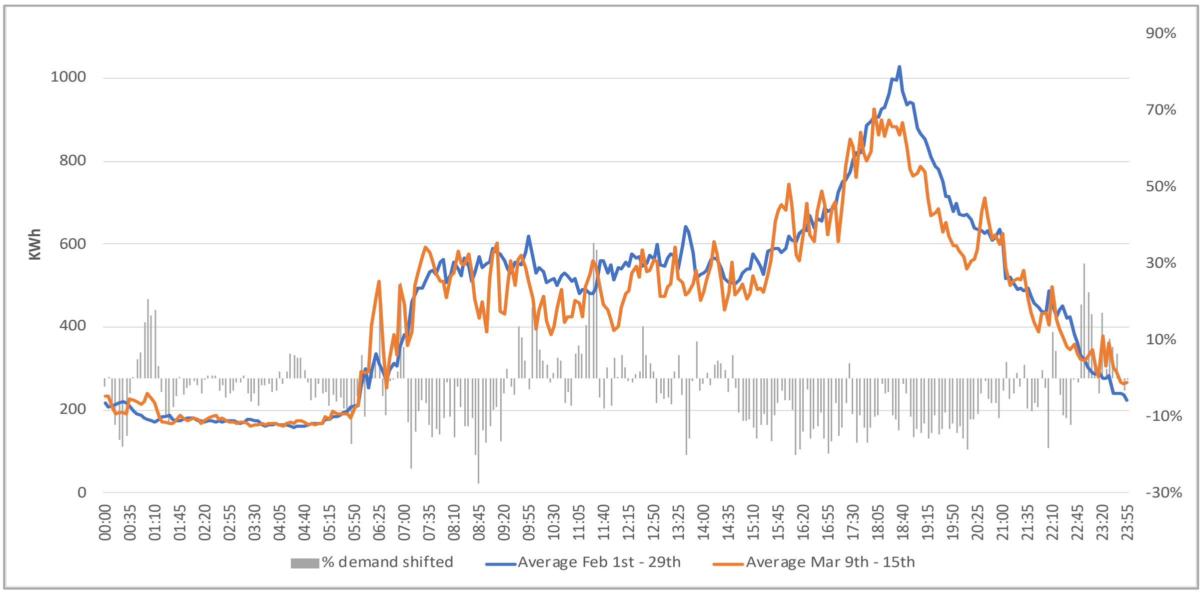
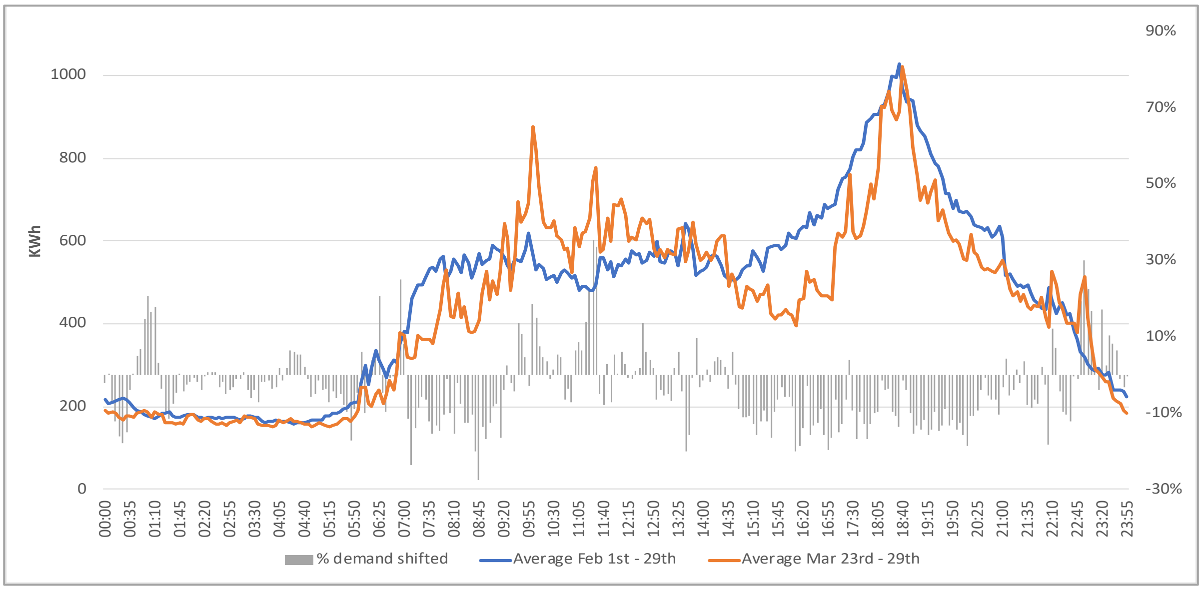


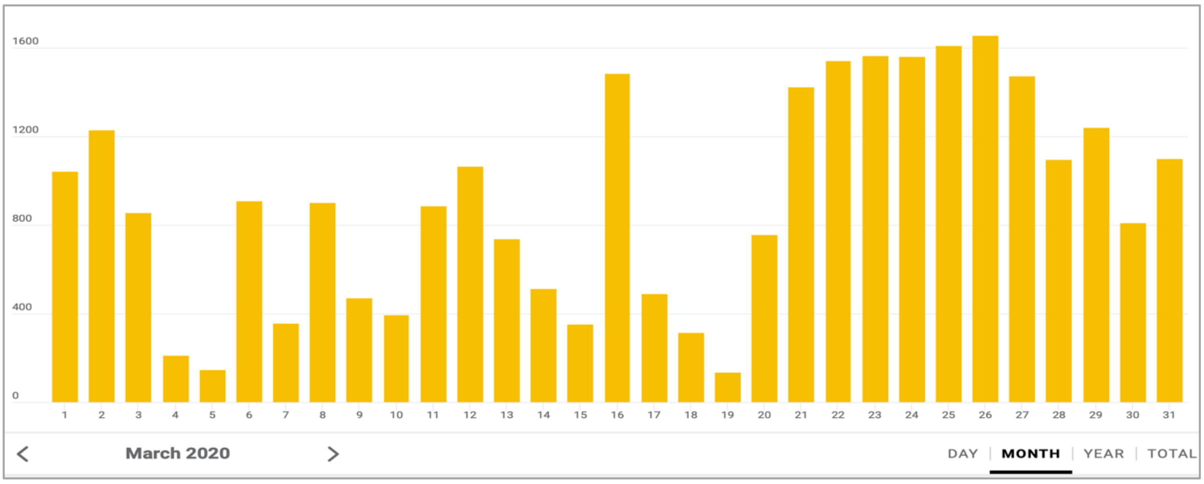
Figure 11: Impact of Demand Shifting due to the ToUT Simulation: Comparing with 2nd week in March



5. with regards demand shifting, the difference was even more marked. During the first week there was a reduction in demand of 4% and 5% during the two time periods outlined above in the first week, and a 14% and 20% reduction in demand during the two time periods in the second week;
6. the only difference between the two weeks was that in the second week, some households were prompted they were going into a peak period by text and WhatsApp messages rather than by emails;
7. however, it may also be the case that households were getting into the swing of things by the second week;

8. In addition, Figure 12 highlights that the second half of March 2020 was far sunnier than the first, maybe encouraging households to focus on demand shifting more in order to maximise the benefit of the solar generation

Figure 12: Solar Production at a BWCE solar array near Bath during March 2020 (kWh)



9. Table 10 summarises the financial savings households would have made if they really had been on a ToUT;
10. the presence of PV and a battery in Balancing Mode made significant financial savings for all householders, in most cases between 30-40%;
11. on the whole, only marginal additional cost savings are made when the battery is in Optimisation Mode compared with Balancing Mode for the larger V4 (4.8kWh) batteries with an associated typically-sized PV array;
12. this is probably explained by the fact that the households' consumption profiles are mimicking the ToUT profile; this is not surprising as having installed PV panels, the householders are much more energy aware;
13. however, in every case for the V4 battery households, their CO2 emissions increased when a ToUT was simulated with the battery in Optimisation Mode compared with the householders' current tariff and the battery in Balancing Mode;
14. this means that the householders are not maximising the use of their PV generation and the battery is being topped-up with grid electricity when the ToUT is low;
15. on the whole, the additional cost savings made when the battery is in Optimisation Mode compared with Balancing Mode are greater for the smaller V3 (3.0kWh) batteries with an associated slightly smaller PV array;
16. this is probably explained by the fact that the V3 batteries cannot be programmed in half hourly slots to respond to a half-hourly ToUT; because of this, Moixa modelled a ToUT response based on a 'lumpy' 3-hour interval;
17. interestingly though, in three of the V3 battery households, the CO2 emissions were actually lower under the ToUT simulation with the battery in Optimisation Mode compared with the householders' current tariff and the battery in Balancing Mode;
18. this is probably explained by 'lumpy' battery response to the ToUT, so the battery stored more PV generation during the day-time so there was less capacity for the battery to top-up with grid electricity when the ToUT is low i.e. over-night;
19. one outlying data point that requires some interpretation is the 81.3% increase in CO2 emissions for Household 7; this is because Household 7 is a very low energy consumer who

is very tuned to their roof-top PV generation and so any minor increase in grid electricity consumption will have a large impact on overall carbon emissions.

Table 7: ToUT Simulation Modelling Results March 2020

Participant Number	Battery size (kWh)	PV size (kWp)	Financial saving from simulated ToUT with the battery in Balancing Mode (%)	Additional saving from simulated ToUT with the battery in Optimisation Mode (%)	Total financial saving from simulated ToUT with the battery in Optimisation Mode (%)	Impact on CO2 Emissions from simulated ToUT with the battery in Optimisation Mode (%)
1	4.8	3.6	37	6	43	14.3
2	4.8	3.9	24	7	31	13.5
3	4.8	3	39	3	42	15.4
4	4.8	1.4	47	11	58	3.6
5	4.8	4	40	17	57	29.4
6	4.8	3.9	37	3	40	27.5
7	4.8	3.5	30	0	30	81.3
8	4.8	3.9	40	0	40	29.4
9	4.8	3	42	6	48	14.3
10	4.8	3	37	11	48	4.8
11	3	3	30	15	45	15.8
12	3	3.3	40	11	51	9.1
13	3	3.9	14	26	40	-5.6
14	3	2.1	40	13	53	-1.8
15	3	3	40	16	56	-15.6
16	3	2.1	30	20	50	-8.8
Totals	**66**	**50.6**	**567**	**165**	**732**	**-**
Averages	**4.1**	**3.2**	**35.4**	**10.3**	**45.8**	**14.2**

9.2.4 Baseline Data Gathering and the Impact of the February HLCYG day

Figure 12 shows the total daily household electricity consumption (blue line) and the proportion of which that comes from the grid (orange line) over the month of February for Household 7, who is a lower than average electricity consuming household. The difference between these two lines on a given day is equal to the energy savings provided by the PV array and battery. Typically, this difference will be smaller on days with high cloud coverage. On days with 100% cloud coverage the difference may be null if the battery starts the day empty. This is clearly shown on the 15th February when the weather was very overcast as all electricity consumption on that day came from the grid and none from PV or the battery, whilst on the 26th February, very little consumption was drawn from the grid, indicating that there was PV generation that day. This is further illustrated in Figure 12 below. Figure 12 also shows Householder 7 response to the HLCYG day on the 28th February with an attempt to reduce grid electricity demand to around 0.5kWh despite sunshine levels being very low (Figure 13).

Figure 13: Daily Electricity Consumption for Household 7 in February 2020

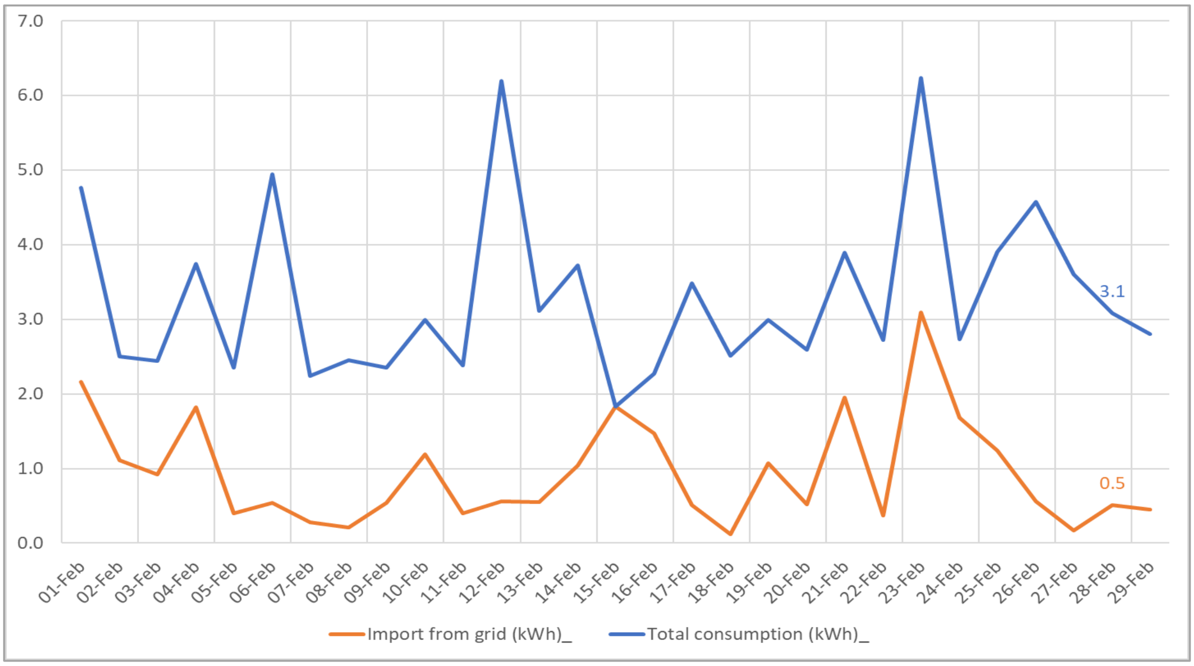
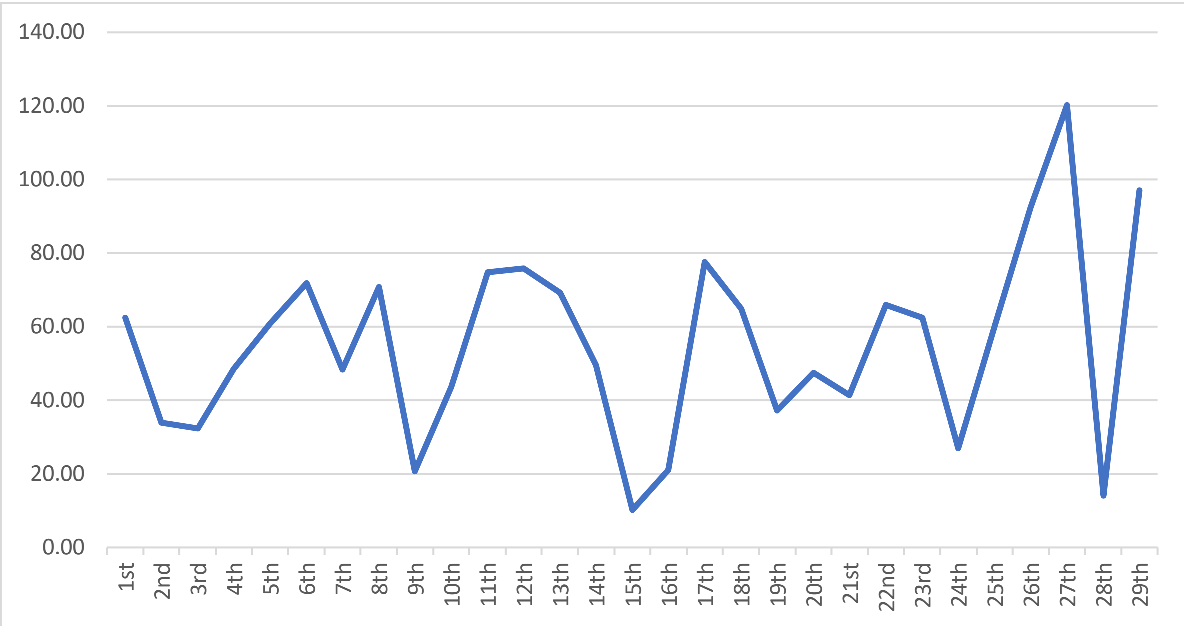
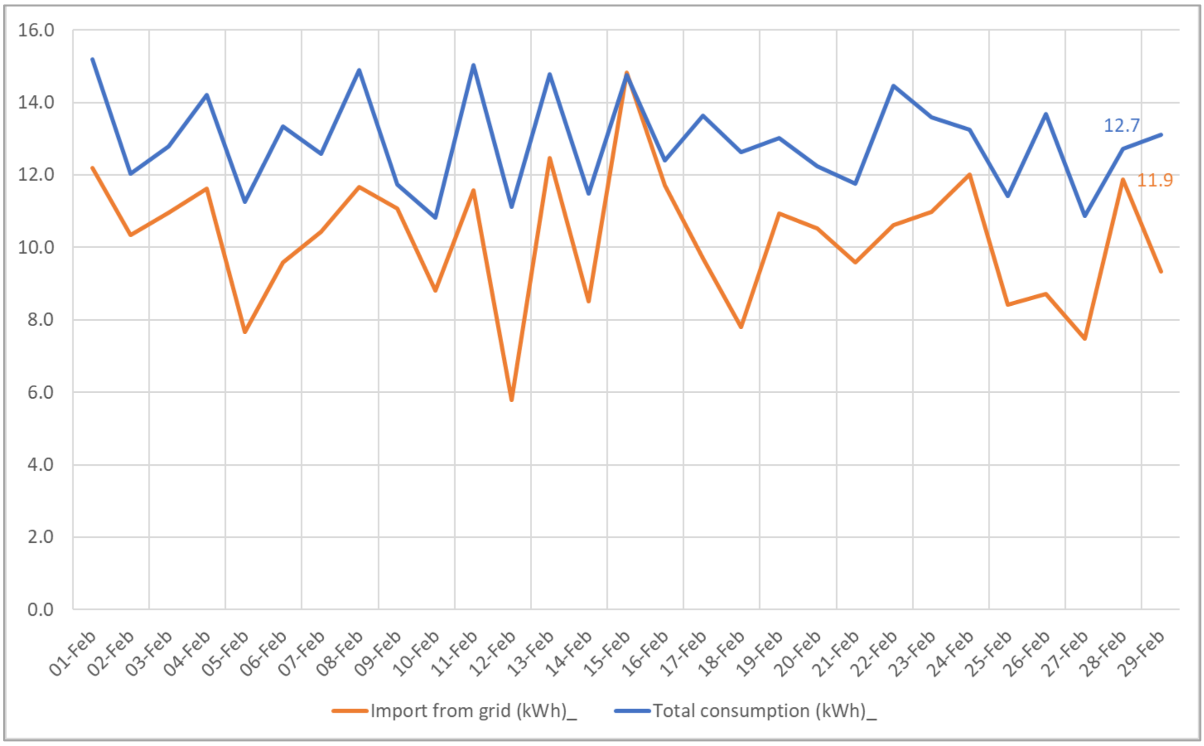


Figure 14: Solar Radiation in Bath February 2020 (W/m²)



By contrast, Figure 14 below shows that Household 6, an average electricity consuming household, did not actively respond to the HLCYG day on the 28th February with household consumption broadly in line with other daily consumption levels i.e. between 12-14kWh. As with Figure 9.0., Figure 14 below shows null PV generation on the 15th February, but PV makes a contribution on the 26th February.

Figure 15: Daily Electricity Consumption (kWh) for Household 6 in February 2020



9.2.5 Simulated ToUT Findings

The general conclusions drawn from the ToUT simulation exercise are dependent upon whether the battery was in Balance Mode or in Optimisation Mode

A householder switching from their current flat rate tariff to a ToUT whilst their battery was in **Balance Mode** (i.e. storing the excess pv generation in the battery) are likely to save money on their electricity bills. The amount of financial saving would depend upon the household's:

1. total electricity consumption;
2. when that electricity was being consumed;
3. when their PV panels were generating electricity.

However, to fully enjoy this financial saving, the householder would need to undertake conscious demand shifting to make best use of the ToUT i.e. actively consume electricity when the ToUT is low and avoid consuming electricity when the ToUT is high. This is because the battery is only responding to when PV is being generated and is not automatically adjusting charging in response to the ToUT.

A householder switching from their current flat rate tariff to a ToUT whilst their battery was in **Optimisation Mode** (i.e. charging when the ToUT is low) would save money on their electricity bills. Again, the amount of financial saving would depend upon the household's:

1. total electricity consumption;
2. when that electricity was being consumed;
3. when their PV panels were generating electricity.

However, when the battery is in Optimisation Mode there is a greater possibility of excess solar PV generation being exported to the grid if the battery is already pre-charged from an earlier response to a low ToUT (i.e. overnight). The householder would continue to enjoy financial savings compared to a flat tariff, but the savings may not be as great as if the free PV generation was used to charge the battery.

This is illustrated in figure 15 below.

Figure 16: Daily Electricity Consumption (kWh) for Household 6 in March 2020 during ToUT Simulation

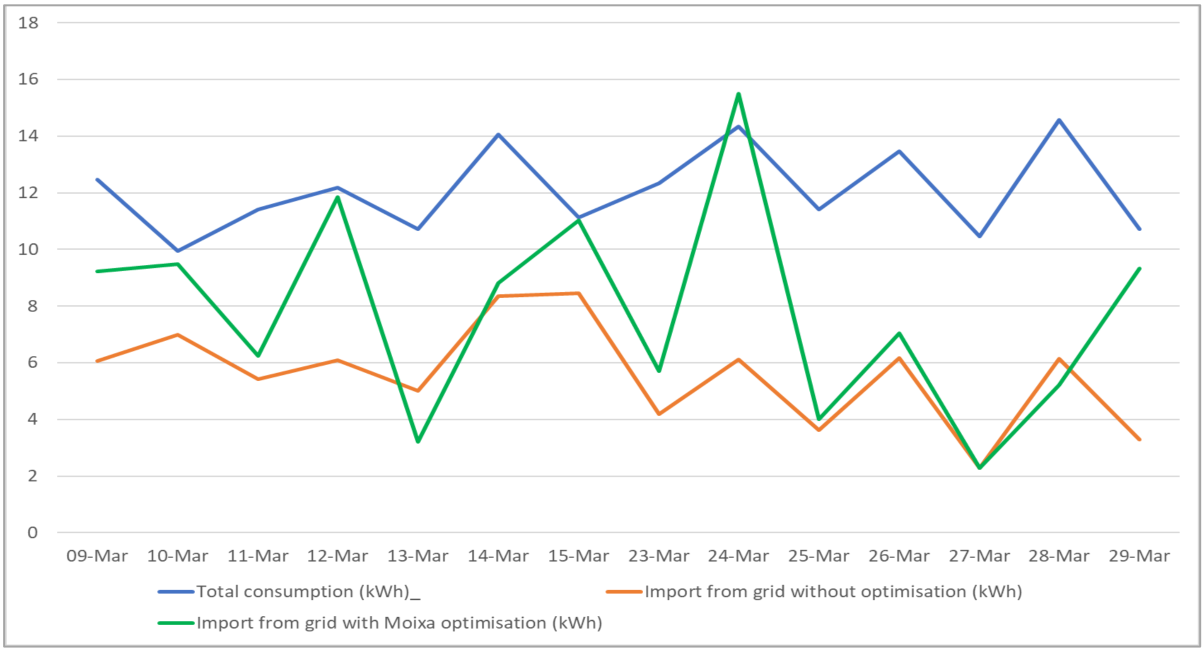


Figure 15 above shows the daily household electricity consumption (in blue) alongside the real consumption (in orange) from the grid whilst the battery is in Balancing Mode i.e. not responding to a ToUT. The simulated household consumption from the grid whilst the battery is in Optimisation Mode i.e. responding to a ToUT, is shown in green.

The difference between the household consumption, and both the real and simulated import from the grid, is noticeably higher here in March than in February (Figure 14) which is largely due to the improved weather enabling more PV generation.

Under Optimisation Mode, if the battery charges from the grid during cheap tariff periods to ensure maximum value delivery during more expensive periods of the ToUT, then the optimised import from the grid will rise, despite improved financial savings to the householder. If however, a day is particularly sunny, the battery may be able to provide maximum value during the expensive tariff periods by charging solely from excess PV generation. In this case, there will be no grid import difference between Optimisation Mode and the Balancing Mode, as shown on the 27th March.

However, a potential conflict arises if the battery, in Optimisation Mode, charges from the grid overnight when the ToUT is low based on an erroneous weather forecast; the battery starts the day full. If the weather is better than forecast and there is excess PV generation not being used in real time during the day, it will be exported to the grid as the battery is full. In this instance, the householder has not maximised the benefit of the free PV generation. Indeed, on the 24th March in Figure 12.0., despite high electricity demand (approx. 14kWh shown in blue) the contribution from the grid (approx. 6kWh shown in orange) is low when the battery is in

Balancing Mode which implies the majority of the electricity demand is being met from PV (approx. 8kWh). However, when the battery is in Optimisation Mode, the import from the grid was simulated to be much higher (in green) as the battery was responding to a low ToUT and not to PV generation.

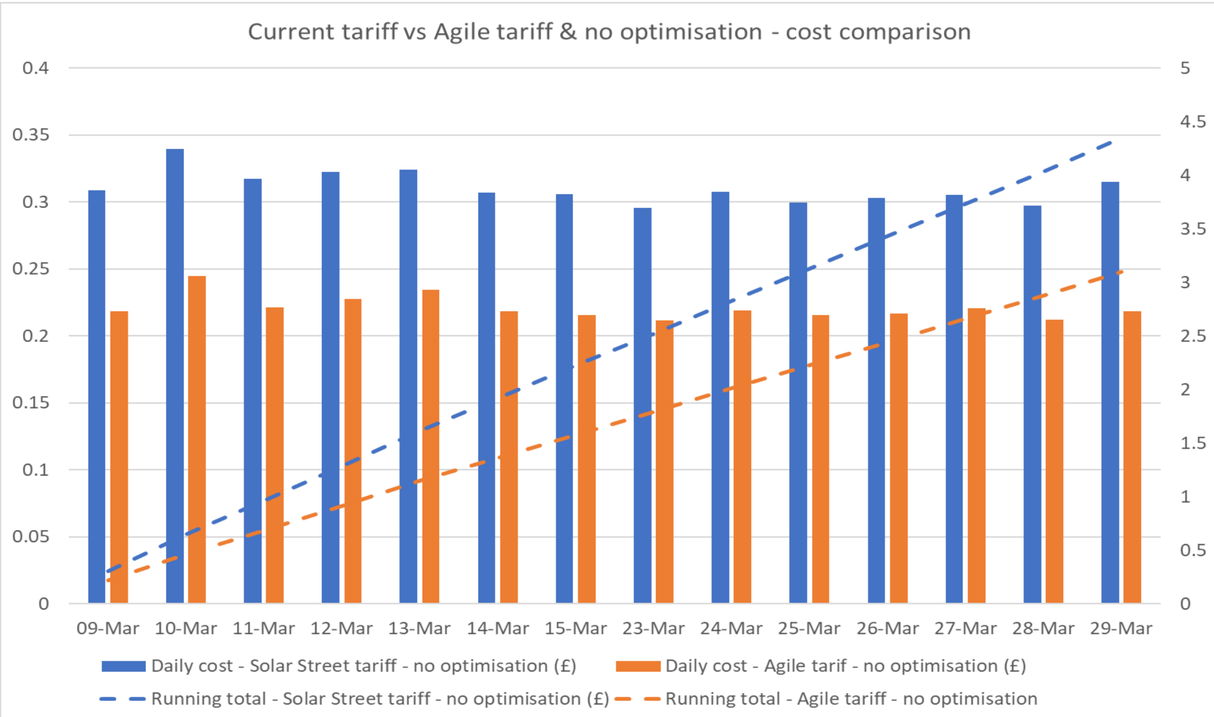
Figures 16 and 17 below show the cost comparison of Householder 7 current tariff with the simulated ToUT when the battery was in Balance Mode and when the battery was in Optimisation Mode.

Figure 16 below shows that if Household 7 had the ToUT but the battery remained in Balancing Mode there would be a reduction in the overall electricity cost in the two weeks in March by approximately 30%.

This suggests that either:
1. the household's default consumption profile was well suited to switching to a ToUT; or,
2. Household 7 actively shifted their demand in response to the daily BWCE prompts to change their consumption pattern to reflect the TOU.

A comparison of average daily demand profiles between February and March (as shown in Figure 9) shows that householders were actively shifting their demand in response to prompts from BWCE.

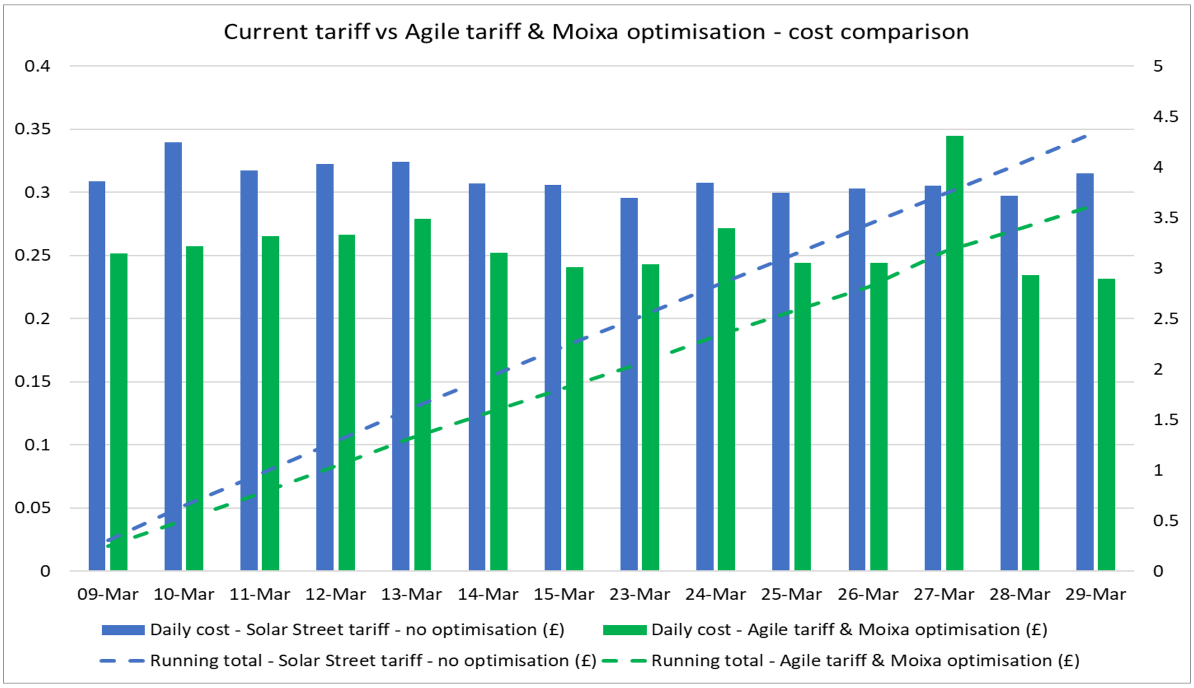
Figure 17: Household 7 Cost Comparison with battery in Balance Mode



Comparing Figure 16 with Figure 17 below, however, shows that when the battery in Household 7 was in Optimisation Mode, the household incurred greater costs, which illustrates that Household 7 is:
1. aware of their daily electricity consumption;
2. aware of the contribution PV generation is making to their consumption;

3. actively shifting their consumption to maximise the use of the PV being generated;
4. therefore, should keep their battery in Balancing Mode and not switch to Optimisation Mode if they switch to a ToUT.

Figure 18: Household 7 Cost Comparison with Battery in Optimisation Mode



By contrast, for a much higher electricity consuming household, Household 3, the cost savings are more significant as shown in Figure 18 below.

Figure 19: Household 3 Cost comparison with Battery in Balance Mode

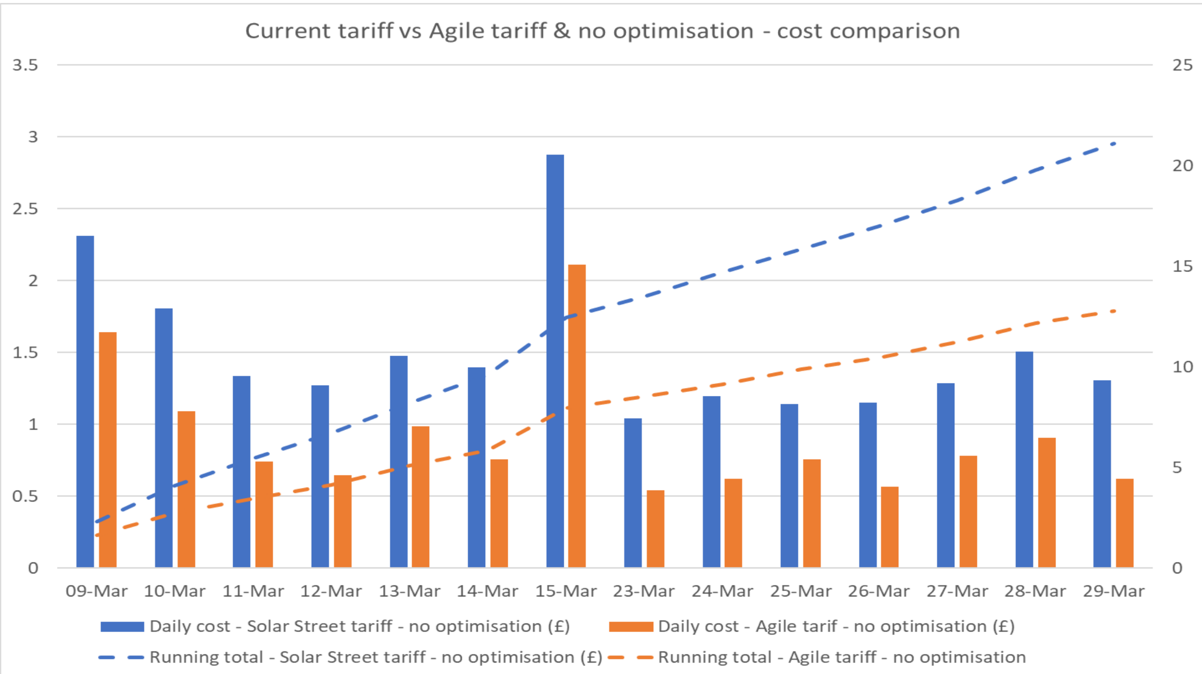


Figure 18 shows that if Household 3 had a ToUT with the battery in Balancing mode, there would be a reduction in the overall electricity cost in the two weeks in March by approximately 39%. Again, this suggests that either:

1. Household 3 default consumption profile was well suited to switching to a ToUT; or,

2. Household 3 actively shifted their demand in response to the daily BWCE prompts to change their consumption pattern to reflect the ToUT.

Figure 20: Household 3 Cost comparison with Battery in Optimisation Mode

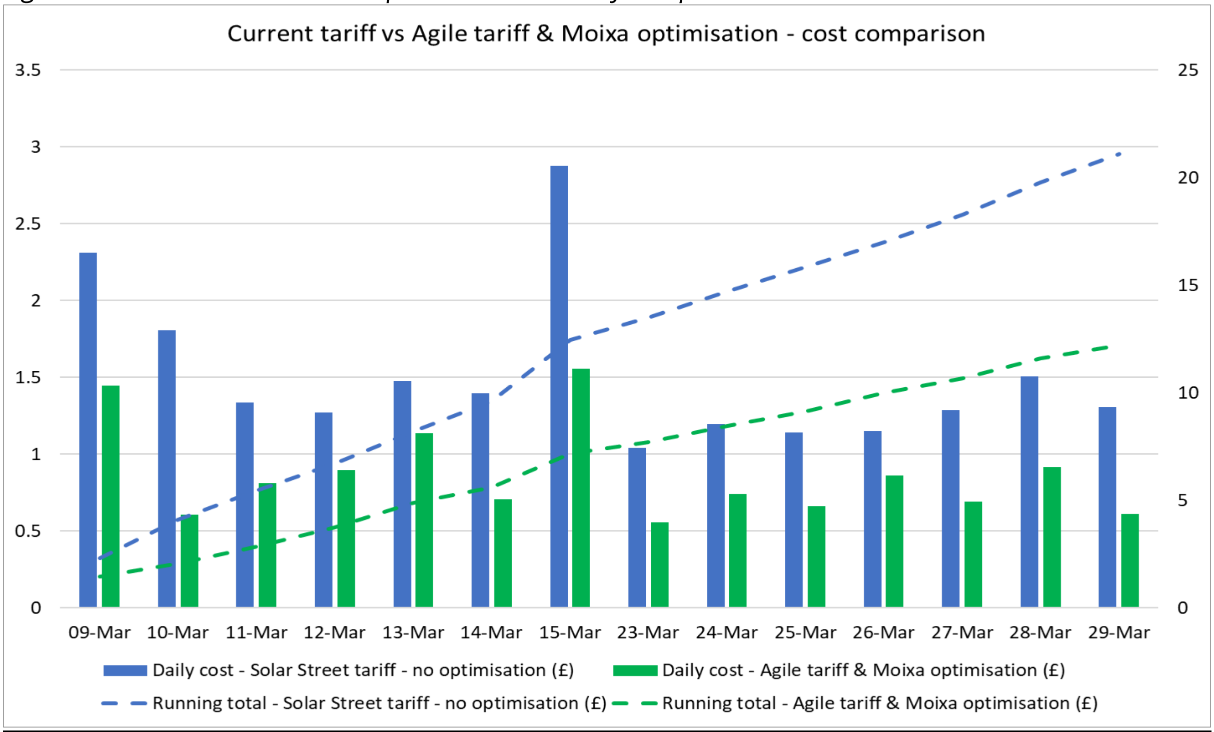
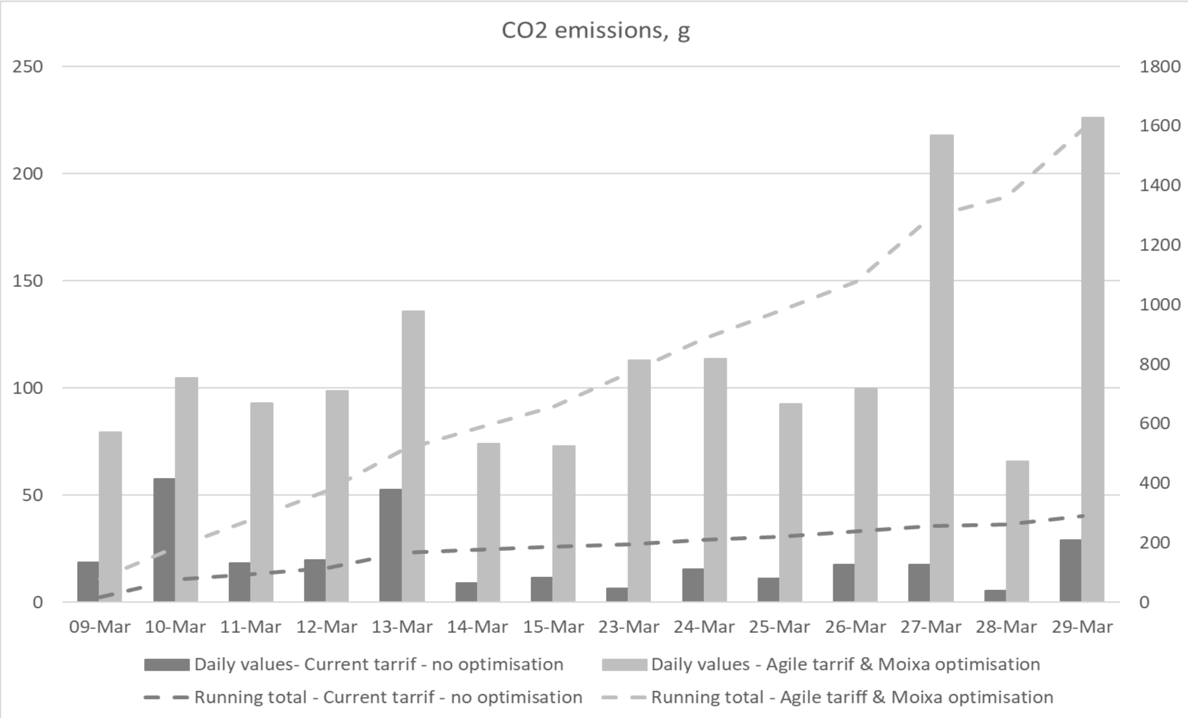


Figure 19 above illustrates that simulating a ToUT with the battery in Optimisation Mode has marginally increased the total potential savings by a further 3% compared with the Balance Mode (Figure 11). This suggests that Household 3 would benefit from switching to a ToUT and re-setting the battery to Optimisation Mode. However, the household would need to be aware that whilst the overall total saving is marginally greater in Optimisation Mode, there are individual days where the cost is higher in Optimisation Mode than in Balancing Mode i.e. 12th March and 26th March. This also implies that as PV generation makes an increasing contribution to the householder's energy supply with the onset of sunnier weather, it is probably not in their best interests to switch their battery to Optimisation Mode.

9.2.6 Carbon Emissions

In addition to modelling the impact of a simulated ToUT on household electricity cost savings, the modelling also included the impact on carbon emissions. Interestingly, for some households, the carbon emissions were greater when responding to a ToUT. This was because when the battery is in Optimisation Mode there is an increased possibility of more grid electricity, as opposed to PV generation, used to charge the battery; see Figure 17 below.

Figure 21: Household 7 CO2 Emissions Comparison Between Balancing and Optimisation Battery Modes



It therefore seems that when there is greater potential for solar PV generation i.e. in sunnier months, it is preferable for the battery to be in Balancing Mode i.e. storing all the solar PV generation that isn't being used in real time. However, whether the householders should switch to a ToUT or remain on a flat rate would depend upon their individual consumption profile and whether the household is actively engaged in demand shifting. An overall conclusion from the ToUT simulation modelling exercise is that switching to a ToUT with the battery in Optimisation Mode may provide the greatest financial savings but may result in higher CO2 emissions.

9.3 Key Findings from Behaviour Surveys

1. Of the 80 households across the two streets that were targeted we had 21 responses (26.25% response rate) to the first survey and 18 responses (22.25% response rate) to the second.
2. Of the 18 respondents to the end of project survey, 14 had installed solar PV and battery storage (out of a total of 16 installations across the project).
3. Solar streets increased householder awareness of the scale of carbon emission reduction required in the home (41% of householders stated they became aware of this because of the project) and the ability to reduce carbon emissions by up to 50% by shifting the time of use of electricity during the day (61% of householders stated they became aware of this because of the project).
4. Solar streets encouraged householders to take actions to reduce electricity demand - 55% of householders stated they made either small or large changes to reduce their demand for electricity because of the project. 71% of householders with installed solar PV and battery storage stated they made either small or large changes to reduce their demand for electricity because of the project.
5. Solar streets encouraged householders to take actions to shift the time when they used electricity - 61% of householders stated they made either small or large changes to change the time of day when they used electricity because of the project. 71% of householders with

installed solar and battery storage stated they made either small or large changes to reduce their demand for electricity because of the project.

6. Before the project 33% of householders said they had made changes to reduce electricity demand and only just under 10% said they had shifted their time of use during the day

Therefore, substantive changes in levels of behaviour change before and after the project as well as actions linked by participants to the project itself were confirmed by the data. More participatory behaviour from householders with solar PV (which isn't surprising) but illustrates the impact that technology can have on behaviour, including the ToUT. Although the sample size is small in this pilot, the findings are in line with the findings from other similar research: see https://energsustainsoc.biomedcentral.com/articles/10.1186/2192-0567-4-13

The percentage of householders that said they were strongly or very strongly motivated to take types of action is shown in Table 4 below.

Table 8: Importance of Motivating Factors on Household Behaviour

Motivating factor	**Percentage of Respondents that said they were strongly of very strongly motivated by factor (%)**
Knowledge that I am involved in a project to promote low carbon energy use	70
Written information on energy efficiency techniques	66
Getting feedback on how my actions are changing the amount of energy I use	58
Reminders and alerts on action to take and when to do it	50
Saving money on my electricity bill	45
Getting feedback on how the collective effort of householders is changing energy use across my community	42
The knowledge that other people in my community are trying to do the same	36
Opportunities to meet up and share experiences with others who are trying to do the same	25
Sharing tips on what works with other householders	25
Moral support to help me overcome barriers, make changes and stick to them	17
Watching videos or hearing talks about changing energy use behaviour	17

It is interesting that saving money is regarded only slightly ahead of factors relating to collaborative action, even after a project that due to external constraints saw enthusiasm wane following project delays.

10 Testing Business Models for Potential Replication

There are two principle approaches that community energy groups might adopt for looking to replicate a Solar Streets type approach that include:

1. community energy funding and ownership of solar and battery assets;
2. aggregating householders within a bulk purchase offer.

10.1 Community Ownership of Assets Approach

The core proposition is that a community energy group procures technology suppliers/installers to create an offer to domestic consumers that provides a solar PV and battery system that:

1. is maintained and insured by the community energy group;
2. is funded by the community energy group and so costs nothing to install for the householder, but is therefore owned by the community energy group;
3. either requires the householder to pay a one off, use of system charge that entitles them to free electricity for the life of the system, or requires the householder to enter into a power purchase agreement with the community energy group whereby the householder pays the community energy group at a discounted rate for every kWh generated that is used by the householder;
4. generates income from trading grid services with the relevant Distribution Network (Service) Operator that will be shared between the householder and the community energy group;
5. secures income to the community energy group from grid export via the Smart Export Guarantee.

The SWOT analysis of this approach is shown in Table 7 below.

Table 9: SWOT Analysis of the Community Ownership of Assets Approach

Strengths	**Weaknesses**
• Builds on existing solar roofs community energy model • Utilises community energy's local presence and accountability to build strong consumer relationships • Utilises proven track record around fund raising to secure capital	• Providing consumer facing services represent a shift for most community energy groups where relationships with local people tends to be as members, investors or as local supporters • Complex financial model with multiple income streams • Solar and battery technology currently too expensive to be financially viable for community energy funding • The trading of grid services will require an additional commercial partner, unless its integrated into the provision of the battery technology
Opportunities	**Threats**
• Working with experienced delivery partners can help community energy groups more rapidly ascend learning curve • Innovation funding programmes could provide community energy groups opportunities to	• Battery technology is rapidly changing and so could be supplying something that becomes sub optimal very quickly • Complex legal arrangements between multiple parties and high transaction costs may undermine financial viability

develop in house experience and build new service delivery capacity • Developing consumer facing services could help community energy groups diversify and continue to add value after the removal of FIT	• Lack of experience of battery technology and grid services markets may place community energy groups at a market disadvantage

The assumptions that underpin the community ownership of assets approach include:

1. O&M and insurance cost £60/yr/system;
2. that on average systems will export 40% of the solar electricity generated;
3. that exported electricity will secure Smart Export Guarantee income of at least 5p/kWh;
4. that inverters will be replaced after 10 years and cost £120/kW;
5. that battery cells are replaced after 10 years and cost £500 per system;
6. RPI at 2.5%;
7. average capacity of 3kW solar PV and 5kW battery per household;
8. average annual yield of 850kWh/kW;
9. at least 100 systems;
10. community finance is raised at 4%;
11. debt is raised to cover 40% of capital at 3%;
12. either:
    a) households are charged for the solar electricity used at 10% discount to commercial tariff (15.54p/kWh average tariff rate in SW https://www.ukpower.co.uk/home_energy/tariffs-per-unit-kwh); or,
    b) households are charged a one-off use of system charge of 25-50% of the capital cost for free electricity for the lifetime of the system and charged an annual fee of £70.

In order to be able to generate sufficient revenue to cover operating costs and £2.5k surplus in the first year then the combined solar PV and battery system price would need to fall by a third to a half to below around £4k and income from trading grid services would need to increase to £100/year/system. This represents an increase in flexibility trading income of between 2 (assuming income based Moixa's current offer) to 10 (assuming income based on WPD's current flexibility offer[4]).

10.2 Bulk Purchase Approach

The core proposition is that a community energy group aggregates interested householders to create a bulk purchase opportunity for solar PV and battery storage that:

1. is not funded and so owned by the householder;
2. is maintained and insured by the householder;
3. all electricity is either used on site by the householder free of charge or exported to the grid and secures income for the householder via the Smart Export Guarantee;
4. generates income for the householder from trading grid services with the relevant Distribution Network (Service) Operator;
5. generates income for the community energy group via a share of the bulk purchase discount to cover overheads.

The SWOT analysis of this approach is shown in Table 8 below.

[4] See https://www.flexiblepower.co.uk/value-calculator for more information, accessed October 2020

Table 10: SWOT Analysis of the Bulk Purchase Approach

Strengths	Weaknesses
• Utilises community energy's local presence and accountability to build strong consumer relationships • Simple model reduces learning curve and opens up opportunity to wide range of community energy groups, including voluntary groups • Limited consumer facing role reduces need for major shift in operation for majority of community energy groups	• Procurement of technology providers may require technical knowledge and process capability for many community energy groups • Solar and battery technology currently too expensive to be financially viable for mainstream householder purchase • The trading of grid services will require an additional commercial partner and significant householder complication, unless its integrated into the provision of the battery technology
Opportunities	**Threats**
• Working with experienced delivery partners can help community energy groups more rapidly ascend learning curve • Referral fees could provide income to cover overheads, though could be within scope of purely voluntary operation and so minimise overhead • Approach could provide community energy groups with ability to create impact and provide added value following removal of FIT	• Battery technology is rapidly changing and so could be supplying something that becomes sub optimal very quickly • Lack of experience of battery technology and grid services markets may place community energy groups at a market disadvantage

The assumptions that underpin the bulk purchase approach include:

1. O&M is not required and there is no additional cost on existing building insurance;
2. that on average systems will export 40% of the solar electricity generated;
3. that exported electricity will secure Smart Export Guarantee income of at least 5p/kWh;
4. that inverters will be replaced after 10 years and cost £120/kW;
5. that battery cells are replaced after 10 years and cost £500 per system;
6. RPI at 2.5%;
7. a capacity of 3kW solar PV and 5kW battery per household;
8. annual yield of 850kWh/kW;
9. annual electricity demand 4,000kWh;
10. households pay 15.54 p/kWh for their grid imported electricity (average tariff rate in SW https://www.ukpower.co.uk/home_energy/tariffs-per-unit-kwh

In order to be able to provide a payback period of 5-10 years to the householder, then the combined solar PV and battery system price would need to fall by a third to a half to around £4k and income from trading grid services would also need to increase to £100/year/system. As outlined above, this represents an increase in flexibility trading income of between 2 to 10, depending on assumed current trading income levels.

In order to cover overheads for setting up and running a bulk purchase scheme for 100 households then its estimated that a referral fee of around 5% of the capital cost might be required, assuming the above fall in capital cost.

10.3 Commentary

At the moment the capital costs of a combined solar PV and battery system mean that replication as a community model is not currently viable and offer payback periods of 20 years plus for householder investment. The analysis suggests that capital costs may need to fall by at least a third and income from grid services double in order to create viable models that might underpin replication of the Solar Streets type model covering both domestic solar and battery storage. In terms of capital costs, this does not seem to be too challenging if solar and battery prices continue to fall at the current rates[5]. As far as battery technology is concerned there is of course a close relationship with the growth of electric vehicles and the weight of investment that is going into new technology development. There is clearly an issue about the sustainability of metals like lithium and cobalt used in the current most common battery technologies. This should also raise serious questions about the desirability of prioritising domestic battery technology over demand side response to create greater grid flexibility at a domestic level.

However new technologies are being developed that might create a more sustainable storage system, though application in a domestic context may take some time to come to market. With regards income from flexibility markets, it is difficult to know whether aspirations of £100/yr/household are achievable given the immaturity of flexibility markets open to domestic consumers. Though maybe lower capital costs might be achieved that would reduce the burden on grid services income to meet the financial gap in generating a viable model.

[5] https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/ and https://www.solarpowerportal.co.uk/news/lcoe_costs_of_solar_pv_continue_to_plummet_in_beis_forecasts