SUPPORTING THE ENERGY TRANSITION WITH THE INTERNET OF THINGS

OPTIMISING LOCALLY PRODUCED ENERGY ON THE ISLES OF SCILLY

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Supporting the energy transition with the Internet of Things. Optimising locally produced energy on the Isles of Scilly.

Smart Energy Islands project - final report.

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Autor's Note

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EXECUTIVE SUMMARY

Achieving the Net Zero greenhouse gas emissions 2050 target set by the UK Government while maintaining security and affordability of electricity supply will require an unprecedented level of change and innovation in the energy system. With low levels of energy-efficient housing, high electricity bills resulting from a lack of a gas grid, no electric vehicle charging infrastructure, low penetration of renewable generation and being located on a constrained part of the electricity grid, the Isles of Scilly exemplified many of the challenges that will need to be overcome nationally if the 2050 target is to be achieved.

To increase sustainability, resilience and reduce fuel poverty, in 2015, the Isles of Scilly set ambitious goals in their Smart Islands Programme: to satisfy 40 percent of electricity demand through local renewable energy, reduce electricity bills by 40 percent and convert 40 percent of vehicles to low carbon by 2025.

Hitachi joined Scilly's Smart Islands Partnership, which also comprises the islands' main landowners and stakeholders, as a founding member to bring technological and social innovation expertise to the programme.

The first project delivered by the Smart Islands Partnership was a smart energy project led by Hitachi Europe Ltd. and supported by the European Regional Development Fund, delivered between December 2016 and December 2019.

Hitachi worked in partnership with UK-based companies Moixa and PassivSystems to demonstrate how PV and smart domestic devices, managed by an 'Internet of Things' (IoT) solution, could provide better and cheaper services to households while supporting the transition to a low carbon energy system. Specifically, a combination of rooftop PV, air source heat pumps (ASHP), hot water tank controls, and domestic batteries were installed in 82 council owned homes along six larger PV arrays, storage batteries and a smart EV charger in the Council's commercial buildings.

On a household level, the primary objective was to meet the requirements for heating and hot water at the lowest possible cost to the household, making best use of behind the meter solar PV and the Economy 7 tariff. This involved complex decision-making by AI-based algorithms developed by PassivSystems, including learning the thermal characteristics of hot water tanks and granular control of heat pumps to achieve the objectives at the best possible efficiency.

The IoT platform prioritised households' heating and hot water comfort choices set by them for their home – only spare capacity was used to manage flexibility within the energy network. Homes involved in the scheme reduced their energy bills by around 20 percent, demonstrating the value of long-term adoption of energy management in supporting the Isles of Scilly's 2025 targets.

On an Island level, the project explored whether curtailment of local PV generators could be mitigated by turning up demand at the time of surplus generation. This element of the project was delivered in collaboration with Western Power Distribution (WPD), the distribution network operator (DNO) in the south west of the UK. Specifically, Hitachi's IoT platform was able to receive curtailment signals from WPD's Active Network Management, translate it into a flexibility request that two separate aggregators, PassivSystems and Moixa, could respond to, obtain a confirmed order and ultimately deliver the required flexibility from multiple devices (EV, ASHP, Batteries and Hot Water). The aim was to absorb the surplus generation and enable the local PV to continue to produce, thus making better use of locally generated electricity.

Communication between parties and the ‘energy flexibility’ trading approach was governed by the Universal Smart Energy Framework (USEF)[1], with Smart Energy Islands (SEI) being the first implementation of the framework in the UK. USEF was selected as the most comprehensive and implementation ready framework available at the time. The core of the IoT solution is Hitachi’s Energy Flex Trader platform developed as part of the project, securely hosted on a public cloud and designed within a micro-services, event-driven architecture. This approach was selected on the premise that it delivers a solution that is easily replicable, scalable and configurable.

A series of trials explored energy demand turnup as well as turndown use-cases, applicable to a range of real-life requirements for energy flexibility. For example, turnup can enable the accommodation of an increased amount of distributed renewable generation on low voltage networks and turndown can reduce peak demand from electric heating and EV charging, thus avoiding or deferring expensive network reinforcements. The key learnings from the trials included:

- The system was able to successfully execute flexibility while maintaining comfort levels within the required user settings (temperature and hot water availability)
- USEF proved an effective way for communication between parties, with 97% of trading cycles completed successfully in the final trial
- Distributed domestic devices can be significant sources of flexibility. In the turnup scenario, a response of up to 31% of the total installed capacity of participating devices was achieved, while turndown proved more challenging, achieving 9%. These values are indicative of what could be achieved if the system was scaled up. For example, to fully offset the curtailment of a 40kW solar garden, approx. 61 participating homes would be required
- Distributed domestic assets can cost-effectively provide flexibility to address grid constraints. While the price range was large (£0-130/ MWh) and did not include aggregator’s operating cost, it is well below the current commercial value (e.g. £300/ MWh under WPD’s Constraint Management Zone (CMZ))
- Bringing flexibility trading closer to real time would facilitate the participation of domestic demand response. The availability of flexibility is highly dependent on factors which are difficult to predict accurately in advance, most importantly user behaviour. At the same time commercial arrangements often require declarations in advance, for example a week ahead, which may create an unacceptable level of risk for the aggregator
- Ideal asset mix is use-case dependant. The mix of generation (solar PV) and heating assets is not an ideal match from the point of view of the curtailment avoidance scenario. Heating devices were less able to provide demand turn up in the summer, when PV is at a higher risk of curtailment. This ability could be more valuable in combination with a different mix of generation, for example for the purposes of avoiding curtailment of wind power
- DNO flexibility services could bring additional income to the Isles, but cost and benefits of participation need to be balanced. The value of these services is location dependant and under the current CMZ scheme demand turn-down on the islands is required mainly during April. The current scheme would generate a revenue of approx. £1,300 in 2020, which was

[1] ‘Energy flexibility’ refers to the ability to shift electricity consumption patterns. This ability can be traded and USEF is a standardized framework which enables such trading https://www.usef.energy/

deemed insufficient to cover the administrative cost. However, this may change in the future, depending on WPD's requirements

- Baselining of domestic flexibility and creating transparency for the DNO is crucial to enable market participation of domestic flexibility providers. The difficulty lies in distinguishing between the device's 'flexed' demand and what the device would be drawing under normal circumstances. As the latter can be highly variable, thus estimating a realistic baseline is not straight forward.

The project also developed a community-based business model with the aim of preserving its legacy and delivering the benefits of the system to the residents. The Isles of Scilly Community Venture was established as a Community Interest Company in 2017. The initial business case indicated that the organisation could become financially self-sustaining, once it accumulated a sufficient asset base. Any surplus generated by the Community Venture would be distributed back to the community in the form of reduced energy costs. Innovative commercial and regulatory arrangements were explored with Ofgem's Innovation Link and a licenced supplier was brought on board as a partner to launch the Isles of Scilly Energy-Share tariff in the Autumn of 2018. The tariff was postcode-restricted and available only to the residents on Scilly, with all locally generated renewable electricity allocated to the tariff by the supplier, with the aim of it becoming cheaper and greener over time. Despite only word-of-mouth marketing, the tariff enjoyed a rapid uptake, exceeding 50 customers within the first few months, testament to the trust of the community in the Community Venture. Complementary to the tariff, a model to charge for behind-the-meter self-consumption at a reduced rate, 40% below the available tariffs, was developed. This meant that the households where PV was installed would benefit from cheaper electricity, while at the same contributing to the Venture. Metering, data collection and provision of billing data was implemented as part of the IoT solution.

Regulatory exemptions were explored with the objective of creating a Local Energy Market that would allow retention of the value of local generation within the community, incentivising further rollout of renewables and creating further incentives to shift local demand in line with generation. These included licence-exempt supply and a virtual meter arrangement. However, this element of the project was significantly impacted by external changes. Firstly, the selected licenced supplier partner, Our Power, went out of business in January 2019 as a result of unfavourable market conditions, which have led to bankruptcies of several smaller suppliers. Secondly, wider changes to the ways network cost are allocated to customers were initiated by Ofgem in the form of the Targeted Charging Review in August 2017 to create a fairer cost recovery mechanism. This meant that derogations from existing regulation for the purposes of innovation were put on hold and created significant uncertainty in the market regarding the future revenue streams for demand response.

Overall, the project has delivered direct and lasting benefits for the islands, valuable learning and replicable technologies for the delivery partners, as well as informed the wider energy market transition agenda. For the Isles, the journey towards sustainability continues with the ERDF-supported Go-EV project, which will install 27 EV chargers across the islands, 10 of them with vehicle-to-grid capability, deploy a fleet of electric vehicles and a car share scheme, as well as additional solar PV generation. The project builds directly on the legacy of SEI with Hitachi and Moixa both involved as technology partners. Go-EV contributes to Hitachi's strategic priorities in the area of mobility and will complement the learning from Optimise Prime, the world's largest corporate EV trial project, led by Hitachi in collaboration with UKPN and SSEN, who operate the electricity distribution networks in London and the South of England.

More broadly, this project has highlighted improvements and further work needed to make domestic flexibility a reality and enable wider market access for aggregators and flexible device owners.

Challenges identified include the need for fair and verifiable baselining approaches, forecasting accuracy and dependence on portfolio size and the nature of the devices controlled. The administrative costs of running a DSR scheme with many small assets and complex commercial arrangements, as well as building customer trust and acceptance of automation are also important aspects to be considered in any scheme. Many of these challenges are currently being addressed by other projects, for example SPEN's FUSION and WPD's Intraflex[47], that the Hitachi project team follows with interest.

1. CONTEXT

The UK first demonstrated its commitment to reducing its greenhouse gas emissions in the *2008 Climate Change Act* – with a target to reduce six key greenhouse gases to 80 percent of their 1990 level by 2050[2]. This followed the publication of *The Economics of Climate Change: The Stern Review*[3], one of the most influential reports on climate change ever produced since its release by Her Majesty's Treasury of the UK Government in October 2006.

In June 2019, the UK became the first major economy to commit to reducing all domestic greenhouse gas emissions to net zero by 2050 – in effect committing to ending the UK's contribution to global warming over the next 30 years[4].

The power generation sector, which contributes around 29 percent of the UK's total carbon footprint[5], will need to innovate how it delivers energy to meet this net zero target. The National Grid's *2019 Future Energy Scenarios* report states that the electricity system will need to operate using zero carbon generation technologies and that the power sector in general will need to deliver negative emissions, removing emissions from the atmosphere[6].

The UK has already installed more offshore wind power than any other country, the cost of which has fallen by half since 2015[7]. Other renewable energy generation technologies are also increasingly contributing to the UK's energy mix. However, many of these technologies are weather and season dependant leading to peaks and shortfalls in energy production.

To meet the UK's net zero carbon targets the National Grid also recognises that homes will need to use one-third less energy for heating. To achieve this, more than 23 million homes will need to install new, low-carbon heating solutions by 2050. The decarbonisation of home heating will take many forms and will include greater electrification, carbon-free gas and the introduction of hydrogen or hybrid systems. Greater electrification through the use of heat pumps, which can efficiently bring heat from outside into the home as a source of low carbon heating, have the potential to reduce running costs compared with oil, direct electric, LPG, or coal, and can provide substantial carbon savings over the lifetime of the installation. Integration of these technologies into the wider energy system was a central component of this project.

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[2] UK Parliament *Climate Change Act 2008*. Retrieved from http://www.legislation.gov.uk/ukpga/2008/27/contents

[3] Nicholas Stern *The Economics of Climate Change: The Stern Review* (2006). Retrieved from https://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm

[4] UK Parliament *UK Carbon Budgets* (July 2019). Retrieved from https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7555

[5] Department of Business, Energy and Industrial Strategy (2018) *2017 UK Greenhouse Gas Emissions, Provisional Figures*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695930/2017_Provisional_Emissions_statistics_2.pdf

[6] National Grid *Future Energy Scenarios* (July 2019). Retrieved from http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

[7] RenewableUK *Offshore Wind Project Intelligence* (June 2018). Retrieved from https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/renewableuk_project_intellig.pdf

1.1 AN ENERGY SYSTEM IN TRANSITION

Historically, non-renewable sources, predominantly coal, oil and natural gas, have dominated the energy supply in the UK. In 1970, coal alone generated 47 percent of the UK's energy. However, by 2019, the contribution from renewable generation was at a record high level, due to increased wind, solar and biomass capacity.

National Grid's data[8] shows that zero carbon, clean energy from wind farms, solar and nuclear energy, alongside energy imported by subsea cables, delivered 48.5% of Britain's electricity in 2019. This compares to 43% generated by fossil fuels: coal, gas, and other carbon sources such as oil and diesel. Biomass, such as wood pellets, generated the remaining 8.5%.

Not only has the cost of wind-power halved since 2015, but the price of solar PV installations has also fallen by around 12 per cent since 2014[9]. As the cost of building new renewable energy generation continues to drop, more and more renewable energy resources will be added to the grid.

An additional challenge for the energy infrastructure is the growing demand for electricity, in part driven by the large-scale introduction of electric vehicles (EVs) and other forms of electric transport. The number of EVs on the roads will reach between 2.7 and 10.6 million by 2030 and as many as 36 million by 2040[10]. Although EVs may be perceived as high users of energy, the smart integration of EVs into the electricity grid may serve to help balance the variability of renewable energy generation. The National Grid suggests that if properly integrated into the network, EVs have the potential to store one fifth of the UK's solar energy generation[11].

Two things therefore drive the transition: the requirement to accommodate a greater amount of distributed, intermittent generation from renewables and an increased demand during peak periods from heat pumps and electric vehicles as the energy system decarbonises. This means developing new approaches to network management, types of connection agreements and commercial arrangements.

1.2 THE CHALLENGE OF RENEWABLES

Intermittent weather dependent renewables, such as wind and solar, bring more volatility to the grid as their output cannot always be accurately predicted or controlled, unlike traditional generators such as gas plants. These issues are often localised and depend on the mix of generation and demand in a given location.

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[8] National Grid *Britain hits historic clean energy milestone as zero carbon electricity outstrips fossil fuels in 2019* (Jan 2020). Retrieved from https://www.nationalgrid.com/britain-hits-historic-clean-energy-milestone-zero-carbon-electricity-outstrips-fossil-fuels-2019

[9] Department for Business Energy & Industrial Strategy *Solar photovoltaic (PV) cost data* (2019). Retrieved from https://www.gov.uk/government/statistics/solar-pv-cost-data

[10] National Grid *Future Energy Scenarios* (July 2019). Retrieved from http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

[11] National Grid *Future Energy Scenarios* (July 2019). Retrieved from http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

Therefore, there must be enough controllable production and stored energy within the system to ensure that there is enough electricity available. Maintaining this extra capacity imposes additional costs on the system, and ultimately the consumer.

The integration of large amounts of renewable generation and low carbon electric heating and transport into the electricity distribution network can require costly reinforcement to transport the electricity from where it is generated to where it is needed. Shifting energy demand to match generation times better can allow the distribution networks to accommodate more generation without costly reinforcements. Controlling large-scale industrial demand or a greater number of smaller facilities can achieve the necessary change.

Surplus production at times of low demand is a problem in areas where renewable generation dominates. When reverse power flows (i.e. toward the grid rather than from it) exceed the capacity to carry these flows without breaching network margins, the network operator restricts embedded generation to protect the network from damage caused by these reverse power flows. The network operators limit or 'curtail' the output of energy generators. This in turn affects the cost effectiveness of renewable energy generators, capping their ability to generate income and affecting the overall business case for their installation.

Technologies that can provide flexibility at the network edge complement the installation of renewables. They will help to compensate for the fluctuations in renewable generation by adjusting their demand accordingly and enabling the Distribution Network Operators (DNOs) to accommodate more renewables on a constrained grid.

1.3 DEMAND SIDE RESPONSE

Demand Side Response (DSR) is a change by end users in their electricity consumption patterns. This may be in response to a price signal, such as time of use or variable tariff, or a direct payment from the network operator. This ability to change energy demand helps to ensure a match between power supply and demand, which in turn prevents the distribution network from becoming overloaded[12]. Demand side response may also allow the addition of more energy generation resources to a constrained network and can defer network reinforcements.

Examples of DSR include shutting down non-essential industrial processes during peak demand or increasing demand by charging electric vehicles and heating up water tanks during a sunny day, when solar generation is abundant, but demand is low.

DSR is a well-established practice with large industrial and commercial users. However smaller, domestic energy resources are rarely integrated due to high technical and commercial complexity. While the response provided by a large portfolio of domestic devices and EV chargers may be significant, the contribution of each of them is relatively small. This creates a need for specialist intermediaries / aggregators with systems, processes and commercial arrangements in place to be able to handle the high complexity and enable individual households to access the DSR market.

[12] The Association for Decentralised Energy *Tools and Resources* (2019). Retrieved from https://www.theade.co.uk/resources/what-is-demand-side-response

1.4 DOMESTIC ENERGY MANAGEMENT

In 2018, the domestic sector accounted for nearly 30 percent of total energy consumption in the UK[13] with space and water heating accounting for about 80 percent of the energy use within each home. Only about five percent of this demand is met by electricity[14] but in places like the Isles of Scilly that are 'off-grid' for natural gas, electricity use is much higher.

There have been several key changes in households that have put downward pressure on energy consumption. The increasing prevalence of energy-efficient boilers, such as combination and condensing boilers, for example.

The proportion of households with a hot water tank remains at around 50 percent[15] and these are a significant component within the home heating system – with a modern, sealed domestic hot water tank operating efficiently when compared to a combination boiler.

To reduce the carbon associated with powering homes, new homes will increasingly look to electric systems to replace the much more common gas heating. Similarly, retrofitting existing homes with new electric systems may be required, if domestic heating is to be fully decarbonised.

Strategies to reduce the carbon footprint of domestic energy include the adoption of domestic heat pumps and the integration of domestic solar PV for energy generation.

More than seven million UK homes are fitted with solar Photo Voltaic (PV)[16] panels for energy generation. Although the rate of growth has slowed more recently, in particular due to policy changes related to Feed-In Tariffs, solar remains popular within community energy programmes. The popularity of domestic solar PV is likely to increase: as technology prices fall, with integration of battery storage and PV panels,[17] and with additional value created by supporting grid management.

1.5 MANAGING THE GRID

Traditionally, large centralised electricity generators and extra high voltage transmission grids deliver electricity over long distances. Distribution networks then carry electricity from the transmission grid to industrial, commercial and domestic users. However, this model does not accommodate embedded renewable generation, reverse power flows, or supply to EVs and heat pumps.

The separation of functions between a Distribution Network Operator (DNO) and Distribution System Operator (DSO), which is a more active role using approaches such as active network management, new-technology and real-time data to make interventions on the network, is emerging. This model is similar to the model applied on the transmission level with a separation of the

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[13] Department for Business, Energy & Industrial Strategy *Energy Consumption in the UK (ECUK)* 2019. Retrieved from https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

[14] BBC *BBC Briefing: Energy* (2019). Retrieved from https://news.files.bbci.co.uk/include/newsspec/pdfs/bbc-briefing-energy-newsspec-25305-v1.pdf

[15] Department for Business, Energy & Industrial Strategy *Energy Consumption in the UK (ECUK) 1970-2078* (2019). Retrieved from https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

[16] Energy Savings Trust *Smart Export Guarantee – a lifeline for the solar industry?* (2019). Retrieved from https://www.energysavingtrust.org.uk/about-us/news/smart-export-guarantee-%E2%80%93-lifeline-solar-industry

[17] National Grid *Future Energy Scenarios* July 2019. Retrieved from http://fes.nationalgrid.com/media/1409/fes-2019.pdf

National Grid into the Transmission System Operator (TSO) and a new independent entity, the Electricity System Operator (ESO), launched on the 1 April 2019. This structure is seen as much more capable of managing the challenges of decarbonisation of the energy system, while ensuring the security of supply and keeping costs down for consumers.

In the UK, there is currently 108 GW of generation capacity, with 71 percent transmission connected, 24 per cent distribution connected and five per cent through microgeneration. The National Grid suggests that distribution connected energy generation could increase to 36 per cent by 2050 – mostly through the integration of renewables[18]. New generation, as well as demand increase caused by the electrification of heat and transport, connecting into the distribution system will cause localised issues for the DNO, as well as impact the transmission grid further upstream and will therefore require the more active form of management provided by the DSO model.

The new DSO model will also incentivise the operators to more proactively manage the distribution grids, make use of flexible resources and foster innovation, however this requires significant regulatory change.

At the time of writing, the details of the future shape of the sector are still under discussion, with Ofgem and the Energy Networks Association[19] investigating several options. The outcomes from the Isles of Scilly project aim to contribute further evidence to this discussion.

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[18] National Grid *Future Energy Scenarios* July 2019. Retrieved from http://fes.nationalgrid.com/media/1409/fes-2019.pdf

[19] Energy Networks Association *Future Worlds: Consultation* 2018. Retrieved from http://www.energynetworks.org/electricity/futures/open-networks-project/workstream-products/ws3-dso-transition/future-worlds/future-worlds-consultation.html

2. PROJECT OUTLINE

The Smart Energy Islands project sought to demonstrate how domestic energy technologies, managed by an 'Internet of Things' (IoT) system in conjunction with a smart energy trading framework, could support the transition to the Distribution System Operator (DSO) model.

The Isles of Scilly have been the first UK location to trial a flexibility solution that integrates locally generated energy, energy storage in home batteries and water tanks within the Universal Smart Energy Framework (USEF). The project focused on designing and testing a model for increased penetration of renewables, within a DSO model, with the aim of reducing the incidence of energy generation restriction (curtailment). Due to distribution grid congestion, at the time of the project scope definition, new solar installations in the South West (including the Isles of Silly) were subject to curtailment as much as 80 percent of the time.

In February 2019, as part of the Flexible Power programme, WPD announced a Constraint Management Zone (CMZ) on the Isles of Scilly[20] with the intention to procure DSR services for 2020. The CMZ is intended to address peak demand issues during April and May, months of highest electricity demand on the islands. This was taken into account during the trial phase of the project to demonstrate that the system is able to address both scenarios – excess generation and excess demand.

The project was part-funded by the European Research and Development Fund, and took place over three years. Smart Energy Islands was a technical partnership between Hitachi, Moixa and PassivSystems. The project capitalised the value of existing domestic energy assets and the changing landscape of home energy management.

The Council of the Isles of Scilly had expressed a desire to increase the level of renewable energy generation on the islands, as part of the islands' 'Smart Islands Programme'. However, the penetration of low carbon and renewable energy provision was low, restricted to a few houses and community buildings that were not part of a smart energy system. Without funding, or the platform to manage a step-change in energy generation across the islands, the Council of the Isles of Scilly was unable to make progress in this area.

The Isles of Scilly were chosen as a trial location as it was determined that the system could be tested while supporting the islands' own transition to adopting locally produced renewable energy and contribute to improving residents' home comfort levels.

The Isles of Scilly provided a discrete platform to study the effect of low carbon technologies on an electrical network. The single 55km, 33 kilovolt connection with the mainland allowed for comprehensive monitoring of the energy demand and delivery from the DNO. Monitoring units on the main substation (pre-existing) and two installed as part of the project on substations at Hugh Town and Old Town – where the majority of the project assets would be located – enabled a granular understanding of the effect of the project on the distribution network.

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[20]Western Power Distribution *Isles of Scilly - CMZ_T3B_SWE_0008* 2019. Retrieved from https://www.flexiblepower.co.uk/scheme/CMZ_T3B_SWE_0008

This combination of the islands' ambition and discrete but grid-connected location presented an ideal opportunity for Hitachi to collaborate with the Council of the Isles of Scilly.

1.6 THE PROJECT'S AIMS

The project aimed to test an innovative IoT solution to address issues associated with excess embedded generation and excess peak demand by integrating technologies installed in domestic and larger-scale installations, whilst creating a legacy of low-cost, low-carbon energy on the Isles of Scilly.

1.7 TECHNICAL OBJECTIVES

Unlock the commercial and technical constraints on the Isles of Scilly, which were stopping the islands from realising their broader low carbon objectives, while trialling an IoT solution for energy management and automated demand side response.

Ensure the infrastructure from this demonstration project continued to support the Isles of Scilly in their wider Smart Islands' objectives.

1.8 SOCIAL OBJECTIVES

Improve social outcomes for the community by providing the infrastructure to reduce fuel poverty through enabling a local energy market and raising aspirations to achieving low carbon energy provision.

Maximise economic benefits by supporting local businesses to actively engage in energy saving strategies.

To help make benefits available to the wider community and any householders not directly involved in the project through programme-funded energy equipment, the project also helped to develop the Isles of Scilly Community Venture – a community interest company. One of the potential revenue streams for the Community Venture will be a community energy tariff, with energy provided from the solar installations, and this offer is currently under review.

1.9 INSTALLATION SUMMARY

Eighty-two homes, a substantial part of the Council of the Isles of Scilly's total stock of social homes, were included in the project. Each was fitted with a combination of energy generation and energy storage technologies and connected to Hitachi's IoT platform.

- In the 82 homes, various combinations of technologies were installed:
- 69 had rooftop solar PV
- Eight homes were fitted with air source heat pumps (ASHP)
- 50 homes were retrofitted with PassivSystems' hot water tank sensors and smart controls for the immersion heater
- Five homes had battery storage, provided by Moixa, installed.

In addition, five other Council-run sites were installed with larger rooftop solar PV systems and a solar garden was constructed at the Airport on St. Mary's.

The IoT system trialled on the Isles of Scilly aims to optimise each building's use of locally generated solar energy, their heating, hot water and their domestic energy storage battery. The system was designed to ensure each household's comfort and energy requirements were maintained whilst maximising the benefit from low-carbon, low-cost energy.

2 PROJECT PARTNERS

HITACHI EUROPE

Hitachi Europe has its headquarters in Maidenhead, UK. The company focuses on its Social Innovation Business – delivering innovations that answer society's challenges. Hitachi Europe and its subsidiary companies offer a broad range of information and telecommunication systems; rail systems, power and industrial systems; industrial components and equipment; automotive systems, digital media and consumer products and others with operations and research and development laboratories across Europe, the Middle East and Africa.

PASSIVSYSTEMS

PassivSystems, an award-winning company, has developed a secure, scalable cloud-based 'PassivEnergy' smart home energy management platform for collecting data from smart meters, low carbon technologies and solar PV which integrates with its Predictive Demand Control (PDC) technology. The Predictive Demand Control (PDC) technology learns the detailed thermal response of a property and builds a physics model of the house and heating system. Using this model, it can optimise the performance of low carbon technologies over the upcoming day, and predict the control strategy that is required to minimise energy consumption while meeting the comfort demands of the occupiers at the lowest possible cost.

MOIXA

Moixa is the UK's leading cleantech company that develops software and hardware to facilitate smart energy storage and sharing. Its GridShare software uses AI technology to learn and optimise daily battery and electric vehicle charging, leveraging low carbon (renewable) resources and time-of-day tariffs. The software also enables aggregation and management of large fleets of batteries and electric vehicles in order to deliver flexibility services into ancillary markets and deliver superior customer propositions and savings. Moixa Smart Batteries are in over 1,000 homes in the UK and over 12,000 third party batteries with approximately 125MWh under the management of GridShare software in Japan.

COUNCIL OF THE ISLES OF SCILLY

The Council of the Isles of Scilly is a unitary local government authority. Uniquely, it provides a broader range of local services to the community than is normal for a unitary council, including air traffic control, water supply, fire and rescue, environment (including the Area of Outstanding Natural Beauty), waste and transport. The Council supports the ambition to be at the forefront of sustainable energy development by providing a test bed for industry to innovate and is part of the Isles of Scilly's Smart Islands Partnership.

EUROPEAN REGIONAL DEVELOPMENT FUND

The European Regional Development Fund (ERDF) in Cornwall and Isles of Scilly is worth €450m during 2014-2020. The programme's priorities for investment in the region include promoting the production and distribution of energy derived from renewable resources and promoting research and innovation in, and adoption of, low carbon technologies.

ISLES OF SCILLY COMMUNITY VENTURE

The Isles of Scilly Community Venture is a not-for profit company focused on developing projects that will help Scilly become fit for the future – self-sufficient, resilient and low carbon. At its core it aims to share the benefits of these projects with the residents and businesses that make up the local community. The Isles of Scilly Community Venture has focused in its early years around the Smart Islands programme. It aims to ensure that any value from projects is retained on the islands and used to develop and deliver further innovative products and services designed to meet the needs of the community for generations to come. The Isles of Scilly Community Venture C.I.C. is a Community Interest Company registered in England and Wales

WESTERN POWER DISTRIBUTION

Western Power Distribution (WPD) is the electricity distribution network operator for the Midlands, South West and Wales. It delivers electricity to over 7.9 million customers over a 55,500 square kilometre service area and employs over 6,500 staff. WPD's Innovation Strategy has three key focus and priority areas – transport, heat and data – to support the UK Government's net-zero 2050 agreement. WPD engages with partners through its Network Innovation Allowance (NIA) and Competition (NIC) projects. In parallel to the SEI project, WPD ran the NIA funded Smart Energy Isles project, working closely with SEI.

3 THE ISLES OF SCILLY – A PARTNERSHIP IN INNOVATION

The Isles of Scilly were selected to trial the IoT platform as they offered a unique opportunity to demonstrate the system's capabilities. Due to their islanded position and single cable connection to the British distribution network, the Isles of Scilly provide a discrete platform: to study the effect of low carbon technologies on an electrical network and to apply learning from this on other electrical networks in the UK.

3.1 SITUATION

The Isles of Scilly are a collection of five inhabited islands in an archipelago of more than 100 in the North Atlantic, located 30 miles off the coast of Cornwall in the United Kingdom.

Day-to-day, the energy supply on the Isles of Scilly is almost completely imported from the mainland by a 33 kilovolt (kV) sub-sea cable. Historically, there has been a small amount of renewable energy generation from solar Photo Voltaics (PV), only installed on a handful of private, domestic dwellings between 2008 and 2012. These deliver between two and four kilowatt-peak (kWp) at each installation. In 2015, renewables met less than two percent of annual demand, 18,500 megawatt-hours per year (MWh/a)[21]). The single 55km, 33kV connection with the mainland allowed for comprehensive monitoring of the energy demand and delivery from the Distribution Network Operator (DNO).

3.2 CHALLENGE

The islands experience a high social cost for the provision of energy due to a reliance on diesel, fuel oil and imported electricity. The Isles of Scilly are off-grid for natural gas and so despite supply tariffs equivalent to the rest of the south-west, electricity use on the islands is about double that of on the mainland. This high energy demand combined with the islands' temperate Oceanic climate has results in a high incidence of fuel poverty (22.4 percent against the national average of 10.4 percent[22]).

Alongside this, the islands are designated a Conservation Area, Area of Outstanding Natural Beauty (AONB) and Heritage Coast. As such, the local authority, must make sure that all development decisions have regard for the purpose of conserving and enhancing the natural beauty of the AONB.

3.3 OPPORTUNITY

The Isles of Scilly experience high levels of solar irradiation, which makes the location very suitable for solar PV generation, but PV penetration is low.

A large, coordinated PV installation project would reduce the costs associated with infrastructure projects on the islands. Increasing renewable energy generation on the islands will lead to greater energy independence and reduced costs for residents.

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[21] Council of the Isles of Scilly/Hitachi Europe Ltd. (2016) *Energy Infrastructure Plan for the Isles of Scilly, Smart Islands*. Retrieved from https://www.scilly.gov.uk/sites/default/files/IoS_Infrastructure%20Plan_FINAL_IoS.pdf

[22] Council of the Isles of Scilly/Hitachi Europe Ltd. (2016) *Energy Infrastructure Plan for the Isles of Scilly, Smart Islands*. Retrieved from https://www.scilly.gov.uk/sites/default/files/IoS_Infrastructure%20Plan_FINAL_IoS.pdf

However, due to the current energy infrastructure in the UK, and the Island's connection to the mainland grid, any large-scale renewable energy generation projects are subject to control by the regional DNO.

At the time of the project scope definition, new solar installations in the south-west (including the Isles of Silly) were subject to curtailment as much as 80 percent of the time. Without effective management, and strategic use of energy during periods of high generation, renewable energy generation was in danger of being shut down due to distribution grid congestion from the already high penetration of solar PV in Cornwall. These curtailments limited the business case for the installation of renewables on the Isles of Scilly, hampering the opportunity to access low cost, low carbon energy.

3.4 SMART ISLANDS PARTNERSHIP

The Isles of Scilly's Smart Islands Partnership is a consortium of Island and corporate stakeholders including the Council of the Isles of Scilly, the Duchy of Cornwall, Tresco, the Islands' Partnership, the Isles of Scilly Community Venture and Hitachi Europe Ltd. This partnership has recognised the challenges faced by the Isles of Scilly, specifically around the cost of energy, as well as the islands' contribution to the UK's climate change agenda.

In 2015, the Smart Island's Partnership set the ambitious goals of:

- 40 percent reduction in electricity bills by 2025
- 40 percent of the islands' energy demand met through renewable generation by 2025
- 40 percent of vehicles being low carbon or electric by 2025
- Full programme of energy efficiency measures delivered by 2020.

Figure 3-1: Smart Islands Programme 2016

In 2019, the Partnership updated its vision:

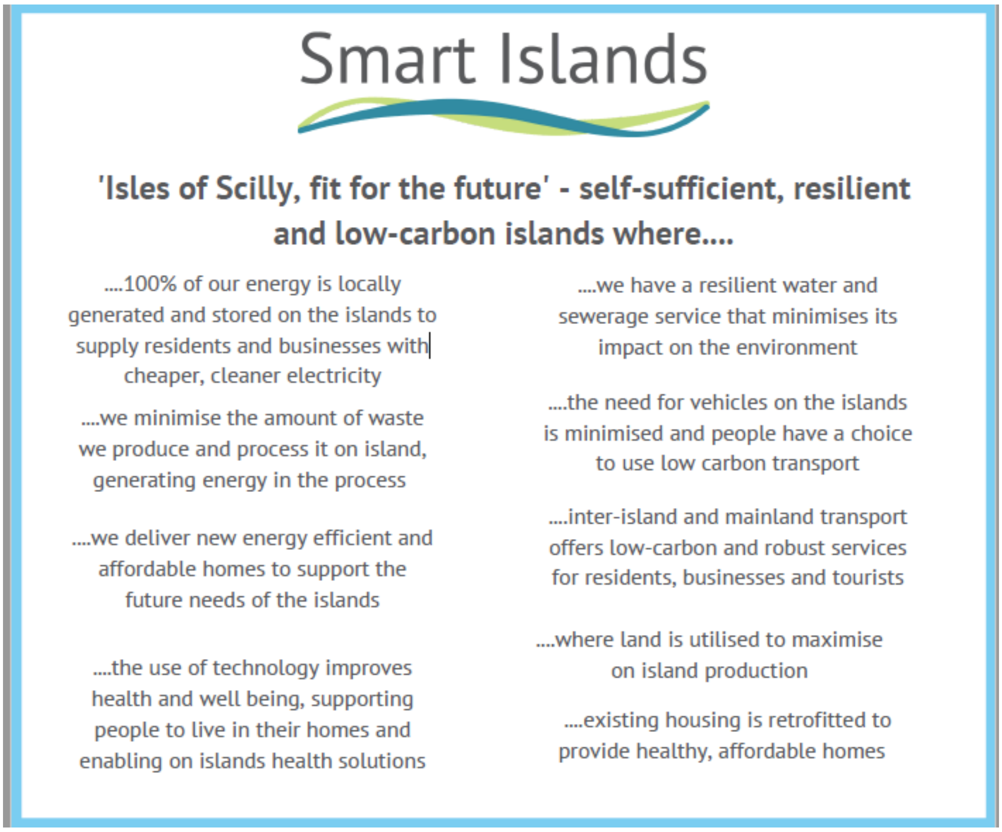

Figure 3-2: Smart Islands Vision 2020

The Isles of Scilly Smart Islands programme will consider energy from wind, tidal and energy from waste in future, considering the merits and drawbacks of each, as it strives towards its greater ambition:

"100% of our energy is locally generated and stored on the islands to supply residents and businesses with cheaper, cleaner electricity"

Hitachi's delivery of the Smart Energy Islands project was an integral first step within these wider objectives. Although the project would only directly contribute a small amount towards these goals, it was crucial in unblocking the current challenges of renewable energy integration that was preventing wider adoption, creating a legacy of improved renewable integration.

3.5 LOCATION

The Isles of Scilly's five inhabited islands are St. Mary's, St. Agnes, Bryher, Tresco and St. Martin's and they have a combined population of around 2,500 permanent residents. The largest island, St. Mary's at 2.5 square miles, contains most of the population.

Composed of eroded out-crops of granite rock, the Isles of Scilly offer a contrasting mix of white sandy beaches, rolling green grassy hills and exposed rock stacks. The islands are famous among birdwatchers for their ability to attract rare birds, while also playing host to some endangered wildlife including the Scilly shrew, Atlantic grey seal, Manx shearwater, puffin, dolphin and porpoise. The islands are designated a Conservation Area, Area of Outstanding Natural Beauty and Heritage Coast. Around the coastline is a Special Area of Conservation and a high number of natural environment designations are in place on the islands including 27 areas of Special Scientific Interest and 238 Scheduled Monuments.

3.6 CLIMATE

The Isles of Scilly are greatly influenced by the North Atlantic Current, which has a tempering effect on extremely cool weather. This creates a subtropical climate, with a daily mean exceeding 10°C for seven months a year, significantly greater than comparable locations on mainland Britain. As such, the islands rarely experience frost or snow.

In comparison, summers are not as warm as the mainland despite the islands being one of the sunniest areas in the Southwest, with an average of seven hours of exposed sun per day in May. Precipitation, which is mostly in the form of rain, averages around 34 inches per year.

Conversely, the Isles of Scilly's location and exposure to Atlantic winds means that winter storms routinely batter the islands. Gale force winds are experienced across the islands approximately 24 days each year and have scoured and shaped the landscape along many of the islands' exposed slopes.

3.7 ECONOMY

The population of the Isles of Scilly is seasonal, reflecting the influence of tourism. The resident population is around 2,300 but increases to as much as 6,000 in the peak of summer. Much of the population lives on the largest island St. Mary's, with a population of around 1,720. The off islands have smaller resident populations: Tresco 175, St. Martin's 136, St. Agnes 85 and Bryher 84.

The visitor economy on the Isles of Scilly is the main provider of jobs and income accounting for 80 percent of employment in Scilly and 85 percent of the islands' economy. As such, the islands welcome over 100,000 visitors per year, predominantly between March and October – which places additional strain on all of Scilly's resources over this time.

Conservation organisations work closely with the tourism industry and the Duchy of Cornwall to ensure that these visits are carefully managed to safeguard the environment and wildlife of the AONB. In particular, the Isles of Scilly Wildlife Trust, which manages around 60 per cent of the area, including the uninhabited islands, plays an important role in protecting wildlife and their habitats.

In addition to tourism, the islands' milder climate allows farmers to grow flowers, the islands' principal export, with harvests typically flowering well in advance of those on the mainland giving growers a distinct advantage over their mainland competitors.

The Council of the Isles of Scilly's Strategic Housing Market Assessment[23] states that there are 989 households on the islands, of which 412 are owned/shared ownership. 187 are social rented accommodation and 390 are privately rented/rent-free. The Isles of Scilly have been part of the Duchy of Cornwall since its beginning in the 14th century. Today the Duchy owns most of the land and nearly a third of the residential buildings on the islands.

[23] Council of the Isles of Scilly *Strategic Housing Market Assessment* (2016) Retrieved from https://www.scilly.gov.uk/sites/default/files/planning-apps/SHMA%20UPDATE%202%20Housing%20Need_0.pdf

Households on the Isles of Scilly are much more likely to be in privately rented accommodation than in Cornwall or England and Wales, and less likely to own their own home. There are 195 second homes and 190 'other properties', which are assumed to be holiday lets and time-shares. Key findings of the Strategic Housing Market Assessment (2016) confirmed much higher house prices than on the mainland, a lower-wage economy, a low availability of owner-occupied housing, and limited access to affordable housing.

The amount of industry is low and is concentrated around Porthmellon Business Park on St. Mary's.

3.8 ENERGY

Unlike most of the UK, there is no natural gas piped into the Isles of Scilly, instead residents rely on a single 55 kilometre, 33kV undersea electricity cable as their primary source of energy. This connection between the Isles of Scilly and the UK's national electricity grid is part of the south west distribution network operated by Western Power Distribution (WPD). The residents have access to the GB retail energy market and are able to switch suppliers just like consumers on the mainland.

Because of the connection to the mainland, the Isles of Scilly are not an 'islanded grid', however, they are able to maintain a self-sufficient electricity supply, if this cable was to fail.

A diesel-powered electricity generating station on St. Mary's, which is operated by WPD Generation, a wholly-owned subsidiary of WPD, can power the islands if required, but at a high cost and carbon footprint. There are also remote, locally controlled generators on two outer islands available for use in certain circumstances. These generators were all required in February 2017, when the cable was damaged catastrophically by an unidentified boat dragging an anchor, leaving islanders to rely upon the islands' back-up generators until 4 April[24], while it was repaired.

Due to the single connection, the islands provide an effective self-contained microcosm of an 11kV and LV electricity distribution system that can be monitored and controlled to provide a reliable and accurate measurement of the impact of any energy interventions.

Residents can import coal, heating oil, bottled gas and wood for fuel, however, these options all come with additional freight costs, making these options about 50 percent more expensive than on the mainland.

Dependence on electricity for energy supplies means that the Isles of Scilly local authority area had the second-highest average domestic electricity consumption per household in the UK in 2016 (second to the Shetland Islands). In 2017 each home used an average of 7,672 kWh, while the domestic average for the UK is 3,921kWh, and the average for Cornwall is 5,353 kWh[25].

The high use of electricity for heating, power and warmth on the Isles of Scilly is analogous of the transition the mainland is expected to go through as homes and buildings move to electrification as a carbon reduction strategy.

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[24] Radio Scilly *Work completed on power cable between Scilly and mainland* (4 April 2017). Retrieved from http://www.radioscilly.com/blog/2017/4/4/work-completed-on-power-cable-between-scilly-and-mainland

[25] Department for Business, Energy & Industrial Strategy (2018) *Sub-national electricity consumption data*. Retrieved from https://www.gov.uk/government/collections/sub-national-electricity-consumption-data

DOMESTIC ENERGY USE ON THE ISLE OF SCILLY

The cost of a unit of electricity on the Isle of Scilly is the same as the mainland (set by national/regional rates) however, due to high electricity usage, residents are spending much more on energy than on the mainland.

The high energy use is due to a number of factors, including climate and age of housing stock. An assessment prior to this project found that homes on the Isles of Scilly are the least energy efficient in the UK, with 35 percent of properties on the islands receiving F or G ratings. Due to their remote location, the community has not benefitted from national insulation programmes. Because of the age of some of the buildings, some residents do not have central heating and must rely on older space heating solutions like storage heaters or electric fires that are energy intensive and provide poor quality heating.

In 2018 the Department for Business, Energy and Industrial Strategy ranked the Isles of Scilly as eighth in the UK for incidence of fuel poverty. Twenty two percent of households in the Isles of Scilly are in fuel poverty, compared to 14 percent in Cornwall and a national average of 10 percent. This affects the health of the population and the cost of healthcare. It also translates into high carbon intensity of the local economy.

SOLAR PV

Despite benefiting from levels of solar irradiation that make the location very suitable for solar PV generation, the Isles of Scilly has had low and sporadic take-up of PVs. Scilly first saw the installation of a solar PV system in November 2008. Subsequent installations occurred between November 2011 and March 2012 but most schemes are small, domestic roof projects, between two and four kilowatt-peak (kWp).

Prior to this project, there had been some larger rooftop PV schemes implemented, primarily on Council-owned schools and the off islands' community centres but there was no experience of ground-mounted installations.

As such, before 2016 the maximum electricity generation on the Isles of Scilly by solar PV was only 270 kWp, around 1.6 percent of the islands' total electricity demand[26].

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[26] Council of the Isles of Scilly/Hitachi Europe Ltd. (2016) *Energy Infrastructure Plan for the Isles of Scilly, Smart Islands*. Retrieved from https://www.scilly.gov.uk/sites/default/files/IoS_Infrastructure%20Plan_FINAL_IoS.pdf

4 DEPLOYING LOW CARBON AND SMART TECHNOLOGY TO DELIVER FLEXIBILITY

The rationale for the technologies selected and the trial locations are discussed in this chapter.

4.1 SELECTION

The Council of the Isles of Scilly was a delivery partner in the project and its social housing and some other Council properties were enhanced with energy generation and energy efficiency equipment. The primary consideration for selecting the households for the project was to ensure that at the closure of the project, technologies could be transferred to the Council's ownership and would continue to contribute to an improved standard of living – improving home comfort levels and reducing energy bills in social housing.

In total, 82 homes were equipped with Home Energy Management Systems (HEMS) and/or installed with rooftop PV. To further test the capabilities of the platform different combinations of additional technologies including batteries, air source heat pumps and domestic hot water controls were also installed into these homes. The technologies installed were selected in consultation with a housing assessment and by agreement of each of the households.

	Technology Combination (all with Home Energy Management System)				**Number of homes**
1		Hot Water Controls			13
2	Solar PV				26
3	Solar PV	Hot Water Controls			33
4	Solar PV		Battery Storage		1
5	Solar PV			Air Source Heat Pump	5
6	Solar PV	Hot Water Controls	Battery Storage		1
7	Solar PV		Battery Storage	Air Source Heat pump	3
Total					**82**

In consultation with the Duchy of Cornwall, the Council of the Isles of Scilly and the Airport, a ground-mounted solar garden with a capacity of 48kWp was installed at St. Mary's Airport. Additionally, roof-mounted PV was installed on Council-owned properties including the Waste Processing Site (85kW), Desalination plant (22 kW), two Fire Stations (10kW and 17kW), and St. Mary's Airport Terminal (12 kW).

4.2 PREPARATION

It was crucial to the delivery of the project that the local community was involved at each stage of the planning process. Prior to the technology deployment, a tenant engagement programme was completed to ensure all participating householders were informed of the benefits, process and the role of these interventions in the wider context for the project and how this sat within the broader Isles of Scilly Smart Islands programme.

The engagement programme was conducted jointly by the project team, working closely with the Council of the Isles of Scilly, the Smart Islands Partnership, as well as energy infrastructure stakeholders. These included: asset managers, building managers, householders and visitors.

Engaging with the community on the Isles of Scilly was not only key to developing a replicable and sustainable commercial model on the islands and beyond, but it also provided an opportunity to engage local people with the project, including the young people at the Five Islands School.

Engagement took place as an iterative process involving a series of workshops and interviews with key user groups, using Hitachi Ltd.'s proprietary service design methodologies such as Business Origami and industry standard tools such as Customer Journey Mapping.

4.3 INSTALLED TECHNOLOGIES

The technologies installed include solar PV generation and heat pumps, batteries, hot water tank controls and an EV charger. From the energy management point of view, these latter devices satisfy demand and storage.

SOLAR PV GENERATION.

Solar PV is a well-established electricity generation technology with tens of thousands of schemes across the UK. However, before this project, the Isles of Scilly had limited experience with roof-mounted PV, with only around 270 kWp already installed. There was no experience of ground-mounted solar PV.

One of the benefits of solar PV is that the energy output is predictable, and its generation curve is easily mappable. A limitation is that generation is only possible during a limited part of each day and is impacted by weather conditions, for example clouds.

Most of the homes participating in the project are connected to one of the two WPD substations: Hugh Town or Old Town. The Hugh Town substation services over 280 residential and non-residential customers. Old Town is mainly a residential area with approximately 100 customer connections. Nineteen SEI homes are connected to it, with 61kW of domestic PV and 59kW of community PV.

Figure 4-1 shows the half hourly generation profile of all Old Town in August 2019 and compares it to total demand on the substation. While in the middle of the day in August the PV is at times able to satisfy almost the entire demand on the substation, it is only able to cover a small portion of the demand in December.

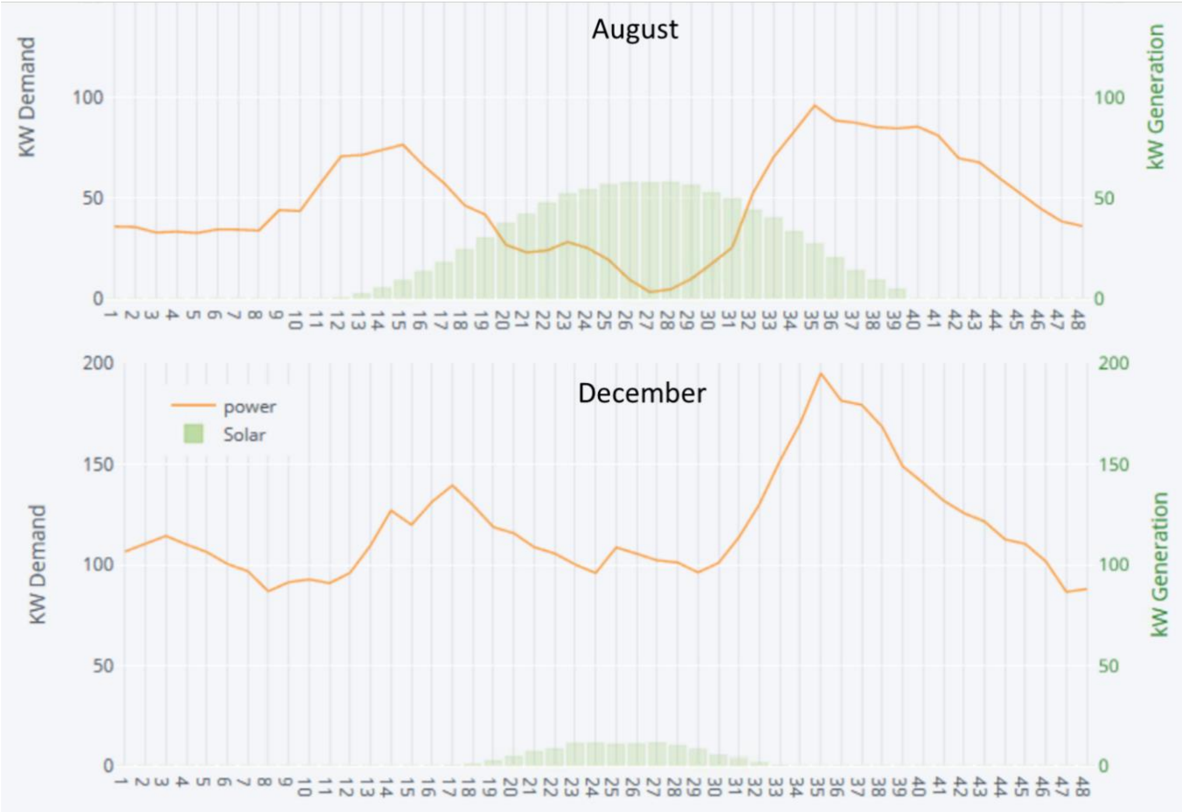

Figure 4-1: Half-hourly SEI solar PV generation profile vs demand on the Old Town substation in August and December 2019

Solar PV's capacity for generation varies across the year, with the majority of electricity generated during the summer months. For Cornwall and the Isles of Scilly around 60 percent of the generation will be in the months March to August.

The potential for high solar PV electricity generation on the Isles of Scilly is greater than the rest of the UK, and better even than Cornwall. This is due to the clear, unpolluted skies and high sunshine hours. These unique conditions make solar PV an ideal choice for low carbon energy generation on the islands[27].

The Isles of Scilly project initiated several strategies to reduce the cost of domestic installation, for example, by installing all solar PV as part of a planned installation programme where the same installation team installed the PV in each home, increasing their understanding of the homes within which they were working and achieving economies of scale.

Despite this, there were additional challenges to overcome during the installation process. These included the age of the homes under consideration, the existing electrical condition and roof condition. Less reflective, matte-finish panels were selected for installation. This decision was taken to respect the Area of Outstanding Natural Beauty.

A block of properties, due for maintenance by the Council, were re-roofed as part of the project to benefit from the economies of scale of working in such a remote location. In recognition of the

[27] Council of the Isles of Scilly/Hitachi Europe Ltd. (2016) *Energy Infrastructure Plan for the Isles of Scilly, Smart Islands*. Retrieved from https://www.scilly.gov.uk/sites/default/files/IoS_Infrastructure%20Plan_FINAL_IoS.pdf

potential visual impact at this particular location, the project installed Building Integrated PVs (BIPV). These panels sit flush with the roofline, as opposed to installed on top of the roof tiles, minimising the visual impact but at greater expense.

Figure 4-2 shows the half-hourly generation profile of PV installed as part of SEI in August and December 2019 (values in kW on the right hand axis) and whole island imports on the undersea cable in August and December 2013 – 2019 (left hand axis, demand is in MW).

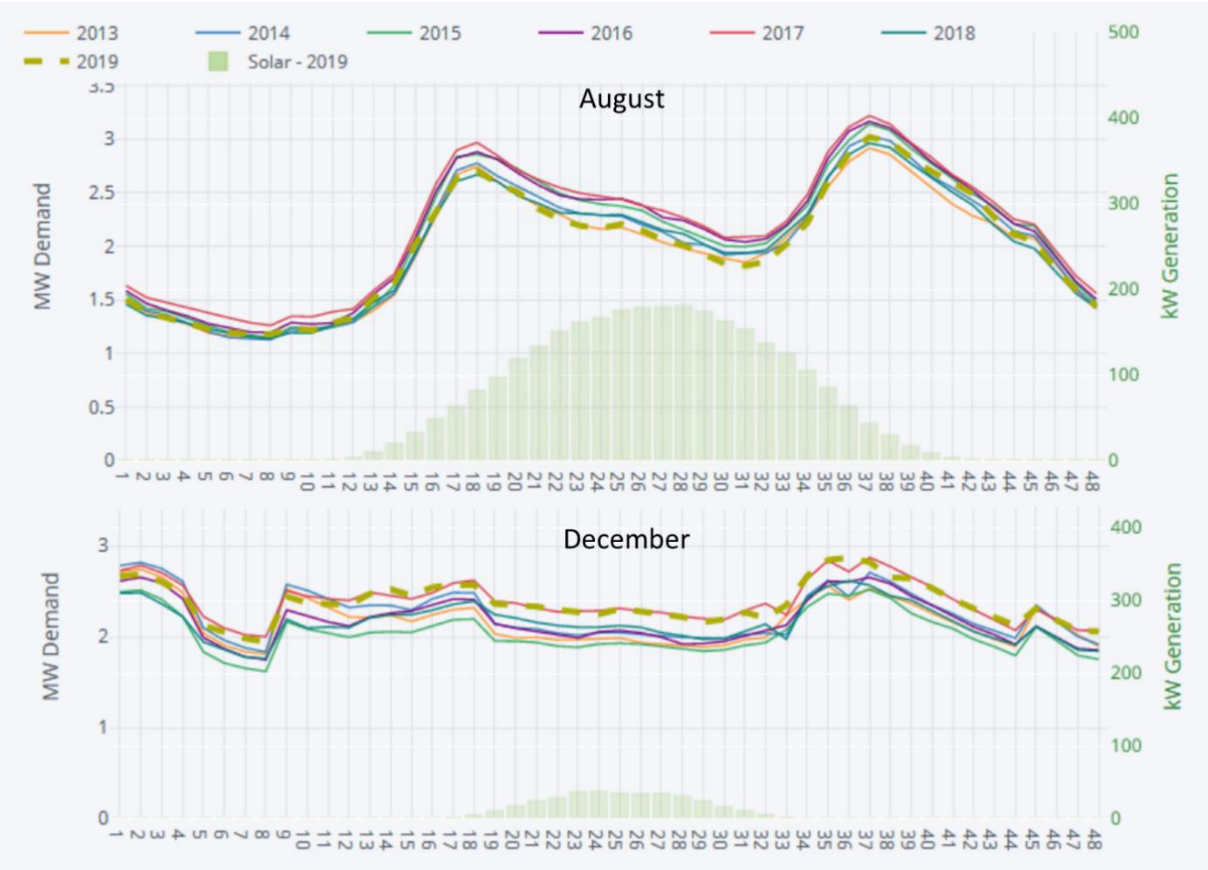

Figure 4-2: Solar PV generation profile vs import profile of the whole islands in August and December

The profile of imports has not changed significantly over the years, with daily peaks occurring around 08.30 and 18:30 and lowest demand between 15.00 and 16.00. While the current PV generation is fully consumed on the islands, with demand outstripping peak generation ten-fold even in August, this illustrates the limits of using PV as the main source of local generation – PV generation is not aligned with demand peaks.

Despite the high installation costs, the unique location and climate of the Isles of Scilly dictates that solar PV is a good choice to form part of the islands' renewable energy portfolio – although it will need to be able to complemented by other forms of generation to achieve the Council's ambition.

AIR SOURCE HEAT PUMPS, SMART HEATING CONTROLS AND SOLAR OPTIMISATION

Eight homes had air source heat pumps (ASHP), HEMS and solar PV panels installed. Three of these homes also had Moixa domestic batteries.

The PassivSystems HEMS comprises a user interface (available via smartphone application or web portal, with some basic physical control available in the home) and a Passiv hub in the home (running software control algorithms, with control interfaces to assets in the home, and monitoring equipment) connected to PassivSystems' servers for data collection and aggregated control.

Powered by electricity, the efficiency of a heat pump is measured by its Coefficient of Performance (CoP), the ratio of the heat produced as an output to the electricity input. For example, a CoP of two means that the heat pump produces twice as much heat, as the electricity it uses. In the case of a storage heater, this ratio is one (as electricity is directly converted to heat). But typically heat from a storage heater is not delivered at the times it is needed, so a lot of energy is wasted. ASHPs are two to four times more efficient than traditional forms of electric heating, leading to significant energy and carbon savings.

Savings delivered by a heat pump system can be further increased by better utilising the solar electricity, as it is cheaper than grid electricity. Innovations demonstrated as part of the Project include 'solar optimisation' to increase self-consumption of PV generation, with and without additional battery storage.

Another innovation demonstrated as part of the Smart Energy Islands project was the coordination of load between heat pumps and (electrical) batteries in homes.

However, the level of benefits delivered by an ASHP is influenced by a complex set of factors.

AIR SOURCE HEAT PUMPS – FACTORS AFFECTING PERFORMANCE.

A number of factors (outlined below) influences the performance of heat pump.

1. **Flow temperature** – the temperature of water delivered by the heat pump into the heating system. The higher it is, the harder the heat pump has to work, and the lower its CoP. Heat pumps are most efficient if allowed to run at a constant rate throughout the day, delivering a lower flow temperature, rather than short bursts of a high temperature. For example, in one of the homes the room temperature was set to 20°C and the heat pump was able to meet this requirement with a flow temperature of 35-45°C. However, the occupants were boosting their temperature manually to 22°C at times, requiring a flow temperature of 50°C. The heat pump was working less efficiently at those times. Another home had the thermostat set at 20°C consistently for the times when heat was needed and did not require a manual boost.
2. **Control Strategy** – defining a heating schedule via the app and minimising manual changes allows the heat pumps to deliver maximum benefit for two reasons:
   - Planning of flow temperatures allows the equipment to work at its most efficient
   - By planning ahead, the system can make better use of solar energy. While this does not impact on the CoP, it allows to maximise benefits to the household. For example, a household with a constant temperature set to 20°C, used solar energy to pre-heat the home to 21°C during the day and little electricity was required from the grid in the evenings.

3. **Energy efficiency of the building** – if a building is poorly insulated, a heat pump needs to either be larger or work harder to deliver the heat required to keep it warm. This might also mean larger radiators to deliver the heat. This is why as part of the initial surveys it was ensured that all the properties where ASHPs were going to be installed had an appropriate energy efficiency rating or had additional insulation where required.

4. **Hydraulic system installation and use** – to ensure optimum system performance, the wet system (radiators) need to be sized appropriately. If the radiators are too small, the heat pump needs to provide a higher flow temperature to bring the room to the desired temperature, leading to lower CoP. This might also happen if the thermostatic radiator valves (TRV) are not fully open resulting in low flow rate. Slightly counterintuitively, energy savings are sometimes possible with heat pumps by opening TRVs because it makes the whole system more efficient. The householder may turn down TRVs in occupied bedrooms, for example, where they want to be cool overnight.
5. **User requirements** – For households requiring a high room temperature constantly, the efficiency is reduced, due to higher flow temperatures required. This was the case in one of the homes, where the required room temperature of 25°C was achieved, but at the cost of lower efficiency.

AIR SOURCE HEAT PUMPS – PERFORMANCE.

Data gaps, mainly due to communication issues, made statistical analysis difficult. Detailed analysis of performance of the systems installed during the project revealed significant differences between the installations, although in all cases the households were much better off with the heat pump than with their previous forms of heating.

The smart heating controls appeared to be working very well at every single home. Generally, the room temperature was managed accurately to within 0.2°C of the desired setpoint with the heat pumps running at low flow temperatures where they are most efficient. There are a few homes where the heat pump struggles, either because the occupant wants the house very warm, or because the occupants frequently boost the system to a high setpoint.

To give an indication of how well the heat pumps performed the CoP and Seasonal Performance Factor (SPF) were considered. The CoP was calculated as the best short-term heat meter output divided by the electrical power input. The SPF was calculated as the long-term heat meter cumulative output divided by the electricity meter cumulative input.

Ideally, an ASHP should achieve an instantaneous CoP of over 3 and an SPF of between 2.5 and 3. The UCL Energy Institute report the median value of the SPF from a sample of 700 ASHPs as 2.65[28].

For the six installations for which sufficient data was available, the average CoP achieved was 2.45 for space heating, with a range of performance (CoP) from 1.9 to 3.5. The slightly disappointing values are hypothesised to be partly due to user behaviour/requirements and potential shortcomings of the hydraulic design of the systems' installation (e.g. radiators might be too small) due to limitations on space in the properties. Nevertheless, in all cases the heat pumps are performing well enough to give the residents substantial savings compared with pure electric heating and hot water.

[28]UCL Energy Institute (2017) *Investigating Variations in Performance of Heat Pumps Installed via the Renewable Heat Premium Payment (RHPP) Scheme.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606829/DECC_RHPP_160428_On_performance_variations_v20.pdf

Solar optimisation is working well in most homes, with the heat pump often successfully pre-warming the house on sunny but cold days, such that little further heating is required later in the day.

CASE STUDY: A HOME KEPT WARM EFFICIENTLY IN COLD WEATHER

This case study shows time-series graphs of the heat pump at one of the homes performing well during two days of the coldest period of the 2018-2019 winter.

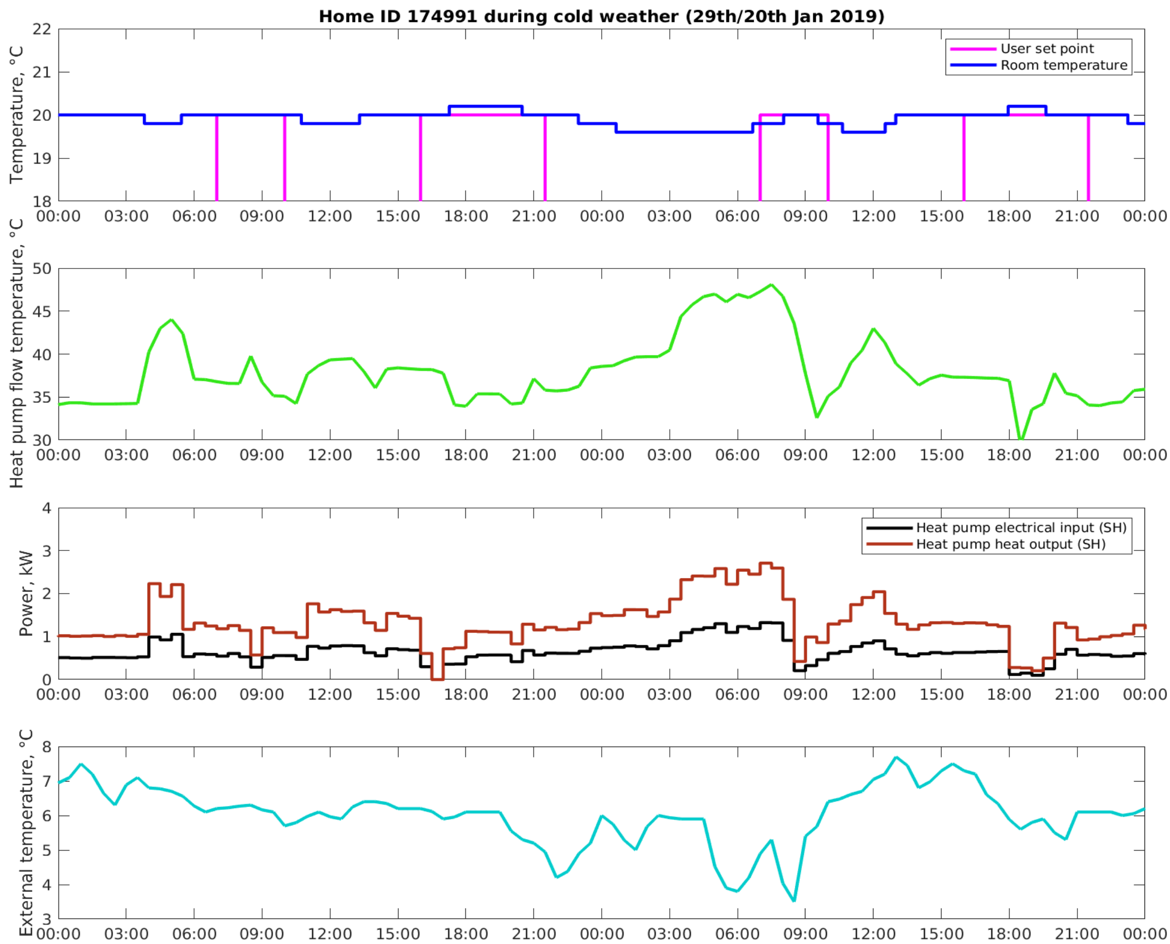

Figure 4-3: Heat Pump Case Study 1 – a home kept warm efficiently in cold weather.

The top figure displays room temperature and the user's requested setpoint, showing that the desired comfort level was always achieved during this period, to a really high precision (always within 0.2°C of desired temperature). The second figure shows the temperature of the water flowing from the heat pump to the radiators; despite the cold weather, the algorithms have realised it is usually possible to keep the house warm with the radiators at only 35-40°C where the heat pump is really efficient. The third graph shows the electrical power input to the heat pump and the thermal output power (the ratio between these is the CoP) showing how the heat pump is operating continuously and gently. Finally, the fourth figure at the bottom shows the external temperatures. The Isles of Scilly are usually very mild and the coldest temperatures were around 3°C.

CASE STUDY: A HOME WITH HIGH HEAT DEMAND DURING COLD WEATHER

This case study shows time-series graphs of the heat pump at a home during five days of the coldest period of the 2018-2019 winter.

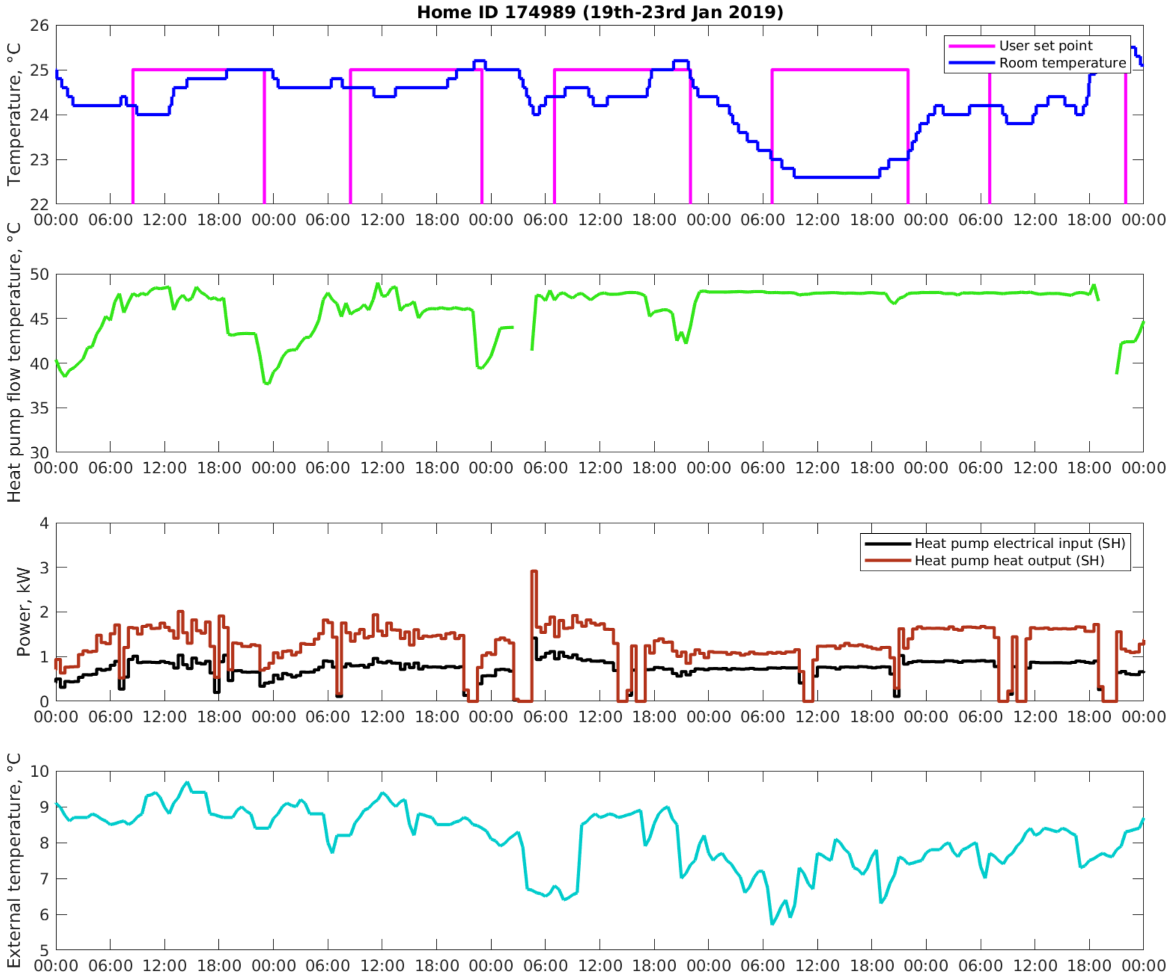

Figure 4-4: Heat Pump Case Study 2 – a home high heat demand in cold weather.

The top figure displays room temperature and the user's requested setpoint; the system is doing its best to reach the desired comfort level of 25°C but is not always able to get there despite the heat pump running flat out. This is a much better comfort outcome than a conventionally controlled heat pump.[29] The second figure shows the temperature of the water flowing from the heat pump to the radiators; most of the time the unit is operating at its maximum temperature of 50°C. The third graph shows the electrical power input to the heat pump and the thermal output power (the ratio between these is the CoP).

[29] Which operate on a 'guess' for the right flow temperature with no guarantee of meeting desired comfort outcomes.

CASE STUDY: RETURNING FROM A HOLIDAY PERIOD

This case study shows time-series graphs of the heat pump at a home over six days at the end of a period where they had set the system to 'away'.

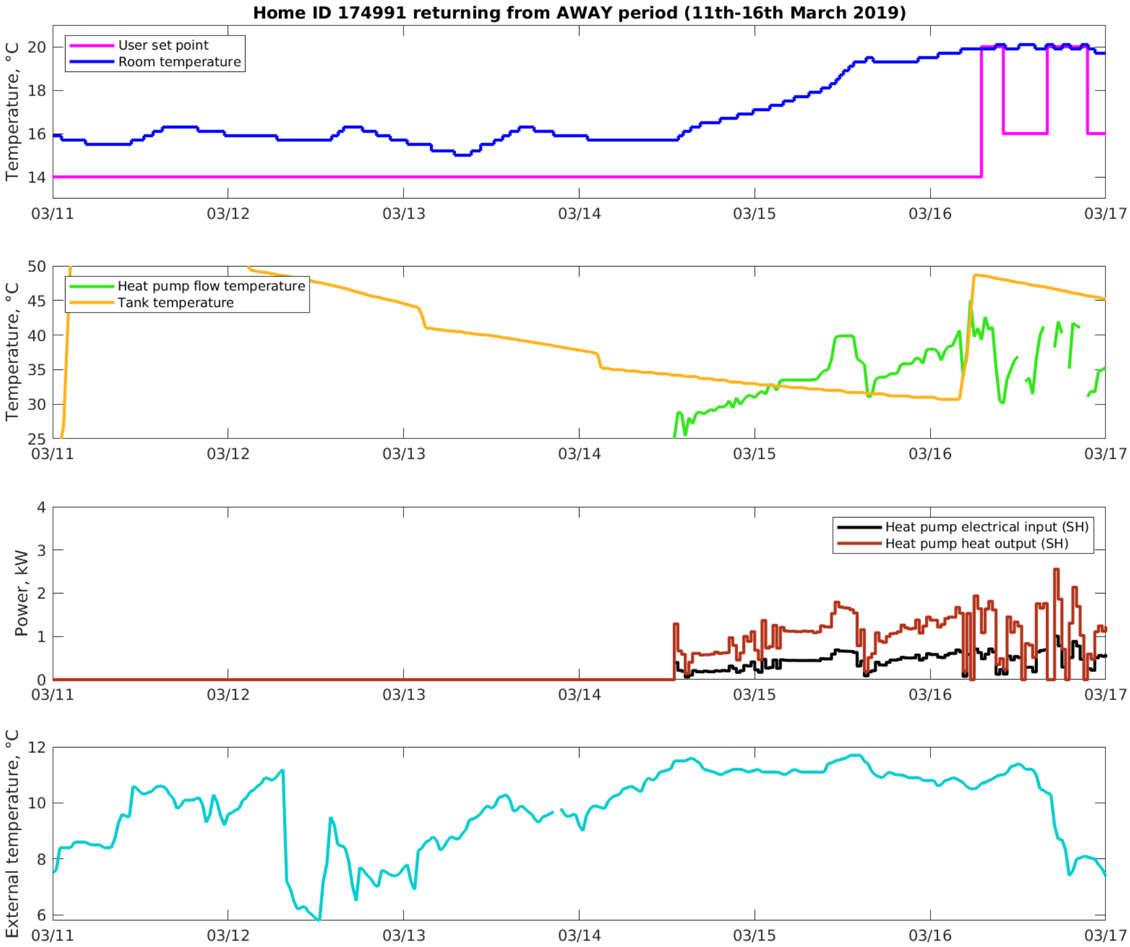

Figure 4-5: Heat Pump Case Study 3 – a home over six days at the end of a period when system to 'away'.

The top figure displays room temperature and the user's requested setpoint. The heating is off for the first few days and the system starts rewarming the home gently and efficiently about 36 hours before the scheduled return, getting the house back to temperature accurately. The second figure shows the temperature of the water flowing from the heat pump to the radiators, and the hot water tank temperature. There was an anti-legionella cycle on the first day to keep the tank sterilised, and it is apparent that on the last day the hot water was reheated ready for the occupants' return. The third graph shows the electrical power input to the heat pump and the thermal output power (the ratio between these is the CoP).

SOLAR OPTIMISATION OF HEAT PUMP HOMES – PERFORMANCE

One innovation demonstrated as part of the Smart Energy Islands project is 'solar optimisation' for heat pumps, where the control system for the heat pumps receives a weather forecast that includes a prediction of solar irradiance, and the optimisation calculation for the heat pumps takes into account the predicted availability of cheap electricity from PV generation. This means that self-consumption of PV generation increases, which saves running costs for the householders.

Typically solar optimisation works by pre-heating the home during the middle of the day so that it stays warm enough for the residents for the rest of the day, and no further heating is needed after the sun goes down.

The ability of a heat pump to self-consume PV generation is limited by a number of factors:

- The heat pump's electrical power consumption is limited to 1-2kW (depending on the sizing of the heat pump) whereas the maximum power (kWp) of the solar panels is 2-3.5kW.
- Demand varies significantly with season: in winter there is little generation and significant heating demand, so we can hope to consume most of the solar generation, but in summer the solar generation significantly exceeds the heat pump capacity.
- The algorithms limit the amount a home can be overheated so that the room temperature is at most 1°C above the maximum upcoming setpoint requested by the householder. If a home has natural solar gains, this limits the amount of heat pump self-consumption further.
- For some periods of the trial, the heat pump controls were programmed to take account of the householders being charged 8.5p/kWh for generated solar power. This may have meant in some circumstances it was not worth using the excess solar (e.g. if a lot of the heat is likely to be lost by the time the occupants return home).

CASE STUDY: SOLAR OPTIMISATION IN NOVEMBER 2019

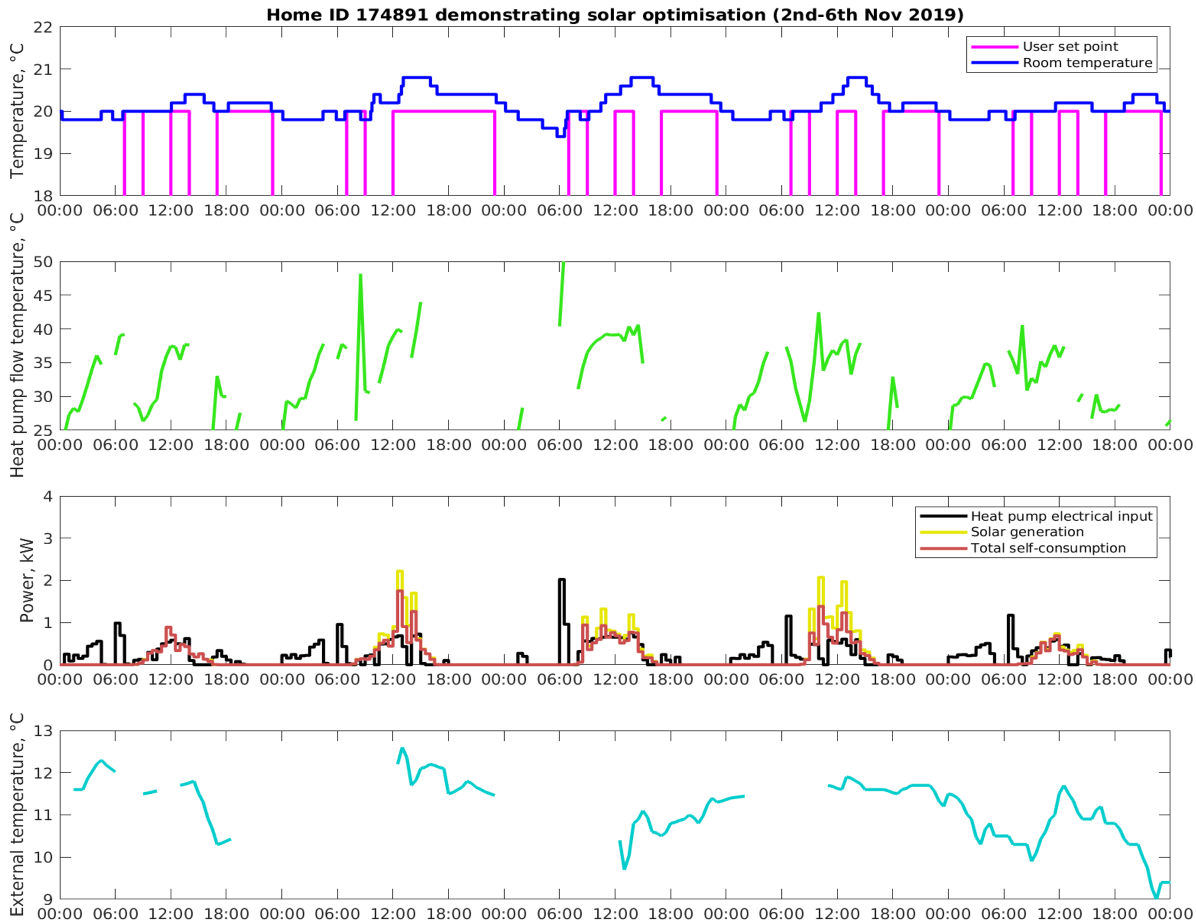

Figure 4-6 Home demonstrating solar optimisation

This case study shows the behaviour of a heat pump over 5 days in November 2019 with varying amounts of solar generation. The top figure displays room temperature and the user's requested setpoint; solar optimisation is apparent from the increase in room temperature during the day, but never more than 1°C above the 20°C setpoint. The second figure shows the temperature of the water flowing from the heat pump to the radiators. The third graph shows the electrical power input to the heat pump, the solar PV generation, and the total amount of self-consumption (including battery operation). On all days, almost all of the solar PV was self-consumed, and very little electricity was required in the evening to keep the house warm as it has been pre-heated using the PV generation.

ENERGY STORAGE

As solar PV is the primary source of electricity generation on the islands for this project, it was crucial to ensure this energy was captured or used during periods of high supply, during the daytime, even if typical demand in buildings was low.

4.3.1.1 HOT WATER TANKS

As part of the SEI project PassivSystems has developed an innovative approach to hot water control using non-invasive temperature sensors strapped to the outside of the tank. Using machine learning techniques and real-time inference, this system allowed the thermal characteristics of the hot water tank to be learnt, and then used to estimate the level of hot water in the tank. This is highly innovative because normally it would be necessary to either replace the tank, or cut away insulation, to get a meaningful indication of the hot water temperature.

Householders chose periods of the day when they wanted hot water to be provided (scheduled occupancy IN periods) and the system used this information to drive hot water production. Householders were also able to manually 'boost' hot water to heat the hot water tank on demand. Interaction was expected to be primarily via the PassivLiving App but many householders took advantage of the physical button in the home as well.

Homes in the trial operated on one of two control modes:

Unmonitored control. During initial stages of the trial, and for homes with hardware, communications or other issues, the Passiv software was configured to heat the hot water tank at fixed times (rather than dynamically adjust the timing according to tank status). The timing of the hot water cycles were determined on the basis of the user's occupancy schedule, whether they were on Economy 7, and other settings chosen by the user. Homes on unmonitored control have not tried to self-consume solar PV generation and were not available for flex (demand response). Some households chose to only heat their hot water via manual boost.

Optimised control. Homes with the tank sensors operating properly were upgraded to PassivSystems' full smart algorithms, which make the most of the tank sensor information and time of use tariffs, require fewer manual user settings, make full use of solar PV generation, and are available for flex (demand response). Only the 'optimised' homes took part in flexibility trials.

HOT WATER TANKS WITH SMART CONTROLS

Prior to this trial, most households had a simple on/off button or physical time clock to control their hot water. Adding smart controls has several advantages to the householders, even before the addition of the non-invasive tank temperature sensors is considered.

In summary, the benefits are as follows:

- Reduced tank losses from only heating the tank when hot water is likely to be required by the occupants
- Enabling the user to set up ‘away’ periods, meaning that tanks are not heated up unnecessarily. The smart controls automatically heat up the tank at the end of the away period so hot water is provided for their return with no additional effort (and with the tank sensors, the tank is automatically heated for a longer duration from completely cold).
- Variety of options for interacting with the system depending on the needs of the user, including manual ‘boosts’ for when additional hot water is required, disabling of automatic hot water provision (heat only on ‘boost’), and overriding the smart system (back to a manual switch), if required.
- Provision of anti-legionella cycles automatically every week in the early hours of Monday morning (01:30 to 04:30)

It is hard to provide statistically valid analysis of these benefits without a controlled trial comparing energy consumption before and after the smart system was introduced (this was not a project aim), however evidence is demonstrated by the following examples.

The below figure is an example for one home where the schedule has been used extremely effectively to minimise energy losses from the tank . For successive days the tank was fully heated ahead of an IN period, only for the user to consume all their hot water shortly after. They then did not require hot water until their next IN period, by which time the tank was heated and ready for use again. The tank was cold most of the time (thus minimising losses).

Note that this graph shows the raw non-invasive temperature sensor traces – one measuring the temperature on the surface of the tank and the other the ambient temperature. The tank is considered hot when the top trace is above 30°C and there is a good difference in temperature between the two traces.

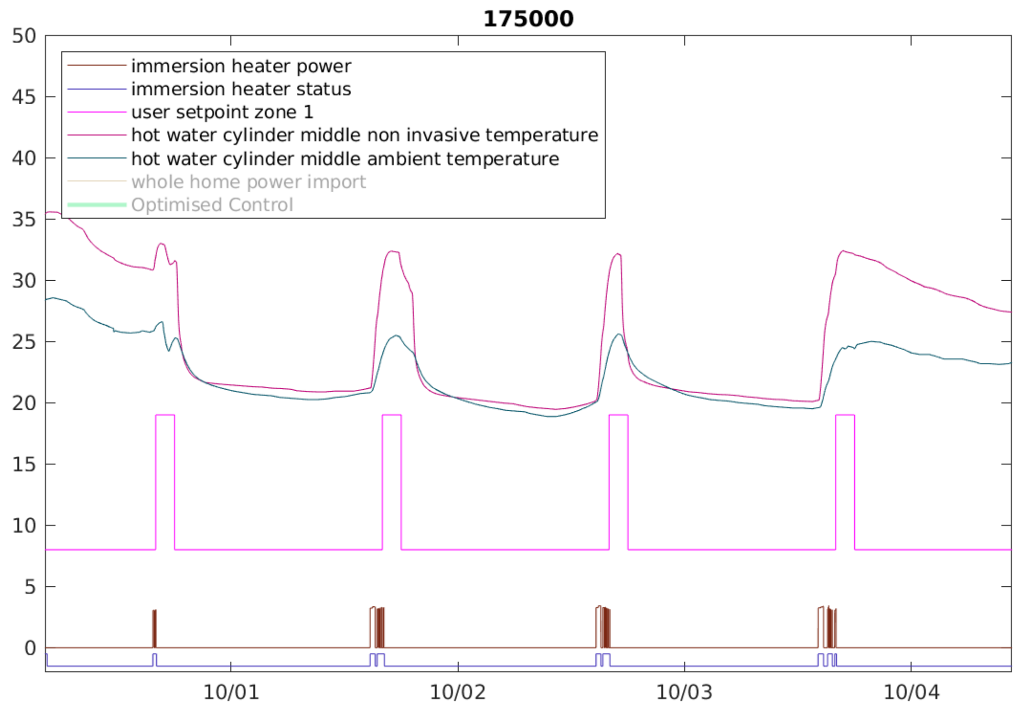

Figure 4-7 Effective use of schedule to minimise hot water tank losses

NON-INVASIVE TANK TEMPERATURE SENSORS

The innovative non-invasive tank sensors developed by PassivSystems as part of the SEI project allow the approximate temperature of the hot water in the tank to be deduced and the behaviour of the tank to be characterised (such as how quickly it heats and cools). The combination of the physical sensors and smart algorithms (optimised control) allow PassivSystems to deliver the following benefits to the households:

- **Automatic re-heating** of the tank when it gets cold or when a lot of hot water is consumed (providing comfort benefits as well as energy saving benefits as this isn't done needlessly)
- **Just in time heating**, in the knowledge of how long the tank takes to heat up, providing energy savings and comfort benefits
- **Partial reheating** of a tank in scenarios where a full tank is not necessary, providing energy savings
- **Smarter use of cheap rate (Economy 7) electricity**: heating up at the end of a cheap rate period with the confidence of meeting hot water needs, and automatically topping up with peak rate electricity where it is needed or more efficient

By and large these benefits are automated and so will not be directly noticeable by the residents, but will result in efficiency and ultimately bill savings.

It should be noted that there were huge variations across the sample in the amount of hot water being used. Anecdotal evidence indicates that some of the households were particularly frugal in their energy use – using only electric showers and kettles to meet their hot water needs, while others had electric showers and under-the-sink instant hot water. On the other hand, a quarter of the homes were extremely high consumers, with draw events after/during most IN periods; whilst the remaining homes typically had very occasional hot water use. This highlights the advantage of a smart hot water system which is tailored to the needs of the occupants.

CHARACTERISING A TANK AND THE HOT WATER IN IT

The examples in this section provide insight into how the non-invasive tank sensors work.

The two plots below highlight two very different hot water tanks. The home 175028 - left heats up very quickly, giving a 10°C delta between the two non-invasive tank sensors, and when hot water is consumed it is obvious (sudden reductions in the delta). In contrast, the home 176059 - right has a tank that heats up more slowly, to only a 5°C delta between the sensors and draw events are much less pronounced.

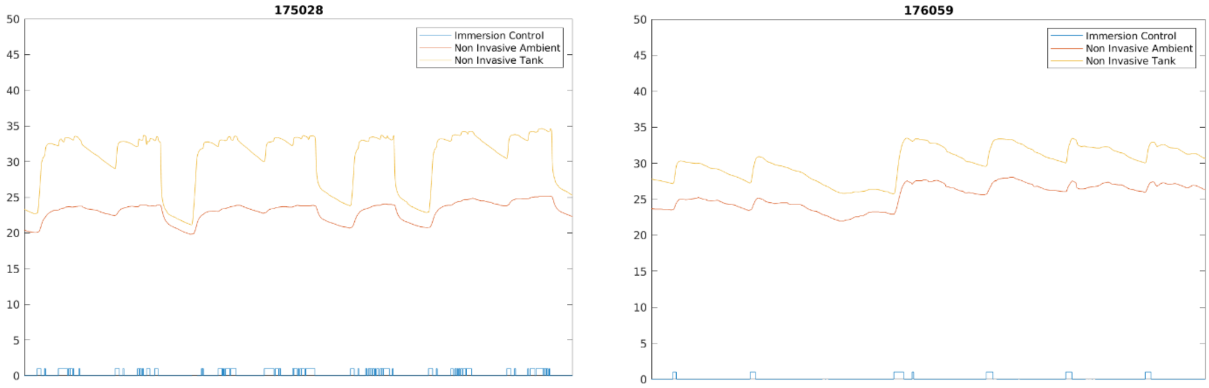

Figure 4-8 Non-invasive tank sensor – comparison of two homes

This example illustrates why it is necessary to have a smart algorithm characterising the tank based on readings from the non-invasive sensors, as the same temperature readings can mean a very different thing without the context of previous behaviour.

The graph below shows raw data together with the algorithm's decision about the level of hot water in the tank (after having learned the tank characteristics). Between 06:00 and 12:00 there are two heating events (c.f. control signal in red at the bottom) which result in an increased hot water level (despite being barely discernible in the raw sensor readings). Shortly after 18:00 there was a hot water consumption event, and the drop in the non-invasive readings are picked up by the algorithm and cause a sudden drop to the estimate of hot water available.

Under optimised control, illustrated by many of the graphs below, this hot water level estimate is used as part of the control algorithms to decide when to heat (and the tank characterisation is used to predict how the tank cools and when the next heating event is likely to be needed).

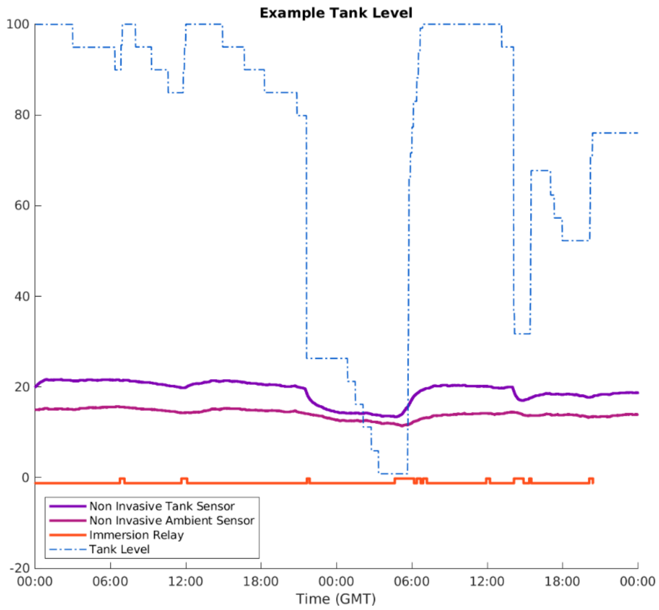

Figure 4-9 Non-invasive tank sensor – example tank level

CASE STUDY: AUTOMATIC REHEATS

The graph below shows three days with contrasting behaviour where the monitored tank gave benefits to the occupants.

On the first day there was a draw event around 18:00 but the algorithm determined there was enough hot water left and a reheat was not necessary.

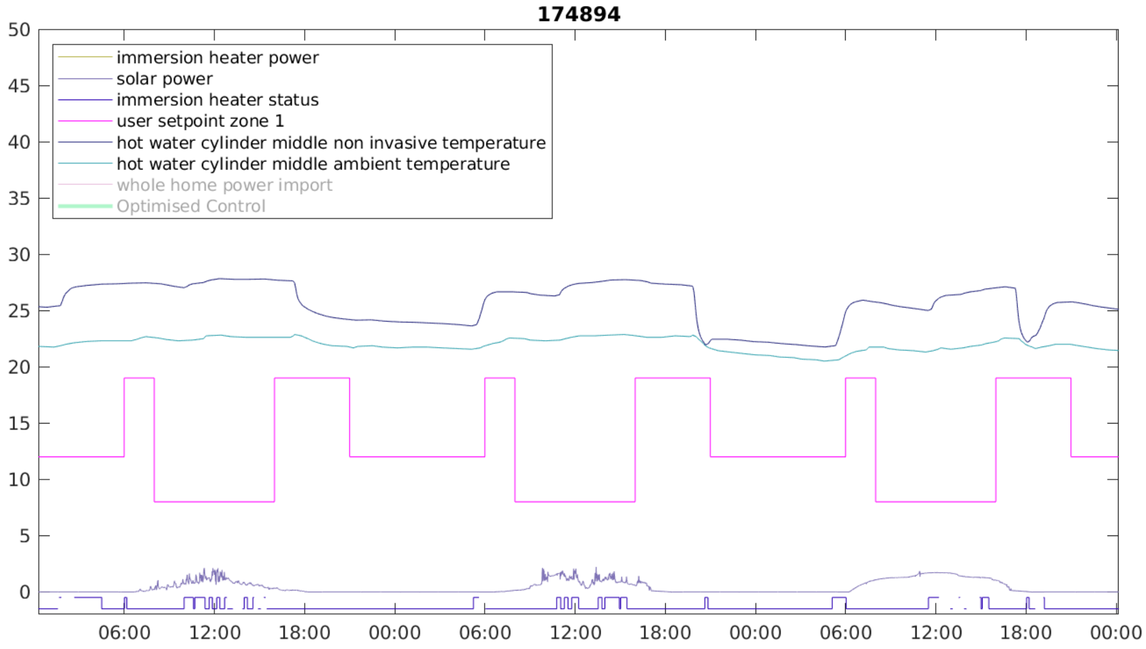

Figure 4-10Hot water tank – automatic reheats

On the second day there was a draw event around 20:00 that largely emptied the tank. The system attempted to reheat the tank but stopped when the occupancy period ended as it inferred no hot water was required overnight, and then reheated the tank only the following morning.

On the third day, there was a large consumption event around 18:00 that left the tank cold and the system automatically reheated the tank for the rest of the occupancy period so the householders did not run out of hot water.

CASE STUDY: REHEATS IN THE PRESENCE OF SOLAR SELF-CONSUMPTION

The graph below shows an interesting series of events over a three-day period.

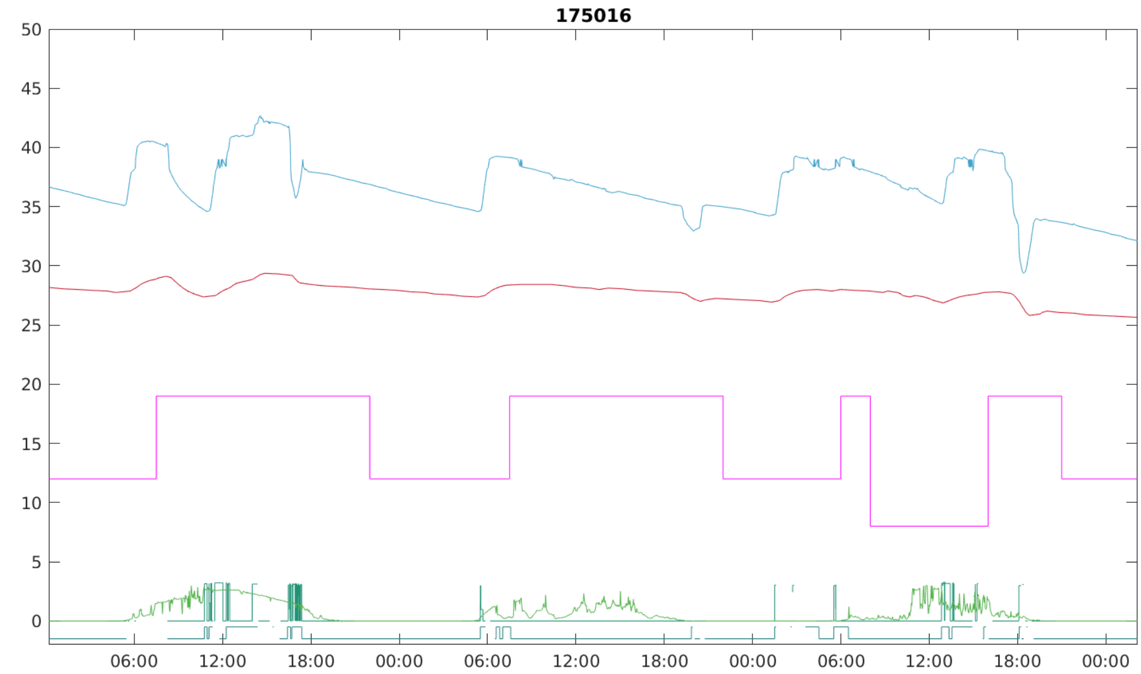

Figure 4-11 Hot water tank – reheats in the presence of solar self-consumption

On the first day, hot water is drawn but the system waits until there is enough solar PV generation before the tank is reheated, as there is enough hot water left in the tank. Later in the day we see another drop in the sensors indicating a further draw, before the immersion is turned on again. This shows how reheats maximised solar whilst ensuring after two uses there was still hot water available. A system which does not infer current available hot water may have missed this and not provided enough hot water for the user. For the following day where there was little draw and less solar, so there was no firing of the immersion during the day as enough hot water was being provided.

CASE STUDY: JUST IN TIME HEATING & VARIABLE PREHEAT LENGTH

The graphs below show average profiles of immersion power consumption contrasting the simplistic ‘unmonitored’ control with the smarter optimised control, with weekdays and weekends separated.

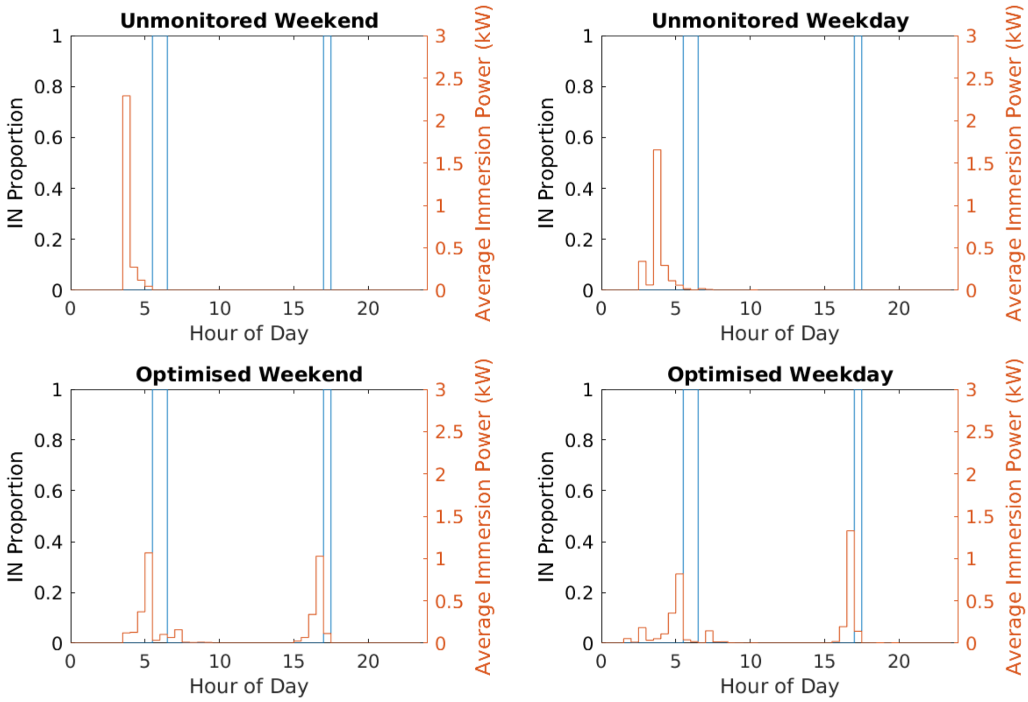

Figure 4-12 Hot water tank – unmonitored vs. optimised control strategy

The unmonitored control period generally began heating two hours before the IN period, however the tank was typically full after half an hour. In the optimised case, we see that typically this has been shifted later with most of the energy into the tank going in in the last half hour. This means that the tank was warm for a shorter period, reducing losses and leading to energy savings for the householder.

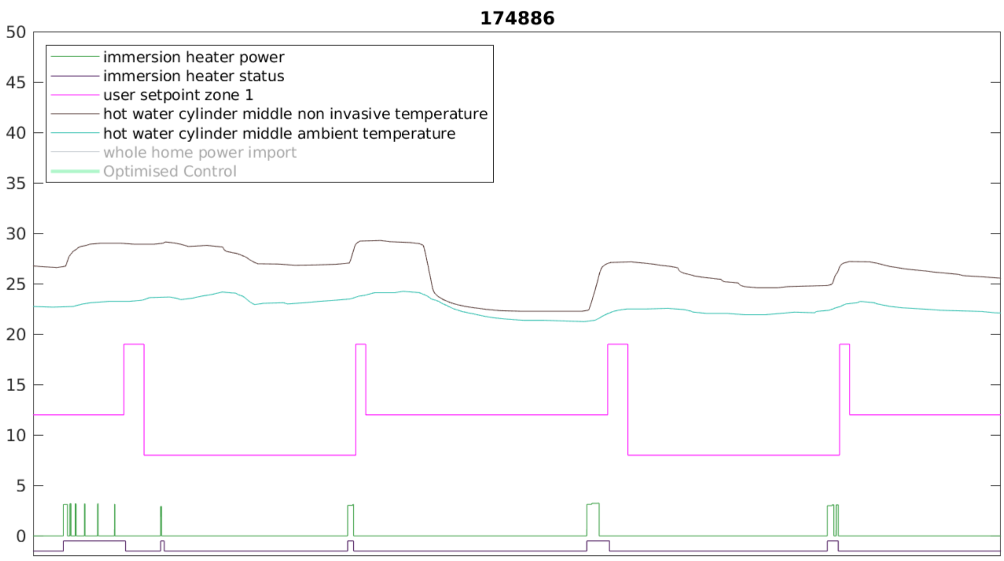

Figure 4-13 Hot water tank – just in time heating

The graph above illustrates just-in-time heating more directly. When the tank is already hot, it only takes 20 minutes to fully heat the tank (so the system delays this as late as possible). Later in the above period, the system detects that the tank is cold and needs to be heated for one hour to provide enough hot water, and subsequently allows sufficient time before the IN period for this to occur.

CASE STUDY: QUANTIFIED SAVINGS DELIVERED BY OPTIMISED CONTROLS

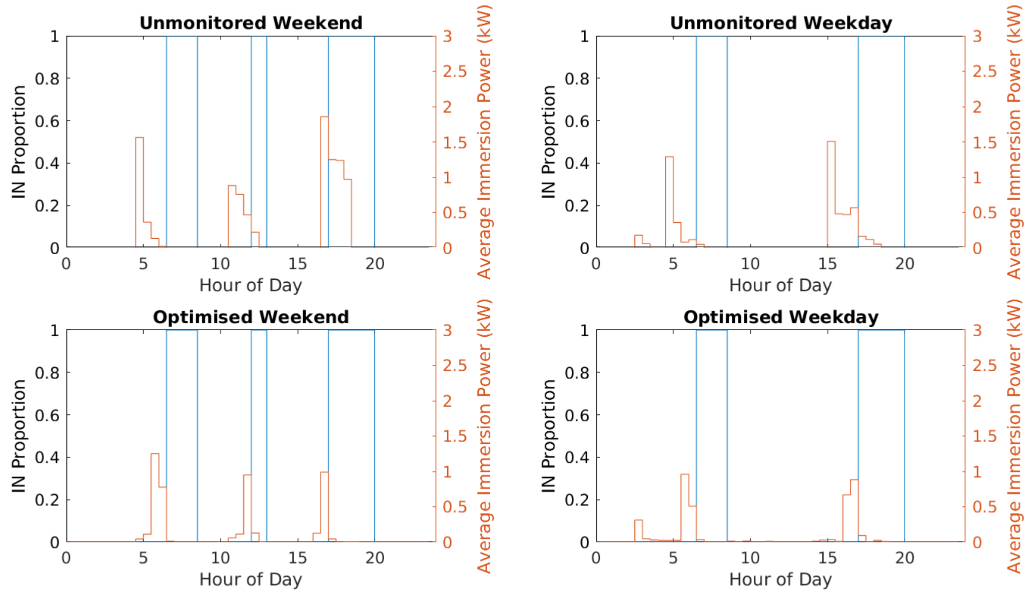

Figure 4-14 Hot water tank – savings delivered by optimised controls

This home provides a case where a quantified comparison can be made between control strategies to work out the benefits of optimised control.

The tank has a relatively high cooling rate when compared with some of the other installs. Under the assumption that flow was equal and similar tank states were achieved, we can compare the average power requirement with and without 'optimised control'. The 'unmonitored' scenario is representative of a non-smart system, and so we can conclude for this home that the introduction of the smart optimised control system (with tank monitoring) gave the householders significant savings.

While this demonstrates that the system was able to learn the characteristics of the tank and deliver a benefit, it should be noted that the magnitude of the savings may not have been as large if the tank was better insulated and had a lower cooling rate. On an annual basis, this would translate into a saving of over £40, even assuming a reduced rate of 8.5 p/kWh.

Illustrative savings level	Unmonitored (kWh)	Optimised (kWh)	Reduction (%)
Weekend	4.90	2.31	52.9
Weekday	2.76	1.89	31.5
Whole Week	23.52	14.06	40.2

Figure 4-15: Illustrative savings level

CASE STUDY: SMART CONTROLS WITH ECONOMY 7 ELECTRICITY

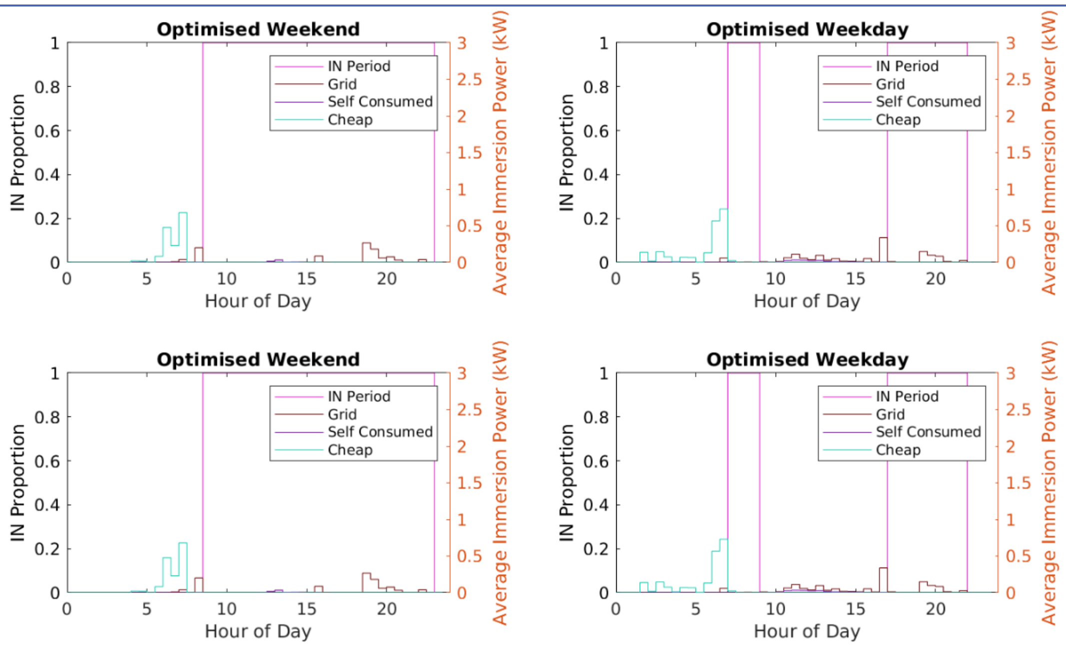

Figure 4-16 Hot water tank – smart controls with Economy 7 tariff

Without smart controls, immersion heaters on an Economy 7 tariff would be typically turned on for the whole night, leading to unnecessary tank losses by keeping the tank warm all night. Also, if much of the hot water requirement is in the evening, there will be further losses during the day, and it might have been more efficient to use peak rate electricity in the evening to top up the tank, especially if it were poorly insulated. PassivSystems optimised controls make quantitative trade-offs between these options, according to the learned characteristics of the tank.

The figure above shows how the tank is heated only at the very end of the cheap rate period (07:30am local time), leading to savings. This is more apparent on the weekend where there is a gap after the tank is heated and before the IN period; this is occasionally supplemented by a small fire before the IN period to ensure a full tank at 08:30am.

The tank is sometimes topped up in the evening, ensuring that hot water is always available to the resident according to their schedule.

SOLAR OPTIMISATION AND HOT WATER TANKS

One of the innovations developed in this project by PassivSystems is 'solar optimisation', where the system assigns a lower price to self-consumed solar PV generated electricity and allows for this in the optimisation calculations. This means that PV self-consumption will be encouraged, but only when it is advantageous to the occupier -- for example, it is not always better to have the immersion programmed to be on in the middle of the day.

One of the key complicating factors is that the immersion power rating (3kW) is almost always significantly greater than the PV power generation. Only four homes ever had a half hour period with more than an average 3kW generation, even without allowing for baseload electricity consumption. As the PV generation cannot be stored, and the immersion heater cannot be modulated to a lower power value, turning on the immersion heater invariably leads to some level of grid import consumption. Furthermore, for part of the trial it was assumed that the residents are charged 8.5p/kWh for self-consumed generation.[30] As a result, there will be a net cost of heating the tank which will be a weighted average of the grid electricity price and the self-consumption price.

This means that the algorithms need to weigh up the benefits of solar-heated hot water with the losses that will occur from the hot water tank from the early heating (hot water is likely to be consumed in the evening or even the following morning). The algorithms will also compare with the cheap rate electricity price for homes on Economy 7 -- it may end up being cheaper to heat the tank with cheap-rate electricity than solar generation -- 8.5p/kWh is roughly the same price as typical night rates on Economy 7.

In summary, there are some key trade-offs in deciding when to heat the tank, which the optimisation algorithms are best placed to decide as they can compare the options quantitatively and dynamically, delivering the best benefits to the occupants.

Self-consumption of solar PV is also limited by a few factors:

- **Tank is hot already.** For example, if the tank has been already heated for the morning period but no hot water was consumed (and the tank stayed warm) then it may not be possible to absorb any solar generation. The immersion thermostat turns off automatically when the tank reaches approximately 60°C and prevents further power consumption.
- **Baseload consumption.** Other electricity usage is non-flexible as far as the smart system is concerned, and this gets first refusal on any available solar generation.
- **Schedule.** Depending on the users' schedule, it may not make sense to use any of the available solar during the day, as cooling losses may mean that we incur a greater cost to the user due to further reheats for the next IN period (e.g. if only one IN period in the morning)

Appendix I presents a few case studies showing the operation of solar-optimised immersion heaters and how much self-consumption was achieved.

HOT WATER TANKS - SUMMARY OF PERFORMANCE

The system is provisioning hot water well for householders with very different requirements and patterns of behaviour. There are different schedules with most using a morning and evening IN period. Some households are using no hot water, whilst others use lots and have schedules set up to reflect that. Homes with high hot water usage inevitably have high immersion power requirements. Away periods are providing an energy saving benefit of making it easy to turn off hot water, while getting a full tank ready for the occupants' return.

The case studies above demonstrate scenarios where significant benefits are afforded to the householders, largely in efficiency savings which will reduce the amount they are spending heating their hot water tank. **In most cases these benefits will not be directly apparent to the residents**, as in the absence of smart meters the savings will not be immediately observable as a separate part of their electricity bill, and they are still being provided with the hot water they need.

[30] Note for some periods of the trial we assumed this value was 0p/kWh to stimulate the algorithms to increase self-consumption.

Tank monitoring: The PassivSystem's non-invasive tank sensors are working well, enabling two key benefits:

- **Just-in-time preheating:** start time (and length) for a preheat ahead of an IN period has been varied depending on our inferred estimate of current tank level, and thus heated 'just in-time' which minimises tank losses (especially when compared with a simple control system).
- **Automatic top-up:** the system was able to detect significant hot water consumption by the householders and automatically reheat the tank in response, meaning that they did not subsequently run out of hot water.

Energy savings from optimised control: the optimised control strategy gives significant energy savings vs the baseline unmonitored strategy where there is comparable data. This is primarily due to the heat 'just-in time' approach which utilises knowledge gained from the non-invasive sensor, as well as avoiding needless reheats.

Economy7 utilised effectively: previous to having Passiv controls, the hot water tank in Economy7 homes would have been fully heated shortly after midnight and kept hot for the rest of the night, whereas the system has been able to heat the tank towards the end of the cheap rate, at the same time as ensuring the tank was hot in the morning and hot water demand was being met.

Smart solar PV self-consumption is working well: on most sunny days the homes were successfully using the generated electricity to store energy in the tank, with less energy required at later times. Tanks were being heated less during the middle of the day on cloudy days, indicating the system is working as expected. The system is also smart enough not to reheat the tank if there is no upcoming requirement for hot water (scheduled IN period). Solar panels are generally producing about half of the immersion power rating (1.5-2kW), so we see typically see self-consumption meet half of the immersion requirement with the other half met by grid – this means that it is very important to make a smart quantitative decision about whether to consume the solar.

Cheap rate and self-consumption work well in tandem: there are examples of homes using very little grid electricity which are primarily making use of either cheap tariff and solar self-consumption to meet heating demands.

Limiting factors observed in hot water analysis:

- Some of these homes use water at random times, uncorrelated with scheduled occupancy periods, making it hard for the algorithms to plan (with cheap rate electricity and solar generation), but the tanks sensors enabled dynamic reheating to meet demand.
- Many of the tanks are full for long periods, preventing self-consumption.
- High baseload, particularly in winter, regularly leads to no available solar for immersion self-consumption.

Note that depending on the user's schedule, it may not make sense to use solar/cheap rate tariffs. These do not necessarily mean that the system is not operating correctly -- in fact it is making smart decisions about what is best for the individual householder.

4.3.1.2 BATTERIES.

Battery technology specialists Moixa supplied domestic and commercial electrochemical batteries that were used across the homes and the council's buildings. Five 3kWh Moixa Smart Batteries were incorporated into five domestic properties and three 4.8kWh Smart Batteries have been installed in three Council properties.

The batteries can charge when surplus solar PV generated electricity is available and feed this energy back into the home or building when there is a demand for immediate energy otherwise sourced from the grid. In this way, the building can make use of the cheaper, renewable energy by offsetting when the electricity is used.

HOME OPTIMISATION – HEAT PUMP AND BATTERY COORDINATION

Another innovation demonstrated as part of the Smart Energy Islands project is the coexistence of heat pumps and (electrical) batteries in homes and the coordination of load between them.

In the case study shown below, the heat pump and battery are working well together; the heat pump appears to the battery like any other electrical load in the home, and thus takes priority on the available solar generation. The battery is then able to soak up any excess generation that the heat pump does not need and discharge it later in the day for use by the heat pump or any other appliance.

CASE STUDY: BATTERY COORDINATION AND SOLAR OPTIMISATION IN OCTOBER

The figures below show time-series graphs of heat pump and battery operation over 6 days in October 2019 when both the heat pump and the battery were involved in the self-consumption of solar PV-generated electricity. During the first part of sunny days, both the heat pump (green) and the battery (orange) self-consume most of the available PV (but successfully coordinate and don't try and consume more PV than is available). By the afternoon, the heat pump has pre-warmed the house as much as it is permitted (1°C above the 20°C room setpoint, as apparent in the bottom graph) and the battery is presumably also full. The systems were not able to self-consume the remaining solar generation later in the day. After the sun has gone down, no more heating is required (as the solar energy has been stored in the building fabric) and the battery is able to discharge to meet other electrical demand. The battery usually has enough left to serve morning electrical demand as well. The last two days were cloudy however and the heat pump could self-consume all the available generation, with the battery acting to balance some of the fluctuations.

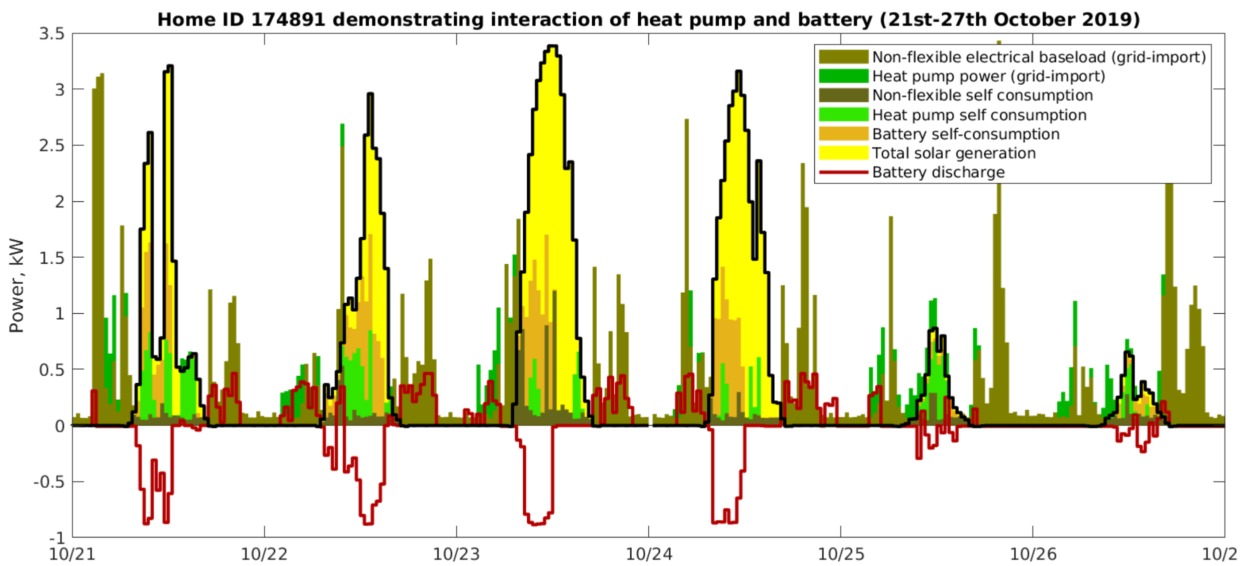

Figure 4-17 Heat pump and battery interaction in October

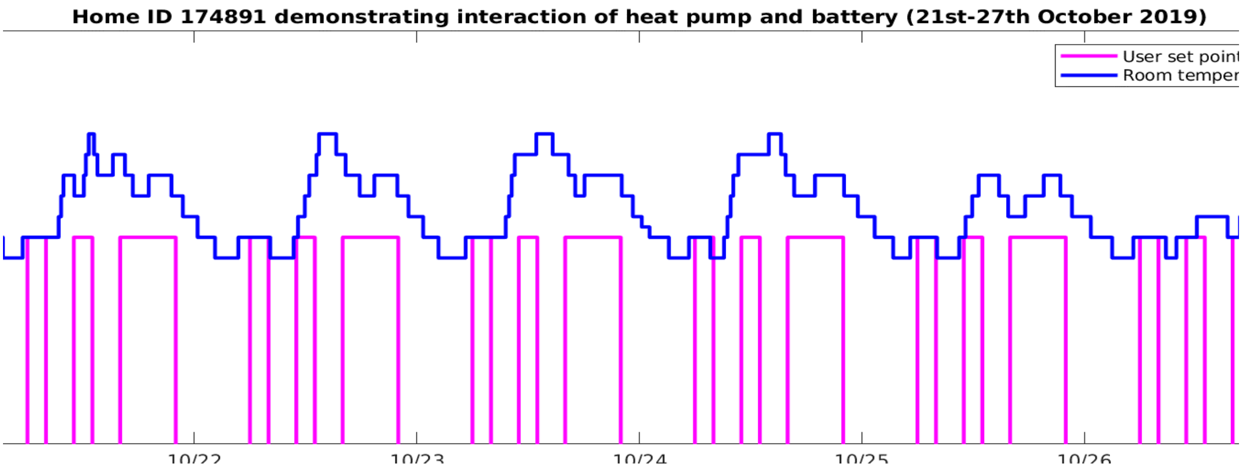

Figure 4-18 User set point and room temperature in October

CASE STUDY: QUANTIFIED BENEFITS OF SELF-CONSUMPTION

This home with PV and hot water tank controls appeared to have a relatively constant level of behaviour throughout the time on each of these control strategies, which means that we are able to carry out a quantified comparison between the two. The unmonitored period 26/03 - 08/04 inclusive (14 days) was compared to 31/08 - 13/09, a two week period on the optimised strategy with comparable solar generation. The graphs below show that in the unmonitored mode the tank was being heated before the morning IN period using grid electricity only.

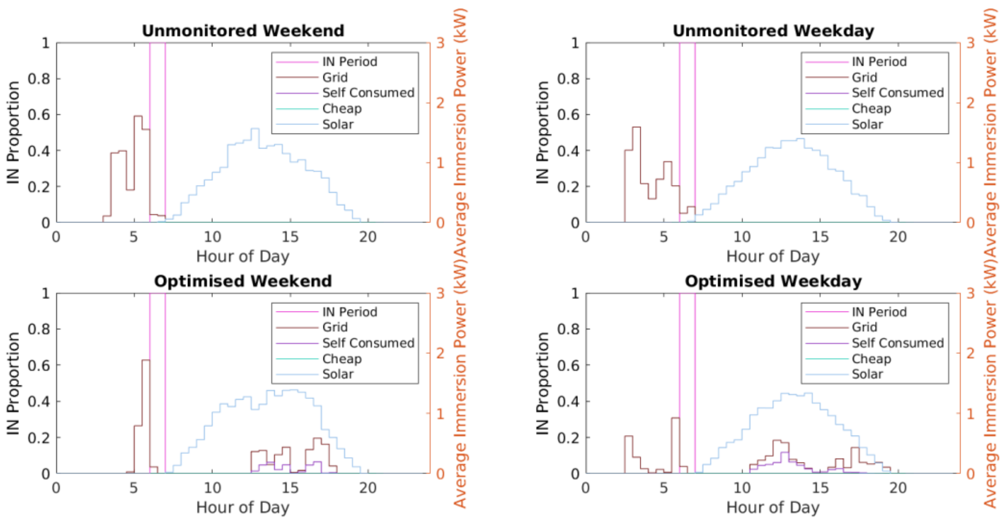

Figure 4-19 PV self-consumption by a heat pump on optimised control strategy

The introduction of the smart control system has provided a sizeable reduction in grid electricity consumption (which is where the cost to the householder occurs), as shown in the table below Note that this is only the electricity consumed by the hot water tank, not the whole home.

	Unmonitored (kWh)		Optimised (kWh)		Reduction (%)
	Grid	**Self Consumed**	**Grid**	**Self Consumed**	**Grid**
Weekend	3.29	0	3.06	0.49	7.0 %
Weekday	3.30	0	2.95	0.78	10.6 %

4.3.1.3 ELECTRIC VEHICLES

With only 15 miles of road on all five inhabited islands, the daily driving distances for vehicles on the Isles of Scilly are very low. EVs are therefore a practical solution for both private and commercial transportation. As part of the Smart Islands Partnership, the Isles of Scilly aims to reach an EV uptake of 40 percent of all vehicles by 2025.

With the small driving distances required, it is unlikely that the EVs will all require daily charging to full capacity, nevertheless, it is possible that each vehicle could use between 2 or 3 kWh of charging each day. If plugged in to an appropriate smart charging point, these EVs could provide demand side response capability of 1,000 to 1,500 kWh each day. This is a useful amount of energy, especially during the peak solar PV output period in the middle of the day when use profiles suggest most cars are parked, as transportation predominantly favours morning and afternoon school run and morning and evening commuting.

For EVs to act as an electricity store, they will typically need to operate at below their full charging capacity, leaving room for additional charging when there is an energy surplus. EVs on the Isles of Scilly are particularly well suited to this requirement as it is viable to maintain vehicles at a relatively low charge (i.e. below full capacity) due to the short driving distance. EVs typically have a range of between 150-200miles and with the Isles of Scilly's small road network 'range anxiety' is less of a factor for daily usage.

It is also possible that EVs could act as a source of electricity feeding back into buildings or the grid through a vehicle-to-grid (V2G) charger. Hitachi has installed two prototype V2G chargers on the islands at the end of 2019 to trial this technology.

As part of Smart Energy Islands, a single smart charging point was deployed on the islands to test an EV Energy Management System. The EV-EMS software will be used as additional charge points are rolled out as part of the Go-EV project.

INSTALLATION CHALLENGES

Many of the key challenges encountered by the project came from installing the physical technology on the Isles of Scilly. Due to the remote location of the islands, a historic lack of investment in certain properties and infrastructure, the unusual and sometimes limited transport options and the often harsh weather that is encountered, it is not as straightforward to install equipment as on the mainland.

As the islands are remote, projects cost more to implement. Typically, a project will cost between 20 percent and 50 percent more to implement on the Isles of Scilly than in Cornwall according to local stakeholders.

For some infrastructure projects, personnel need to be brought across from the mainland.

With so many partners involved in SEI, the need to secure personnel with the correct expertise, as well as the challenge of working with historic housing stock, meant that this phase of the project took longer than expected. Additional technical expertise during the installation process was secured from the mainland, with firms selected from Cornwall where possible.

The project faced several challenges during the equipment installation phase both for solar PV and the in-home technologies. These included the age of the homes under consideration, the existing electrical condition and roof condition.

A more detailed audit of the housing stock to be fitted with technological interventions highlighted that the true number of suitable roofs on social housing properties was lower than initially expected. Secondly, the practical suitability of some of this stock for solar panel installation was further reduced due to the type and quality of roofs present. Some roofs were replaced at additional cost to the project but this was not feasible for all the buildings, which lowered the total number of roof-top solar PV installations possible.

The installation of air-source heat pumps, in-home batteries and retro-fitted hot-water tank heating controls was also more complicated than expected again due to the additional works required to fit and commission the equipment in conditions that were not as ideal as expected. For example, the integrity of the home electrics, walls, floors, ceilings or communications infrastructure resulted in unexpected delays or faults during commissioning that resulted in additional and unplanned costs.

Due to the remote location, qualified and experienced tradespeople and their equipment had to be shipped to the islands. Severe storms during this transportation and subsequent installation phase caused additional delays and expense.

5 DOMESTIC ASSETS SUPPORTING GRID MANAGEMENT

5.1 NETWORK/ GRID CHALLENGES

As Distribution Network Operators (DNOs) are required to accommodate more distributed intermittent generators and increased demand from heat pumps and EVs, they are developing new approaches to network management, types of connection agreements and commercial arrangements.

These include Active Network Management (ANM) connections offered in areas of the network where available capacity is limited. An ANM connection allows the DNO to connect more generation to the network, while reserving the right to curtail excess generation at times to avoid network overload. The methodology behind the order of curtailment is based on 'Last In, First Out' (LIFO), whereby generators are curtailed in the reverse order that the connection offers were accepted - curtailment could mean a simple cut-off or it can be a reduction in generation to a set limit. This arrangement is implemented on a regional basis, so the Isles of Scilly are treated as part of WPD's South West area.

At the time of SEI project scope development in 2015, the excess generation problem was particularly acute in the South West, where historically curtailment rates have been as high as 80 percent in some cases. Under LIFO, island generators could be curtailed and revenue from solar generation forfeited because of surplus generation on the mainland, even though the island's generation could be absorbed locally (i.e. no backflow to the mainland over the undersea cable). The related regulatory issues are discussed in more detail in section 10.

Currently, ANM connections can only be offered to generators connected to the 11kV network and above. Being able to manage a group of Low Voltage (LV) generators connected to the same 11kV point, could allow ANM connections to be offered to distributed generation connected to the LV network, such as small commercial PV installations on the Isles of Scilly. This would require the capability of curtailing those generators when required based on the outputs of the ANM system. To explore the technical and commercial aspects of such extension to the ANM, WPD has set up the 'Smart Energy Isles' funded by the Network Innovation Allowance[31]. The project was run in parallel to SEI and in close collaboration.

Following WPD's network reinforcement programme in 2017, the curtailment risk in the South West was substantially reduced and the larger PV generators installed as part of the SEI project were able to connect unconditionally, i.e. without future curtailment. However, for the purpose of the project, ANM terminals enabling curtailment were installed on the SEI funded installations. Curtailment signals adopting the subsea cable as a common constraint for the Islands were simulated and sent by WPD to Hitachi's Energy Flex Trader to test the system's capabilities.

While not an immediate problem for the SEI generators, new generators looking to connect to the WPD network on the Isles of Scilly in the future may become subject to curtailment and the excess generation problem remains pertinent in other parts of the network. For example, to reach its 40 percent renewable energy target by solar PV alone, the Isles of Scilly would need to install approx.

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[31] https://www.westernpower.co.uk/projects/smart-energy-isles (Accessed on 08.01.2020)

6.8MW of solar, which would potentially exceed the peak demand in the summer by a factor of three. While a more diverse generation mix, as envisaged by the Isles of Scilly Community Venture (see Figure 5-1) would likely be more aligned with the demand profile, the risk of curtailment of additional generators is real. Currently, the Single Premises Connection Procedure allows for a connection of new generation systems up to 3.68 kWp. However, any larger installations may become actively managed in the future.

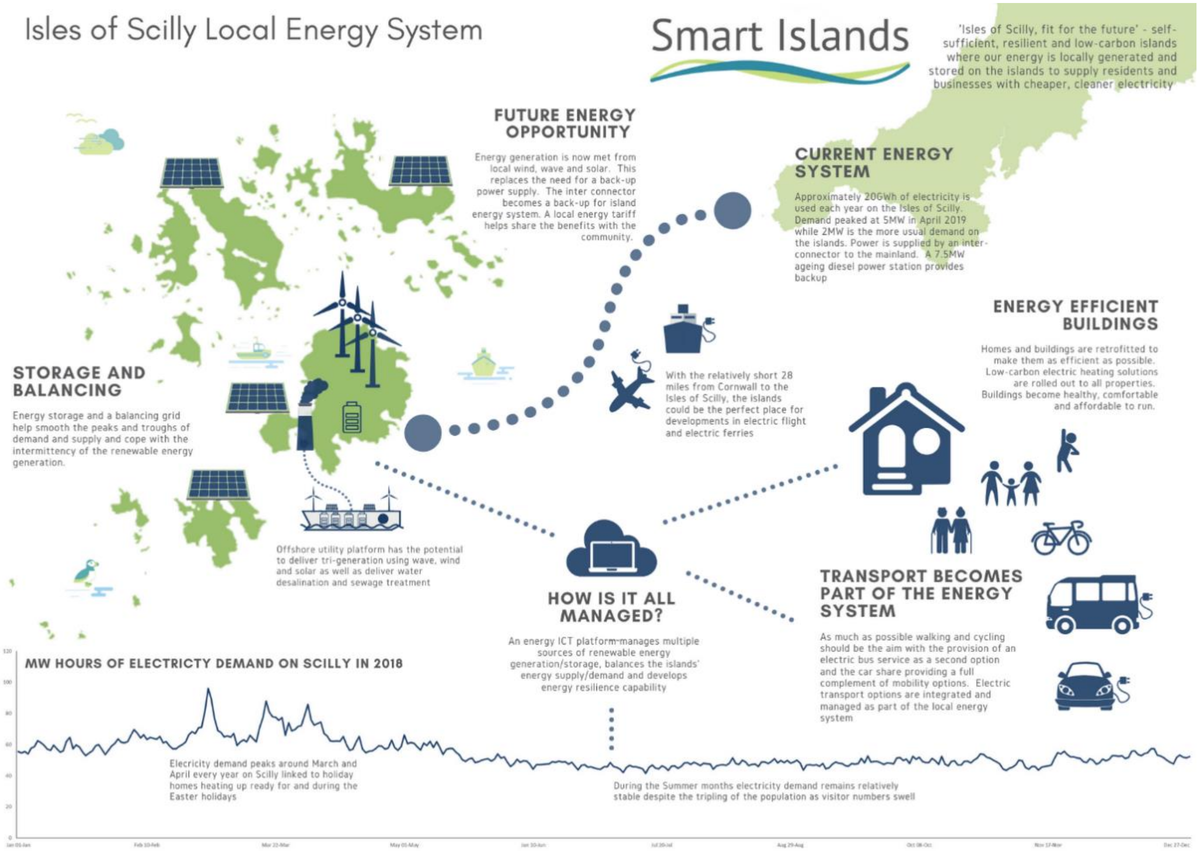

Figure 5-1: Isles of Scilly Local Energy System (Source: Isles of Scilly Community Venture).

In common with many DNO network regions, there has been an explosion over the past decade in the connection of embedded generation at all voltage levels within the South West region of WPD's network. For example, in 2016 in their note on capacity restriction on their 132kV Bridgwater to Avonmouth line WPD stated that there was 1.95GW connected and 1.35GW of accepted offers within the South West[32]. This is within a region with a winter maximum demand of 2.53GW and a summer minimum of 0.98GW. There is clearly significant risk of generation exceeding demand within the region and if export from the region via the transmission network is constrained then there is no option but to constrain generation. The latest constraint map of the region[33] does indeed show substantial constraints on the Extra High Voltage network (33kV and above), including on the link to the Islands. The risk to generators of constraint is therefore very real.

[32] https://www.westernpower.co.uk/downloads/3871 (accessed on 09.01.2020)
[33] https://www.westernpower.co.uk/downloads-view/79015 (accessed on 09.01.2020)

Further, in February 2019, as part of their Flexible Power programme, WPD announced a Constraint Management Zone (CMZ) on the Isles of Scilly[34]. The CMZ addresses the opposite problem – the risk of excess peak demand. WPD is currently procuring demand turn down services for peak demand times – mornings and evenings, mainly throughout the month of April. Annual peak demand on the Islands usually occurs in March -during the Easter holidays, when tourists start to arrive and the weather is still cold.

The graph below shows the historical annual demand patterns.

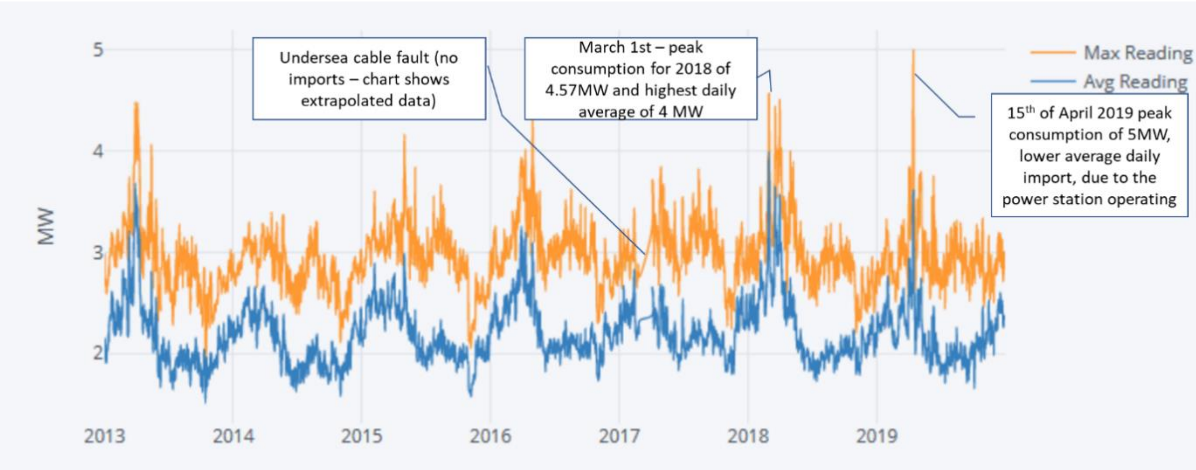

Figure 5-2: Average and Maximum Daily Imports on the Undersea Cable (MW)

Note that this graph represents the import via the undersea cable, which is equal to the demand on the islands minus the generation of the local WPD-owned diesel power station.

While the primary purpose of the power station is to provide emergency back-up, it also often operates at peak demand times during the winter. As the power station is aging and whilst WPD is considering options, including replacement, demand-side response (DSR) may be used as an interim solution. This in turn, may lead to DSR becoming part of its future strategy for replacing the power station.

The whole island import data provided by WPD illustrates the annual demand patterns on the islands. Figure 6-1 shows the daily average and maximum demand on the subsea cable – any on-island generation reduces the amount of electricity imported. While data on the operation of the power station is not available, it can be inferred from the import data. The highest half hourly import was recorded on 15 April 2019, when it reached 5 MW. The power station does not seem to have been generating at the time, but was on during other times of the day, bringing the average demand down. This illustrates the reasons why WPD is looking to procure demand turn down in April to mitigate the peaks.

[34] https://www.flexiblepower.co.uk/scheme/CMZ_T3B_SWE_0008 (accessed on 03/01/2019)

The ICT solution put in place as part of the project was able to accommodate the CMZ scenario, which requires turn down of demand during morning and evening peaks, as opposed to the turn up of demand required to counter curtailment.

5.2 THE PROJECT

This project set out to demonstrate how energy-using technologies could be connected at the domestic level, aggregated and controlled by IoT technologies to deliver benefits at the DNO level.

The ICT solution was designed to receive curtailment signals from WPD and utilise domestic heating, hot water and batteries to change local demand to absorb excess generation, rather than curtail a specific generator. For example, at times of high PV generation, the domestic assets described in Chapter 2, including EV batteries, domestic batteries, ASHP's and hot water cylinders, could be turned on to absorb the surplus generation locally, to avoid the excess supply affecting the constrained parts of the grid.

The ICT solution also has the capability to simulate DNO curtailment signals, which allowed the project to simulate and test scenarios reflecting WPD's requirements under the Constraint Management Zone scheme.

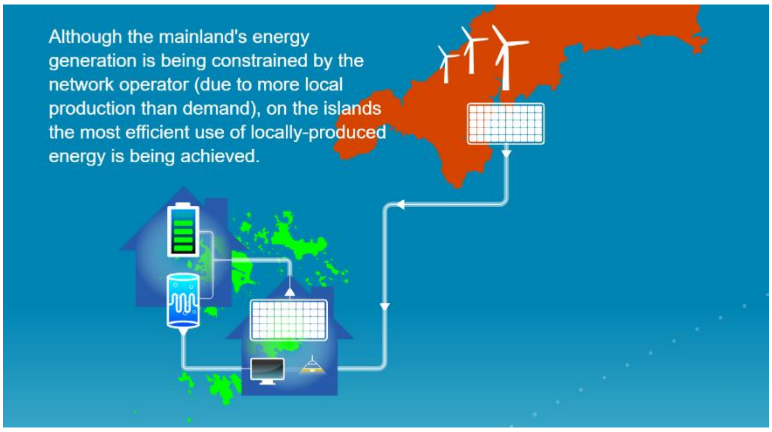

Figure 5-3 Curtailment avoidance concept overview

6 THE SMART ENERGY ISLANDS' ICT SOLUTION

This section provides an overview of the relevant aspects of the ICT solution and describes how it was implemented within Smart Energy Islands.

The core of the ICT solution is Hitachi's Energy Flex Trader. Hitachi's Energy Flex Trader platform was developed as part of the project and is securely hosted on an AWS public cloud designed within a micro-services, event-driven architecture. This approach was selected on the premise that it delivers a solution that is easily replicable, scalable and configurable. The solution is capable of adding new aggregators, multiple constraints and can concurrently handle multiple congestion points and flex cycles, enabling geographically granular control.

The security of the AWS configuration and Energy Flex Trader solution was tested by an external party (penetration testing). This means the solution is secure against external attacks, e.g. denial of service.

6.1 THE ICT SOLUTION

The solution comprises three primary sub-systems, each is described in more detail below.

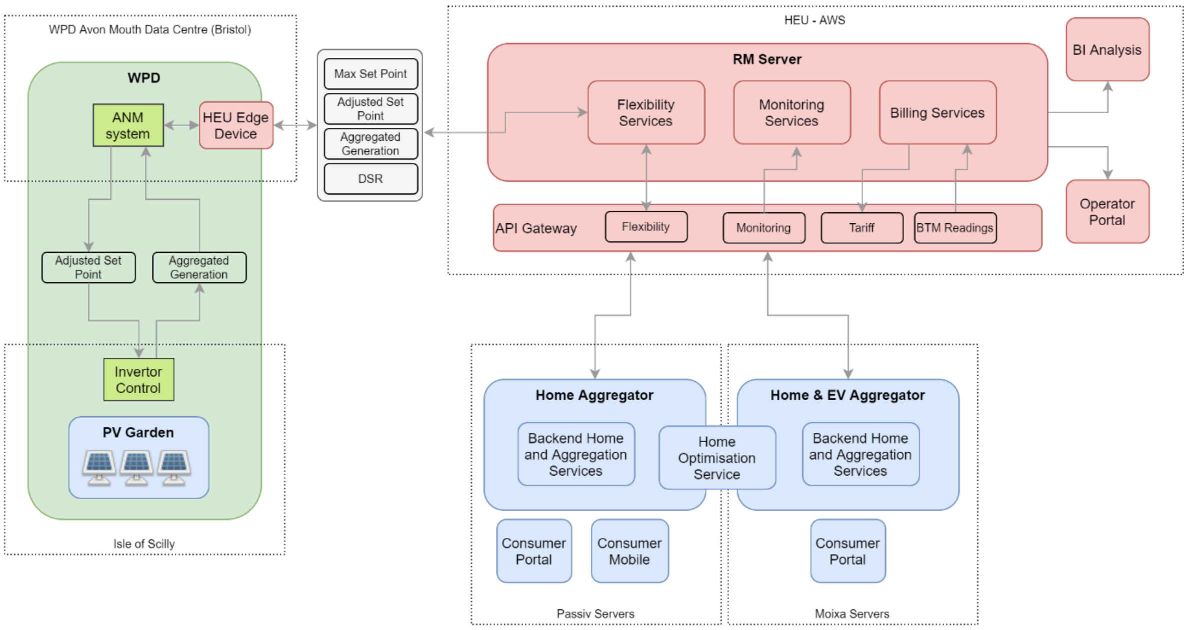

Figure 6-1 the top-level solution architecture for the ICT solution.

WPD sub-system

The management of the electricity grid and the project's primary solar generation assets on the islands (PV gardens) are captured within the WPD sub-system. Key components within this sub-system are WPD's Active Network Management (ANM) solution with invertor control and an analogue interface to the Energy Flex Trader's edge device. The analogue interface provided a secure method of integration and was located within WPD's innovation data racks at their Avonmouth data centre in Bristol. Energy Flex Trader 's edge device converts analogue signal to digital and vice-versa and integrates with Energy Flex Trader using AWS IoT.

Energy Flex Trader sub-system

At the core of the ICT solution is Hitachi's Energy Flex Trader. Hosted within AWS' public cloud, it was designed within a micro-services, event-driven architecture. The solution is capable of concurrently handling multiple congestion points, enabling geographically granular control. The application of Continuous Integration/ Continuous Delivery processes and test automation make the solution easy to maintain and quick to modify.

Key components include:

- A USEF-based flexibility trading system (described in more detail below),
- A behind-the-meter (BTM) billing service for capturing individual property's usage and providing this to the community venture for billing purposes.
- Energy Profile Manager which enables the configuring and scheduling of flex cycles.
- An Edge device for integrating with WPDs analogue interface at Avonmouth.
- An Operator's Web portal for monitoring and management of the Energy Flex Trader.
- A dedicated environment for performing analysis and exploration of the data captured during the project.

Aggregators' sub-system

At the bottom of the diagram we can see the aggregators' sub-systems. Each sub-system was built and managed by the respective aggregator, Passiv for heating devices and Moixa for batteries and EV chargers. Both sub-systems are connected by the Home Optimisation Service (HOS). This service was co-developed by both Passiv and Moixa, and is used to provide a consolidated optimisation for properties where both of their managed assets were installed.

Because the Smart Energy Islands project capitalised on the aggregation of several different devices within each home, it was crucial that these were all integrated into one system and fully optimisable.

Each aggregator presented the portfolio of its assets as a single entity, and the portfolios were then further aggregated as part of Hitachi's flexibility trading system, the Energy Flex Trader, creating a single virtual resource which could be used to offer flexibility to the network.

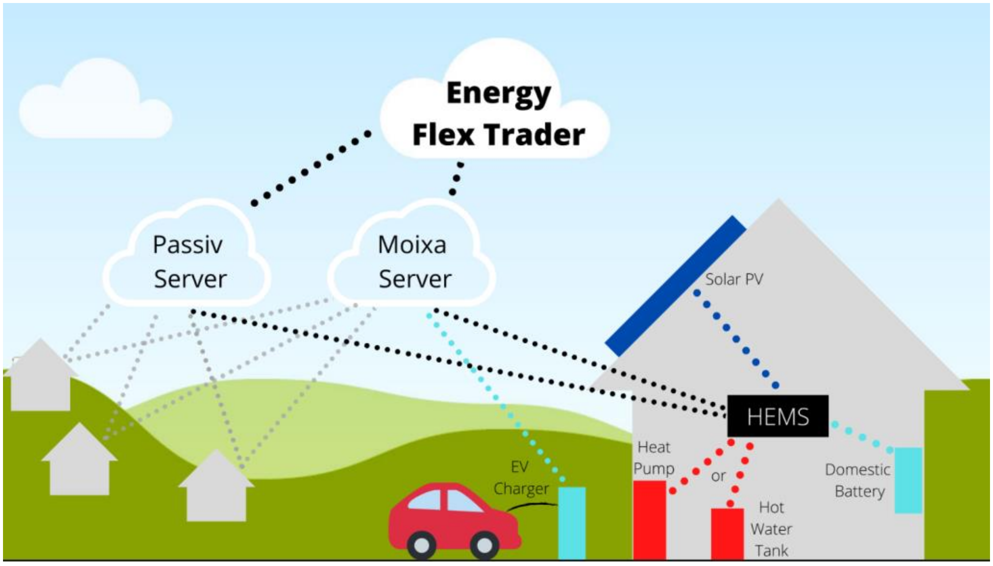

Figure 6-2 Home energy management and aggregation for flexibility

As discussed earlier, occupier comfort was a priority. The solution was optimised for the consumer and their needs were considered during every part of the design and implementation process.

The aggregator sub-systems used machine learning to predict the unique energy use profile of each individual property – ensuring that energy and warmth matched the user's needs at time of requirement. Information into Passiv's system was provided from a variety of sources including the smart thermostats and the retrofitted sensors on the hot water tanks to create a prediction for how each home used electricity on any given day.

By being able to predict how each home would use energy on any day and to be able to switch on or off any of the smart assets within the building, the system then demonstrated a unique ability to shape energy use, or load, in a property at any time, allowing a home to either increase or decrease its internal energy requirement in response to an external signal.

In short, each building could now operate as an automated demand-side response asset, changing its behaviours in response to network need.

6.2 FLEXIBILITY SERVICES

The flexibility services managed from within the Energy Flex Trader are based on the Universal Smart Energy Framework (USEF) standard (www.usef.energy). The Framework is being developed and managed by the USEF Foundation. USEF is a standardised market-based framework. It defines products, market roles, processes and agreements, as well as specifies data exchange and interfaces to enable a market where flexibility can be traded. The purpose of USEF is to accelerate the transition to a smart, flexible energy system to maximise benefits for customers. Smart Energy Islands project partners selected USEF as it was, and continues to be, the most complete and developed framework of its kind. USEF protocols have been implemented for flexibility trading between aggregators like PassivSystems and Moixa and a DNO such as WPD (Western Power Distribution).

Hitachi, PassivSystems and Moixa have collaborated on the design, implementation and operation of a USEF-based flexibility trading system. This has included identifying and agreeing modifications to the standard to support residential scale assets being traded within short time windows, which was an extension to the USEF specification.

USEF defines different market roles and the interactions between them, where one entity can deliver more than one role.

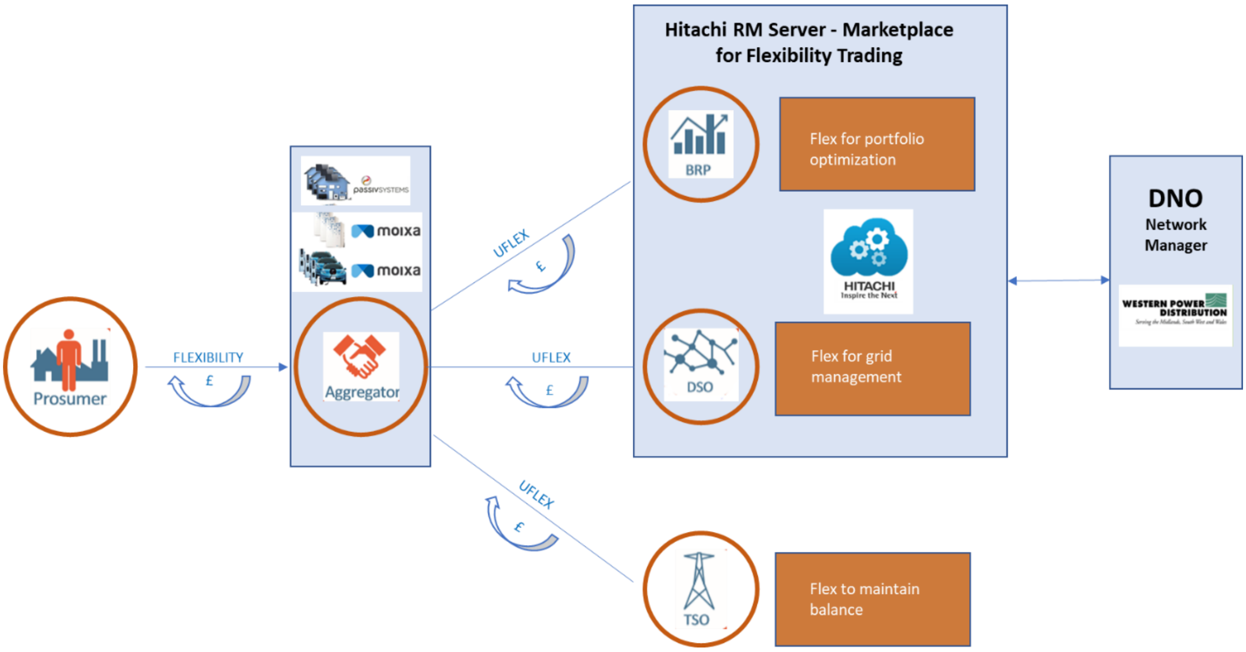

Figure 6-3: USEF roles and their application to the project.

UFLEX – Flexibility managed according to USEF's rules and guidelines is called 'UFLEX'.

Prosumer – A 'prosumer' is an end user that no longer only consumes, but also produces energy. USEF does not distinguish between residential end users, small and medium-sized enterprises, or industrial users; they are all referred to as prosumers. In Smart Energy Islands, each of the participating households and commercial sites is considered to be a prosumer. The prosumers have final control over their assets, which means the aggregator's control space is limited by the prosumer's comfort settings.

Aggregators – 'aggregators' are responsible for acquiring and accumulating flexibility from prosumers and offering that flexibility to market participants (e.g. DSO, TSO, 'Balance Responsible Parties' – BRPs). They play a central role in maximising the value and use of demand-side flexibility by utilising it for the service that offers the highest value. The aggregator cancels out the uncertainties of non-delivery from a single prosumer so that the flexibility provided to the market can be guaranteed. This prevents prosumers from being exposed to the risks involved in participating in the flexibility markets. This role was performed by PassivSystems (for heat pumps and hot water tanks), Moixa (batteries and third party EV charger), as well as Hitachi (aggregation of response from Passiv and Moixa).

BRP – 'Balance Responsible Party' (BRP) is responsible for actively balancing supply and demand for its portfolio of producers, aggregators, and prosumers. Unlike a DSO, the BRP is not concerned with grid constraints, but purely with matching the demand and supply of electricity bought and sold in each settlement period (half-hour in the UK). The BRP role was not exercised during the Smart Energy Islands project, but the DSO functionality implemented in the Energy Flex Trader can deliver this role in the future if required.

DSO – The DSO is responsible for the active management of the distribution grid and cost-effective distribution of energy while maintaining network stability in a given region. This is a new role being developed in the UK energy system as part of the DNO to DSO transition initiated by the Smart Systems and Flexibility plan. These organisations would manage and maintain distribution-level energy systems, addressing local constraints in a way that the Electricity System Operator is currently unable to.

The following DSO responsibilities have been implemented in Hitachi's Energy Flex Trader:

- Create and publish congestion points for aggregators. 'Congestion point' is a USEF term for a point on the electricity grid, beneath which congestion occurs. This could be for example a transformer or a cable with insufficient capacity. Flexible assets can be mapped to a congestion point, giving the solution an ability to respond to localised constraints utilising the assets which have the most impact. On the Isles of Scilly, only one congestion point exists – the undersea cable connecting the islands to the mainland.
- Receive the day-ahead plan, called the 'D-Prognosis' plan, every day from the aggregators. The D-Prognosis is the aggregator's forecast of electricity demand of its prosumers for the following day.
- Send 'Flex Requests' to procure flexibility from aggregators for the following two scenarios: 'Day-Ahead' and 'Intra-Day'.
- The *Day-Ahead* scenario sees the need for flexibility anticipated based primarily on the latest weather forecast. A Flex Request is issued to aggregators for the following day comprising of:
    - Type of flexibility required: demand turn up or demand turndown
    - Period for which it is required – broken down in half-hourly intervals
    - Magnitude or amount of flexibility required in each of the half-hourly periods (in KW)
- The *Intra-Day* scenario represents the curtailment use case by which Flex Requests are triggered as an immediate response to signals received from WPD's Active Network Management (ANM) system.
- Receive 'Flex Offer' from aggregators, evaluate and select the best offer based on a set of criteria.
- Dispatch 'Flex Order' to the aggregator for the selected Flex Offer.
- Receive updated D-Prognosis plan.

USEF defines five distinct phases of operation of the flexibility market.

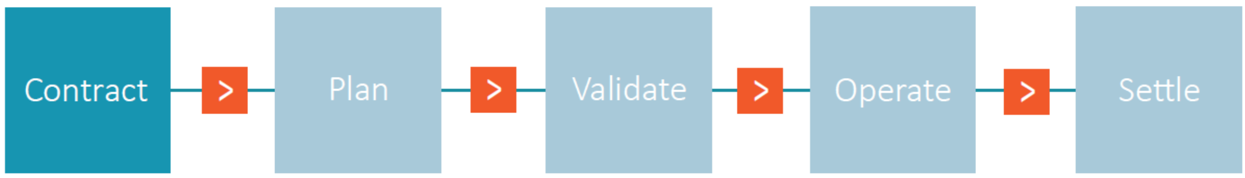

Figure 6-4: USEF phases

1. During the 'Contract' phase, contractual arrangements are established between the parties involved, including DSO, Aggregators, BRP, Prosumers. These are crucial to the operation of the framework. Contractual arrangements were not explored in detail as part of the Smart Energy Islands project.
2. During the 'Plan' phase, aggregators and the BRP plan ahead with the view to balance the supply and demand of electricity within the BRP's portfolio at lowest cost. This can happen well in advance.
3. During the 'Validate' phase, once the expected demand and generation becomes more certain, flexibility is traded based on predictions (Day-Ahead) or in response to an immediate need (Intra-Day)

4. During the 'Operate' phase real-time control of the smart appliances is delivered. In the Smart Energy Islands project, this trading was always triggered by the DSO requirements (real or simulated), but under USEF it could also be performed to balance the BRP portfolio on short term basis.
5. In the 'Settle' phase, the calculation of how much flexibility was delivered is done retrospectively.

See Appendix 2 for further details and screen examples.

The 'FUSION' project led by SP Energy Networks (SPEN) is exploring how USEF applies to the current UK energy market regulatory framework and the initial due diligence has concluded that the framework could be widely applicable in the context of DNO to DSO transition. Smart Energy Islands is engaging with FUSION to share project learning and inform future policy.

6.3 USEF FLEX CYCLE

Under USEF, the Flex Cycle, a series of events when flexibility is traded between Prosumers, Aggregators and the DSO, is clearly defined. The diagram below illustrates the different steps as executed during the project. The same steps are always followed, both for Day-Ahead and Intra-Day scenarios, but on different timescales. Day-Ahead trading is executed as part of the Validation phase.

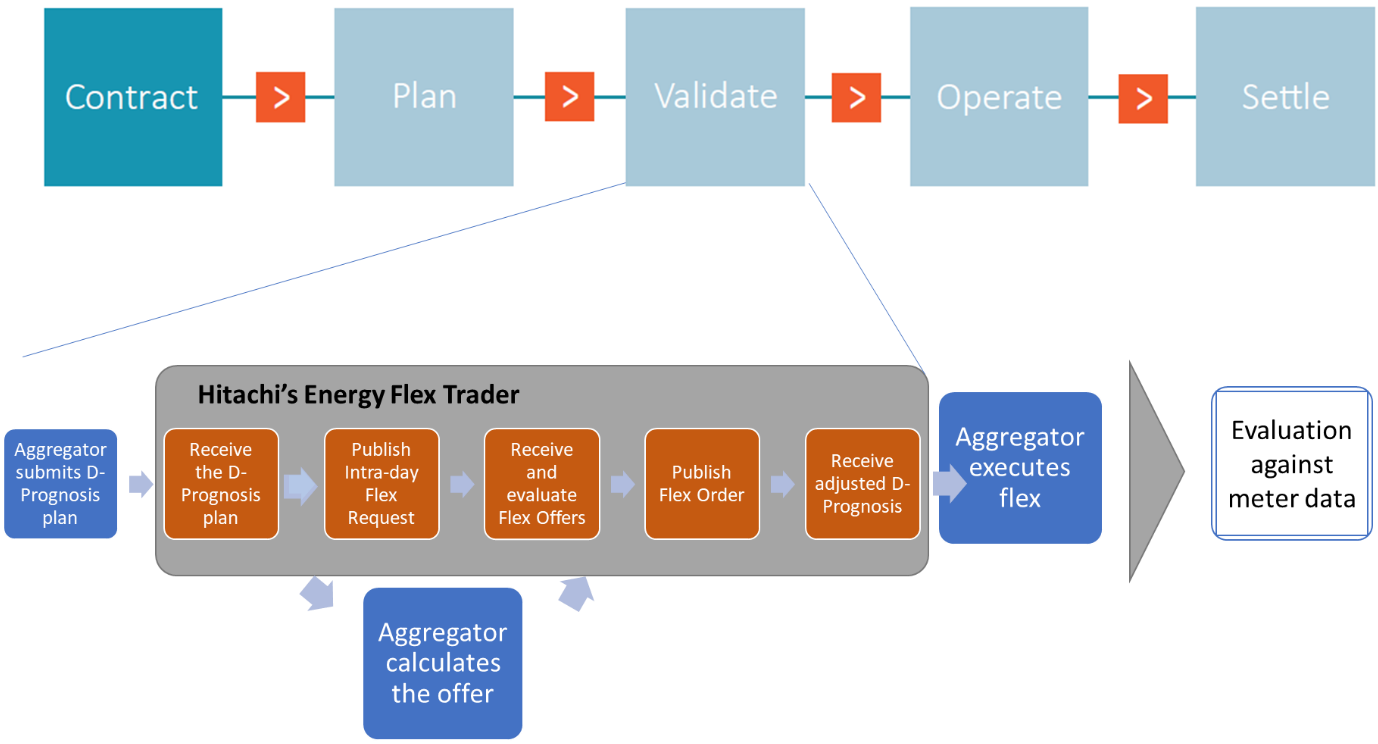

Figure 6-5: Role of Hitachi's Energy Flex Trader in executing the USEF phases – Day-Ahead use case

The Intra-Day scenario was designed to provide an immediate response to generation curtailment signals sent by a DNO, to alleviate the curtailment of generation by turning up demand. In USEF terms, it is part of the Operate phase.

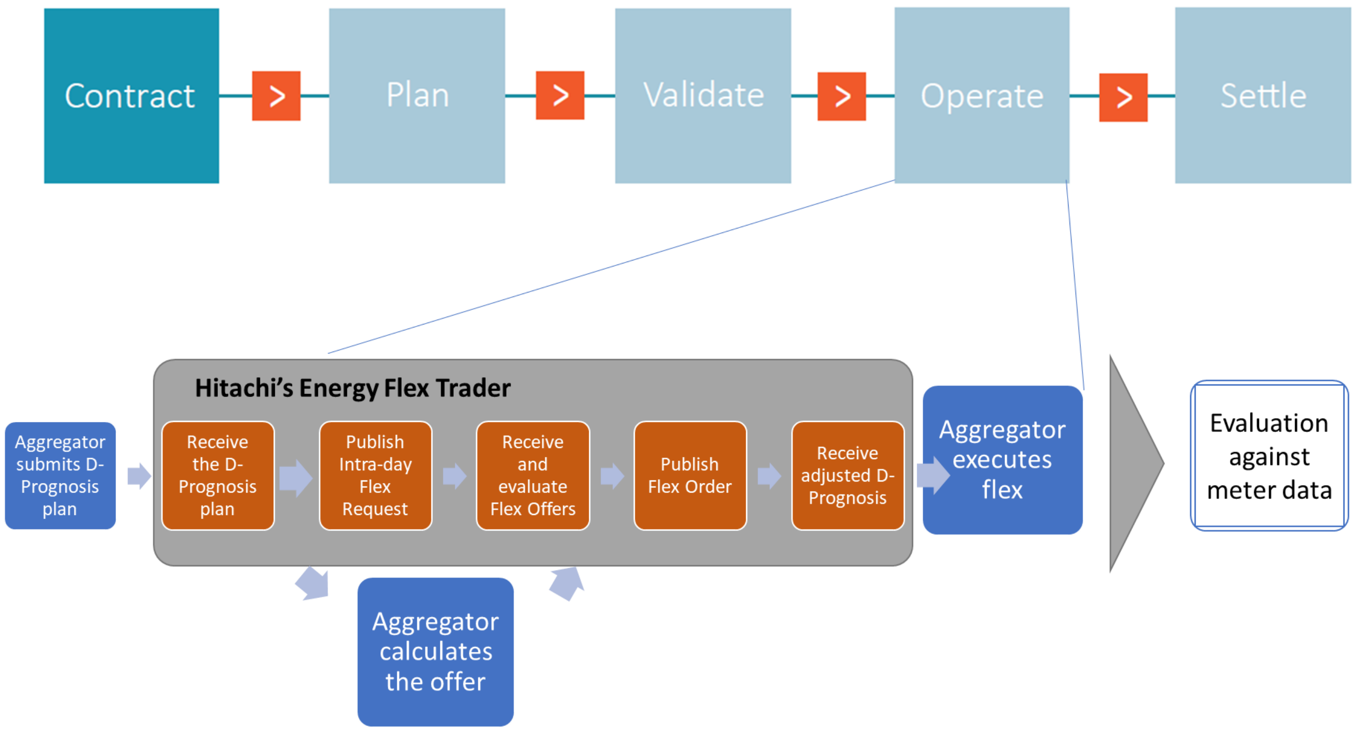

Figure 6-6 Intra-day flex cycle executed within the Operate phase

All aggregators are required to submit a **daily D-Prognoses** to the Flex Trader on a regular basis (at least once per day) so that the need for Flexibility can be assessed and planned for each managed congestion point. Passiv and Moixa have developed their own complex algorithms to generate these plans. They take into consideration factors such as the properties insolation, latest weather forecasts, and the user's current control settings.

In response to scheduled day-ahead planning cycles, or adhoc intra-day planning cycles (triggered manually for trials or automatically based on DNO Active Network Management signals), the Flex Trader accumulates the D-Prognoses received from the Aggregators and determines if Flexibility is required. The Energy Flex Trader performs this process for each congestion point and if flexibility is required creates a 24-hour **Demand Requirement Profile**. Based on the profile, it **publishes Flex Requests** to all the registered aggregators for a given congestion point. The aggregators then respond with their associated **Flex Offers** and the **Energy Flex Trader evaluates** them against a set of criteria including duration, magnitude and price of flexibility. Finally, the Energy Flex Trader will **publish the resulting Flex Order** to the successful aggregator for implementation. The USEF Validation phase concludes when an **adjusted D-Prognosis** is received from the aggregator.

In the USEF **Operate phase**, the Aggregators (Passiv and Moixa) **dispatch the constraints to individual devices** (heat pumps, hot water tanks, batteries, EV chargers), e.g. turning hot water tanks and heat pumps up or down or charging/ discharging batteries.

The Energy Flex Trader does not provide **settlements** at the moment. However, as part of this project, detailed post-analysis of Flex Order delivery against metering data was performed.

The Flex Offer evaluation algorithms within the Energy Flex Trader are not prescribed by USEF. They were developed by Hitachi to be specific to the needs of the project but can be easily modified, depending on the DSO requirements for a given congestion point.

While on the Isles of Scilly only one congestion point currently applies (the undersea cable), the system can run Flex Cycles for multiple congestion points concurrently, e.g. to alleviate constraints on a particular substation on the islands.

The end-to-end performance of the solution was tested and evaluated at each step of the Flex Cycle during a series of trials, the following sections discuss the design of the trials, their results and lessons learned.

7 FLEX TRIALS IN ISLES OF SCILLY HOMES

The trial period took place from July 2019 to January 2020, covering a busy part of the tourist season, as well as part of the winter heating season. The trials were divided into three batches:

- Trial 1 (Beta testing) - Summer (June – July 2019)
- Trial 2 - Autumn (September – November 2019)
- Trial 3 - Winter (December 2019 – Januany 2020).

This allowed time for learning and refinement of the systems.

7.1 TRIAL PARTICIPATION.

Only homes where the system has stabilised and was deemed to be performing adequately were selected for trial participation. The households were offered shopping vouchers as a reward for taking part and were able to opt-out at any point during the trial.

The number of participating homes varied throughout the trials and was influenced by factors such as communications outages and equipment upgrades. The table below summarises participation in each of the batches of the trials. In addition to domestic devices, Trial 3 included three batteries installed on the larger commercial sites and an EV charger.

Technology configuration			**All SEI Homes**	**Trial 1**	**Trial 2**	**Trial 3**
	Hot Water Controls		13	6	5	2
Solar PV			26	0	0	0
Solar PV	Hot Water Controls		33	16	12	12
Solar PV		Battery	1	1	1	1
Solar PV	Air Source Heat pump		5	5	5	5
Solar PV	Hot Water Controls	Battery	1	1	1	1
Solar PV	Air Source Heat pump	Battery	3	3	3	3
		Total	**82**	**32**	**27**	**24**

Figure 7-1: Number of homes participating in flexibility trials

7.2 TRIAL SCENARIOS

The aim of the flexibility trials was to exercise the IoT platform in real life scenarios and demonstrate the ability of the smart system to provide demand response to alleviate network constraints.

Two main scenarios were trialled:

- **Demand turn up to avoid curtailment** – turning up demand at the time of surplus generation, when the output of local solar generation was being reduced by WPD's Active Network Management in response to grid congestion[35].
- **Demand turndown** – shifting/ turning-down demand to reduce peaks. This was deemed to be a relevant use case as in the course of the project WPD announced that the Isles of Scilly will become a Constraint Management Zone (CMZ). This means that at times of the year when

[35] Some of the cycles were initiated by a signal received from WPD's ANM, others were initiated by a scheduler within the Energy Flex Trader.

demand is highest (April and May), WPD will be paying demand response providers to reduce the demand at peak times.

Under each of these scenarios day-ahead and intra-day cycles were executed.

Key areas explored as part of the flex trials were:

- **Performance and reliability of the integrated cloud based IoT solution** to respond to turn up and turndown signals and successfully conclude flexibility trading cycles.
- **Magnitude and duration of demand response delivered** – how much demand response are the aggregators able to deliver? How might asset characteristics and other factors, such as response duration, influence this response? Is the response sufficient to be a meaningful alternative to curtailment or demand peaks for a DSO? What level of response could be expected if the system was scaled up? What scale would be required to alleviate constraints on the Isles of Scilly?
- **Reliability of the response delivered**. Reliability of response was measured as the amount of flexibility delivered against the amount of flexibility offered by the aggregators. Delivering a reliable response was considered a high priority for the project, as revenue from commercial services, such as the CMZ, is highly dependent on the reliability of response provided. This analysis raised interesting questions regarding baselining domestic demand response, which are not unique to this project or USEF.
- **Price of flexibility**. What is the cost of domestic flexibility and what factors might influence it? The project did not explore the question of rewarding end-users or business models to incentivise DSR participation in a commercial setting.

Area	**Questions**	**Key metrics / analysis**
Technical Performance	How well did the system perform?	% of successfully completed flex cycles
Magnitude of DSR	How much DSR was achieved? What factors affect the magnitude of response	Max DSR (kW) from the aggregated portfolio Comparison of DSR achieved at different times of the day, times of the year, weekdays/ weekends, days with different solar irradiation Avg DSR achieved as % of installed asset base.
Reliability of DSR	How well do the aggregators perform against their own forecasts?	% DSR delivered vs. DSR offered Accuracy of D-Prognosis on non-flex days
Price of flexibility	What is the cost of domestic flexibility? What factors affect the price of flexibility?	Cost per kW of response offered by the aggregators

	Could domestic flexibility be a cost effective alternative to grid reinforcement?	

Figure 7-2: Flex trials scenarios

Due to differences in USEF interpretation, the level at which DSR was provided and the small number of domestic batteries deployed, comparison between response delivered by different asset types would not be meaningful.

PassivSystems delivers DSR on device level, meaning that the prognoses and flex offers only include the demand of the devices under PassivSystems control (heat pumps and hot water tanks). Moixa in turn provides the prognoses on whole home level, forecasting the demand for the whole home and utilising its batteries to adjust the demand profile. These differences were driven by the type of controlled devices. The heating assets not being able to export energy, they have no capability to compensate for other changes in load.

The differences of approach became apparent in the course of the project and while both approaches have their merits, they make comparisons between the aggregators difficult. It is not currently clear which way the market will go in the future: asset-based DSR or whole-home-based DSR and it is possible that both approaches will coexist.

For this reason and because of the larger sample size, most of the analysis below focuses on the heating assets controlled by PassivSystems.

8 FLEX TRIALS: RESULTS AND EVALUATION

Headline figures:

Number of completed flexibility trading cycles: **268**

Successful completion rate: between **67%** in Trial 1 to **97%** in Trial 3

Maximum demand response delivered by heat pumps and hot water tanks in a half-hour:

- **turn up: 32 kW**, equal to 31 % of the total installed capacity of devices participating in Trial 3
- **turn down: 10 kW**, equal to 9% of the controlled capacity in Trial 2

Average demand response delivered by heat pumps and hot water tanks during Trial 3:

- **turn up: 14 kW**, equal to **13%** of participating capacity
- **turn down: 4 kW**, equal to **3.8%** of capacity

Maximum demand turn up delivered by the combined portfolio (heating devices, domestic and commercial batteries) in a half-hour: 28 kW

Approximate number of homes needed to offset a complete curtailment of 1 MW of generation in the winter (demand turn up): **1,535**

8.1 TECHNICAL PERFORMANCE OF THE INTEGRATED CLOUD BASED IOT SOLUTION

The performance was measured as a percentage of successfully executed flexibility trading cycles.

The following cycles were considered successful:

- Cycles which completed fully – starting with the flex request issued by Hitachi's Energy Flex Trader all the way through to flex being pushed to the homes.
- Cycles where no offers were accepted based on offer score and therefore no changes were made to the behaviour of the devices in the homes. In those cases, the cost of flexibility outweighed its value, or the flex offer did not meet other criteria.

The success rate improved steadily throughout the trial period and reached 97% in Trial 3, with only one of the 36 cycles failing due to technical reasons.

It should be noted that Trial 1, where only 67% of cycles were successful, was considered part of the system's beta testing. Previous integration testing was done using simulators and virtual homes, Trial 1 allowed the fine-tune of the systems in response to real behaviour of the trial households. The results of Trial 1 are included in the analysis, as this was the only trial run over the summer period, when generation was highest and heating demand was lowest. They are not fully representative of what the system is capable of achieving once fine-tuned, but have been used as being indicative to illustrate the differences in results between summer and winter.

The reasons for cycle failure included factors such as a sudden unexpected departure from the predicted consumption pattern, significant enough to cause the aggregator to change or revoke the offer during the cycle and technical bugs in one or more of the integrated systems, which could only be uncovered based on real life scenarios.

Changes made on Trial 1 learning included:

- Decreasing Passiv's system sensitivity to an individual home changing its planned energy usage in between a flex request and a flex offer. In practice this occurred more frequently than would have been expected from testing and with less homes in the sample size than originally planned (only optimised homes were included), the impact of such a change was much larger than expected.
- Reduction in the duration of a Flex Cycle in the Energy Flex Trader from 600 to 300 sec to help address the problem above.
- Improvement to forecast and flex algorithms based on learning that most households were not using the predicted amount of hot water at the start of their in occupancy periods.

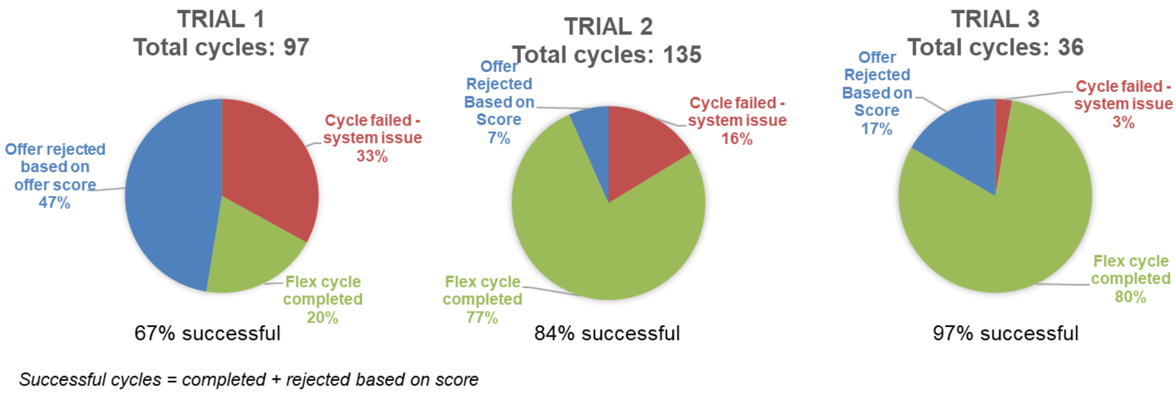

Figure 8-1: Flexibility cycle success rate.

The above analysis includes flexibility cycles for both aggregators.

As part of the intra-day cycles, connectivity between Hitachi's Energy Flex Trader and WPD was tested. Hitachi's Edge Device that's placed in the WPD network was successfully able to convert analog signals to digital setpoint signals to trigger intra-day flex cycles in Energy Flex Trader. And vice versa - on successful completion of the Flex Cycle, Energy Flex Trader was able to convey DSR effort back to the WPD through the same interface by converting digital to analog signals. The number of successful intra-day cycles confirms the stability of the WPD interface.

8.2 MAGNITUDE AND DURATION OF DEMAND RESPONSE

Magnitude of response was calculated as a percentage of the total installed capacity of the devices under control. For example, if an 11 kW heat pump was turned down from 6 to 5 kW, this would mean a 9% response. As outlined earlier, a heat pump is not expected to operate at full capacity, nor is it expected to be turned down to zero, so the actual capacity available for flexibility is never close to 100%. The situation is different for hot water tanks, which do not offer granularity of control and can be either on, drawing at full capacity, or off. However, within a portfolio of hot water tanks, at any given point in time, some will be available to provide demand response and others will not. Therefore, on a portfolio level, the percentage response is not likely to be high. The main purpose of expressing the magnitude of response achieved as percentage of installed capacity is to be able to inform the scaling of the system. For example, if the system was installed in 50% of homes on the islands, how much demand response could be delivered?

For the purposes of this analysis, the D-Prognosis was used as baseline meaning that any change in demand is measured against this theoretical baseline optimised to meet customer requirements at a lowest possible cost.

Maximum response achieved during trials in any half-hourly period was 32 kW for demand turnup and 10 kW for demand turndown for the heating asset portfolio (DHWs and ASHPs), equalling 31% and 9% of the controlled capacity.

The figure below illustrates the three most successful cycles (note that no. 3 and 4 represent the same cycle, which was both most consistent and delivered the highest amount of turn down).

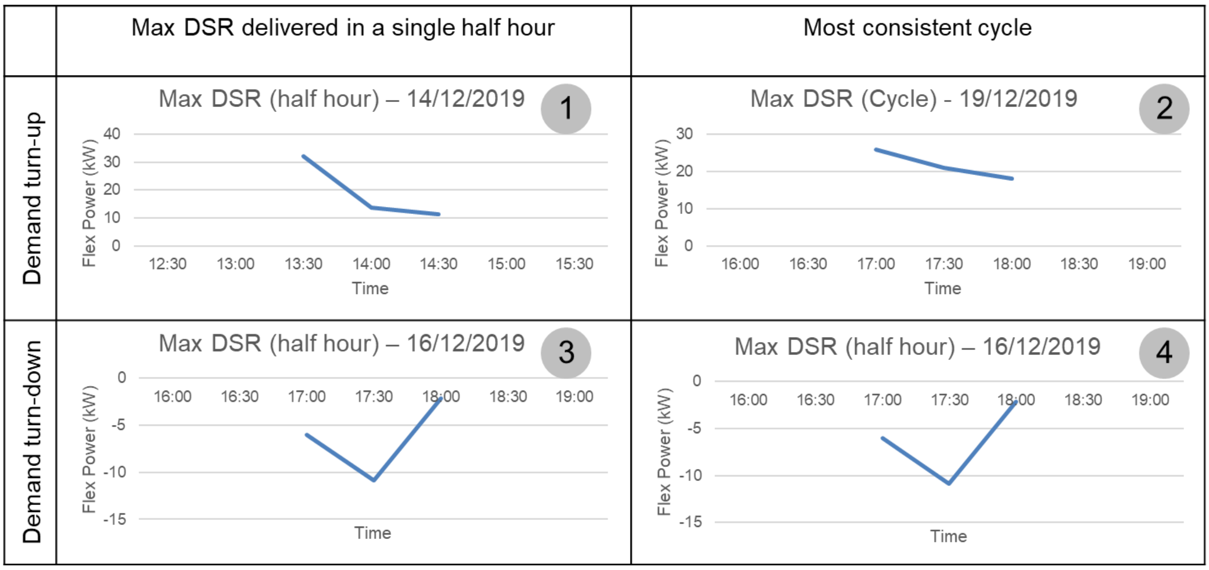

Figure 8-2 Maximum turn up and turn down response provided by heating assets in a single half hour and across the whole flex cycle.

For Moixa, the numbers were considerably lower (see below). While the batteries performed as expected, the overall response delivered was limited by the small number of domestic batteries trialled on the project and other changes in the homes' electricity consumption (Moixa provided data on whole home level, as noted above). The latter issue is explored in more detail in Appendix 3. Data for battery performance was simulated, as a technical issue caused by the interaction of PV inverters and battery controls has caused unexpected behaviour during some of the trial flex cycles. The simulation was based on trial data and the simulator used has been validated to perform with +/-2% accuracy. Maximum response achieved from the battery portfolio was 11.4 kW for turn up and 4.5 kW for turn down.

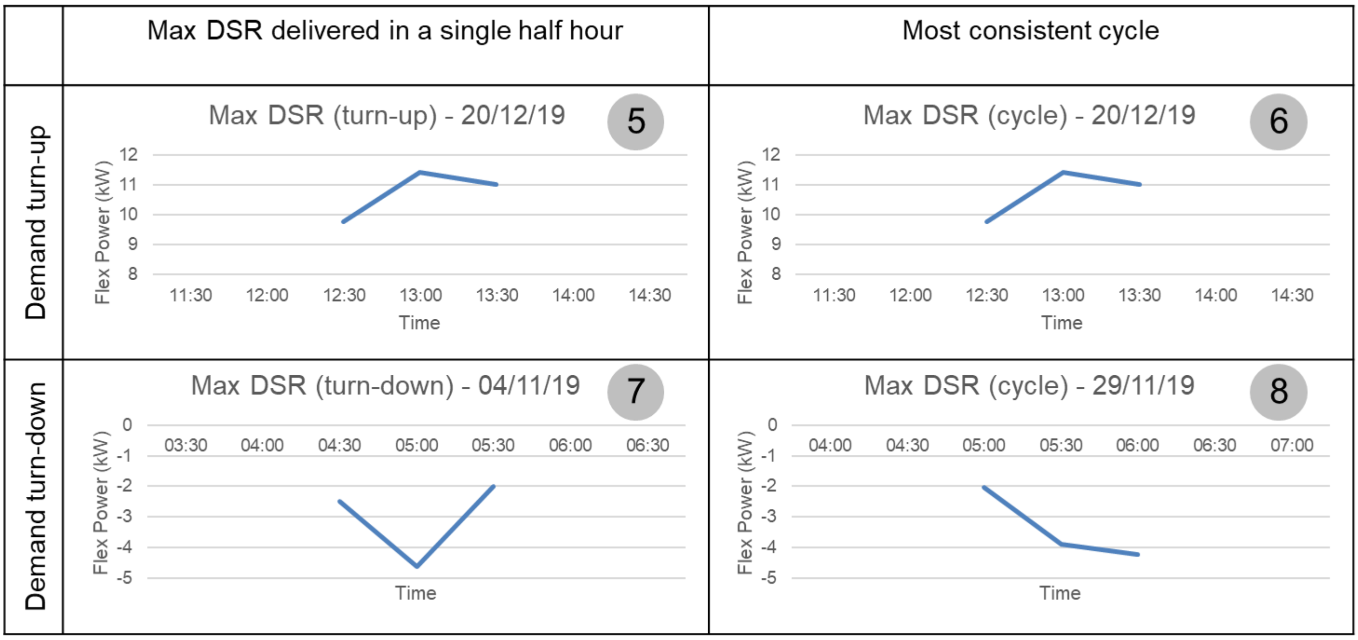

Figure 8-3 Maximum turn up and turn down response provided by batteries in a single half hour and across the whole flex cycle (simulated).

Note that the most successful turn up cycle (5 and 6 in figure 9-3) included domestic, as well as commercial batteries.

In terms of duration, Trials 1 and 2 have shown that magnitude of response reduces significantly for cycles beyond an hour.

In Trial 3 the focus was on shorter cycles of an hour and a half. Even so, the response provided varied in each half hour. For example, on the 16th of December shown above, the system was able to provide response during the first hour of the call, but in the last half hour the demand reverted back to baseline. This is largely due to the nature of the devices involved and the granularity of control.

While heat pump control can be more granular and they are better able to sustain a consistent level of response, the hot water tanks draw at maximum capacity once turned on and switch off once the desired temperature is achieved. As outlined earlier, no new hot water tanks were installed, controls were retrofitted to existing equipment. Turn up is limited by the tanks being full – after half an hour the tanks are often fully heated. Turn down in the evening peak is limited by usage later in the evening. Given the total amount of flex delivered, a change in just one of the homes can affect the flex delivered by the whole portfolio.

The figures below show differences in the magnitude of response delivered across selected successful turn up and turn down cycles[36]. The flex power delivered is calculated as an average response provided across all the half hourly periods in each cycle. All cycles in Trial 3 were an hour

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[36] Some of the successful 268 cycles were excluded from analysis as unrepresentative. This was due to errors in forecast algorithms and equipment failures, which were rectified ahead of Trial 3

and a half in duration, while in Trials 1 and 2 duration varied. The requested flexibility always exceeded what the aggregators were able to deliver, so the amount of DSR provided reflects the maximum that could be delivered by the system.

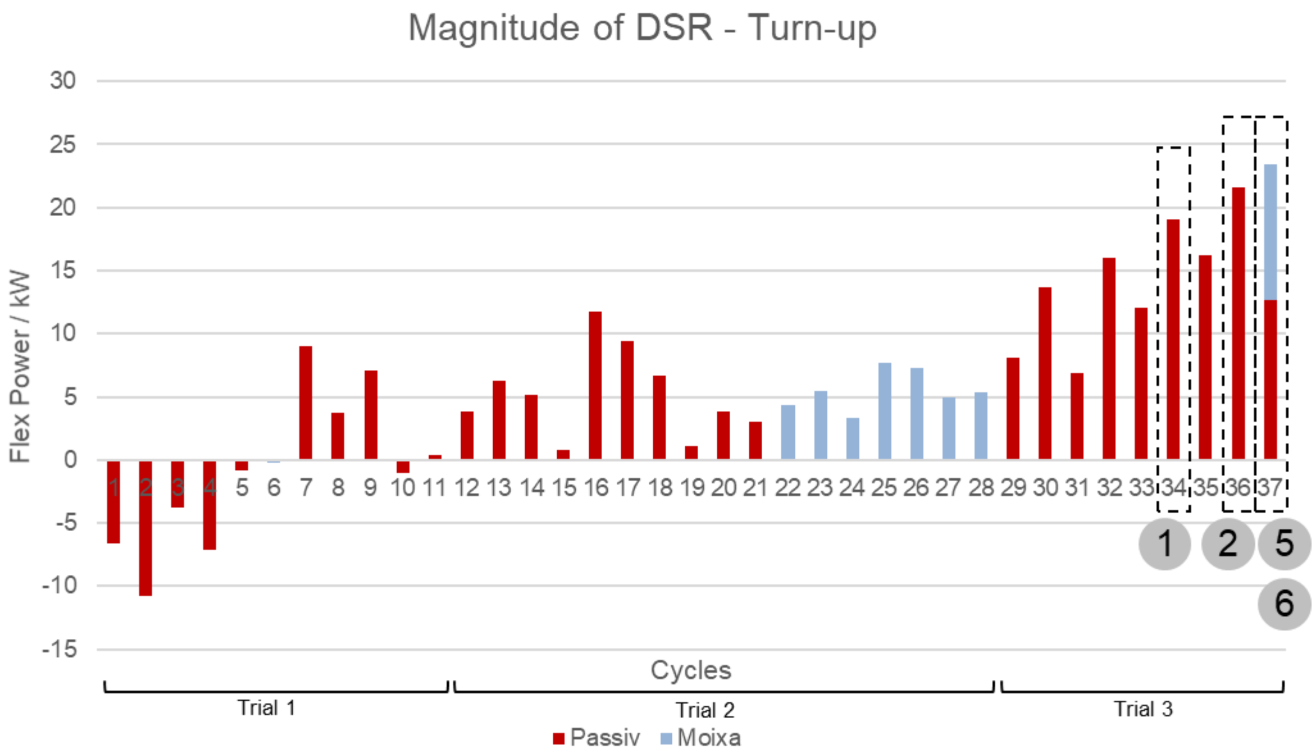

Figure 8-4 Magnitude of demand response delivered per cycle

As shown in the reliability section below, significant improvements have been made in the quality of forecasting between Trial 1 and Trial 3. The magnitude of response measured against the D-Prognosis is therefore not directly comparable between the trials, but the general conclusions as to results achievable in the Summer and Winter are in line with expectations.

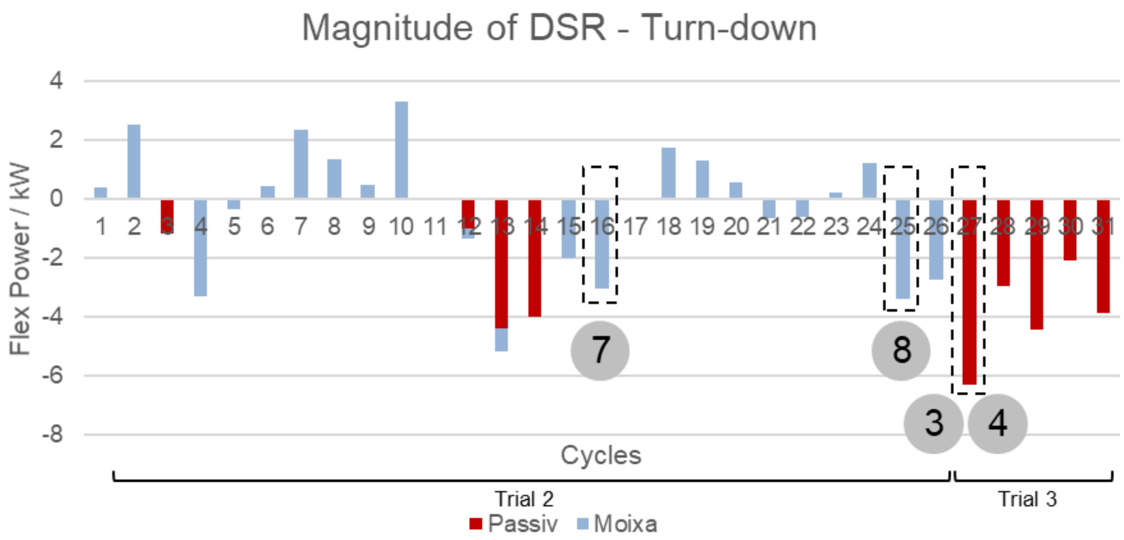

Figure 8-5 Magnitude of demand response delivered per cycle - turn down

Due to different interpretation of USEF by Passiv and Moixa, the response reported by the aggregators is not comparable. While Moixa's D-Prognosis baseline represents the whole home consumption, Passiv's D-Prognosis represents only the expected demand from the devices under Passiv's control. To avoid double counting, flex cycles were run separately with each of the aggregators during Trials 1 and 2. While the batteries have performed as expected during both turn down and turn up, this was often offset by other unexpected changes in the home. For further details see Appendix 3.

In a fully-fledged implementation of USEF, the DSO would be able to compare the response provided by the aggregators and its own network monitoring data. The Meter Data Company could provide data on request of the DSO to verify that the aggregated reported DSR is consistent with the response seen on the network, thus avoiding the effects of double counting.

Batteries on commercial sites were a late addition to the project and were included in flex trading only towards the end of the project. Cycle 37 in

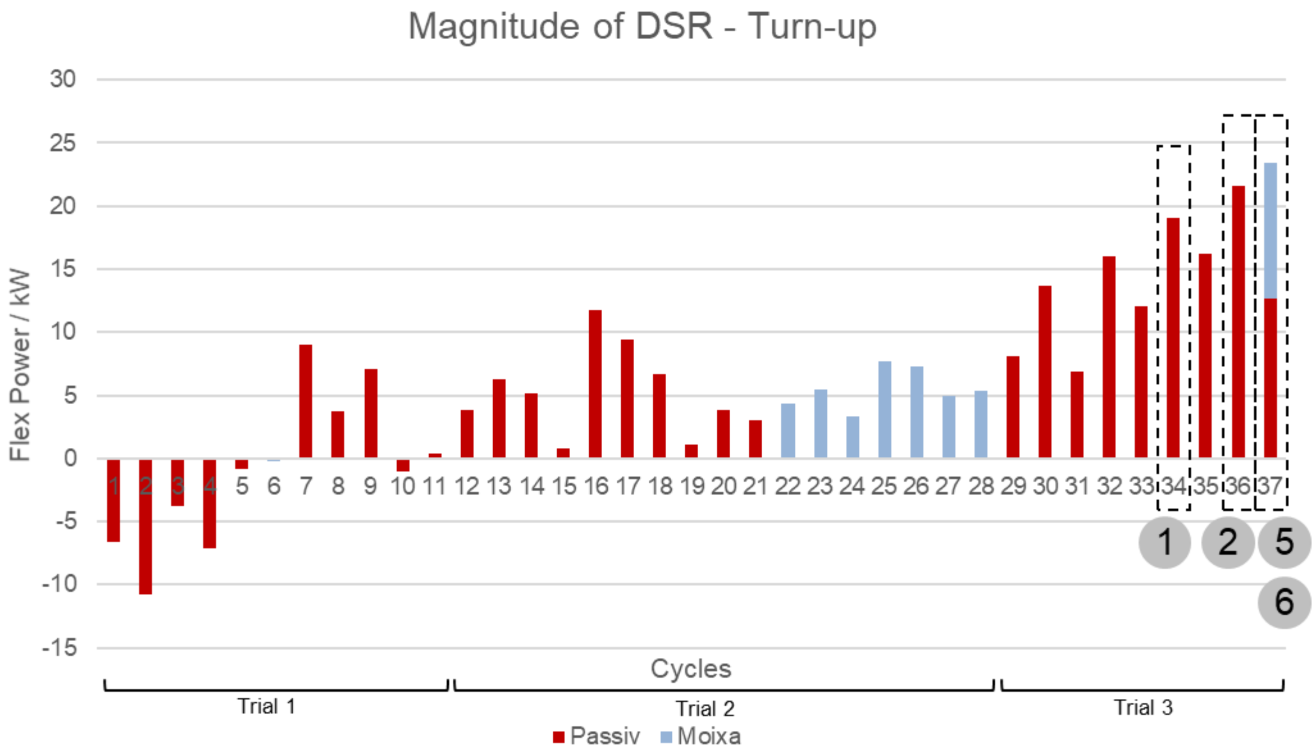

Figure 8-4 included both aggregators concurrently.

Moixa's portfolio included three V4 batteries of 2 kW/4.8kWh each collocated with PV installations on the Waste Site, the Fire Station and the Airport terminal as well as an EV charger. The combined response provided by all Moixa controlled devices (including domestic batteries) was an average of 4.39 kW across the three half-hours requested.

In the curtailment-avoidance turn up scenario, applicable mainly in the summer when the risk of excess PV generation is highest, scope for demand turn up in Trial 1 (June – July) was limited. As the majority of the participating homes had rooftop PV, the controlled devices were already scheduled to make the best use of solar behind-the-meter, leaving little scope for absorbing additional energy. This raises an interesting question regarding baselining of the response. Working to maximise the use of free/cheaper rooftop solar electricity behind the meter, the HEMS system benefits not just the household, but also reduces the export to the grid. This contributes to the reduction of excess generation at times of low demand by maximising behind-the-meter self-consumption. However, the resulting benefits of this approach to the network operator are difficult to account for if the optimised D-Prognosis is used as a baseline. A possible solution to this problem would be to use a non-optimised demand profile as a baseline for commercial agreements, however in reality this may be difficult to obtain as it would require running the system for an extended period of time without optimisation.

8.3 FACTORS INFLUENCING AVAILABILITY OF DEMAND RESPONSE

Large variability of response was observed between cycles. A multitude of factors affect the availability of flexibility, including the configuration of equipment installed, insolation /solar generation, time of day, weather and user behaviour. Isolating the effect of any single variable is extremely difficult.

While statistical analysis is not possible given the large number of variables, the following was observed:

For demand turn up, Trials 1 and 2 showed delivery of turn up was significantly better in the morning, with the magnitude of response 60 percent higher. As discussed above, this is unsurprising given that most houses in the trial had rooftop PV and during the day the behind the meter self-consumption limited the availability of flex, i.e. the tanks were already hot with less scope for additional turn up.

In terms of asset configuration, hot water cylinders provided over two-thirds of turn up flexibility in Trial 3, while heat pump were more effective in providing turn down. Heat pumps were also able to provide a much more consistent response across the half hourly periods requested. This was in line with expectations, given the asset characteristics and the complexity of forecasting hot water tank status accurately. Hot water demand is subject to more sudden changes than space heating, therefore making it much more difficult to forecast. In this project, only the space heating element of heat pumps was utilised to provide flex. It is much less likely to have a sudden change in temperature giving unexpected flex for space heating, but it is common for the hot water to be drawn from the tank to suddenly change the amount of flex/headroom available. Forecasting hot water usage accurately is the most important addition needed to improve the accuracy of demand response plans.

In the case of homes with PV, battery and heat pump configuration, it was expected that sometimes a conflict between the two aggregators competing for solar electricity might occur. A simple principle proved effective to prioritise usage: heating devices had priority in terms of solar PV usage, all surplus PV generation could be used to charge the batteries. For purposes of DSR planning, the battery would assume heating/hot water demand as a given and plan any flexibility around it. As flexibility was only ordered from one of the aggregators at any given point in time, this arrangement proved effective. In a future market design, if two or more independent aggregators control resources within the same home, arrangements to coordinate between them may be required.

The cycles included both day-ahead and intra-day cycles. It was expected that day-ahead should be able to deliver a more significant response due to planning, but no significant difference was observed.

8.4 SCALING UP

Adding more homes/ devices to the system would create a larger and more diverse portfolio, improving the magnitude and reliability of response. While each individual heat pump is likely to provide less flex than a hot water cylinder at any given time, the response of a larger group of heat pumps would be more reliable.

During Trial 3, which provided the highest levels of DSR, the turn up response of the heating assets averaged 13% of the total available capacity, meaning that the combined portfolio of hot water tanks and heat pumps of 104 kW was able to deliver a turn up of 14 kW on average. A median home in the winter trials provided 0.33 kWh per half hour. Therefore, to fully offset the curtailment of the 40 kW solar garden, approx. 61 participating homes would be required.

While not entirely realistic (scope for turn up is lower in the Summer if homes have their own PV), this example illustrates the order of magnitude that would be required to generate a more meaningful response.

Turn-up cycle number (Passiv)

29	8%
30	13%
31	7%
32	15%
33	12%
34	18%
35	16%
36	21%
37	12%
Average capacity utilisation	**13.5%**

Turn-down cycle number (Passiv)

27	6%
28	3%
29	4%
30	2%
31	4%
Average capacity utilisation	**3.8%**

Figure 8-6 Demand response as percentage of controlled heating devices' capacity (Trial 3)

Demand turn down of the heating assets was trialled to demonstrate the viability of participation in WPD's Constraint Management Zones. The performance of the heating portfolio proved weaker in this scenario, delivering only ~4kW (3.8% of installed capacity).

However, this raises again the baselining question. Flexibility is essentially the departure from a normal demand profile. The underlying normal baseline behaviour is already optimised to provide best value to the household, which may reduce its capacity to provide additional demand response. For example, a system with solar PV and DHW controls will already optimise to make best use of cheap solar electricity behind the meter when available. This likely means a reduced ability to provide demand turn up in the curtailment-avoidance scenario, as the DHW tank may already be at target temperature and not able to absorb more of the excess generation.

Further, the amount of flexibility does not provide any information on the underlying baseline demand, which might have been low already, limiting the scope for turn down.

In the example above, the system might decide to export the rooftop solar electricity to the grid early in the day, while reserving some of the hot water tank capacity to absorb solar generation at midday, when the grid suffers from excess generation. Such decisions are value driven with the intention of maximising the value for flexibility providers. Care must be taken to ensure that commercial models implemented do not incentivise flexibility providers to benefit at the expense of the consumer. In this example, the demand turnup should only be provided if the value of flexibility exceeded the opportunity cost of foregoing behind-the-meter solar consumption. This trade-off is reflected in the offer price quoted by the aggregators.

This discussion does not address the question of value distribution between the different parties involved: the householder who pays the electricity bills, the Council or Community Venture as asset owner, the network operator or the aggregators. This will be an important aspect to consider in a commercial implementation.

8.5 RELIABILITY OF DEMAND RESPONSE

The reliability of the response delivered has improved significantly over the course of the trials. This was mainly due to improvements in metering, control strategies and forecasting algorithms of the heating systems.

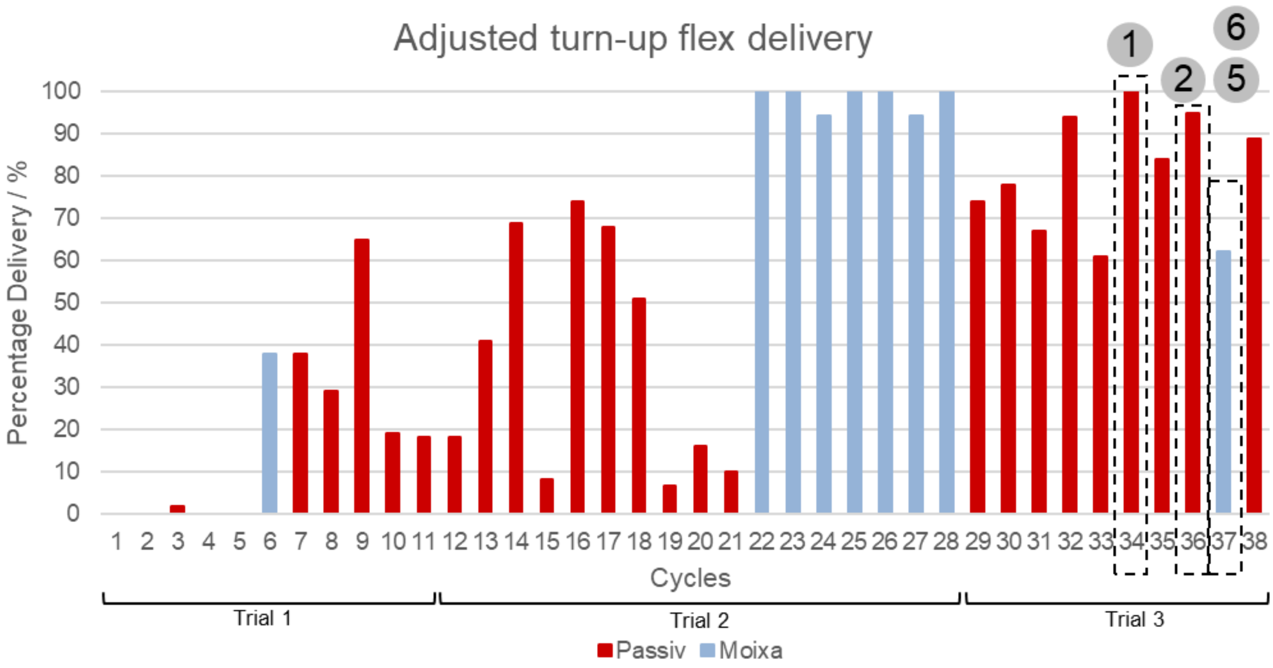

Figure 8-7 Reliability of demand turn up delivered by the aggregators.

D-Prognosis forecast provided by the aggregators was used as baseline, overdelivery (response larger than requested) is ignored.[37] Cycles 1, 2, 5 and 6 marked on the figure above refer to the successful cycles discussed in previous sections.

[37] Calculated as average of percentage deliver in a PTU for all PTU in the cycle, cycles of different duration.

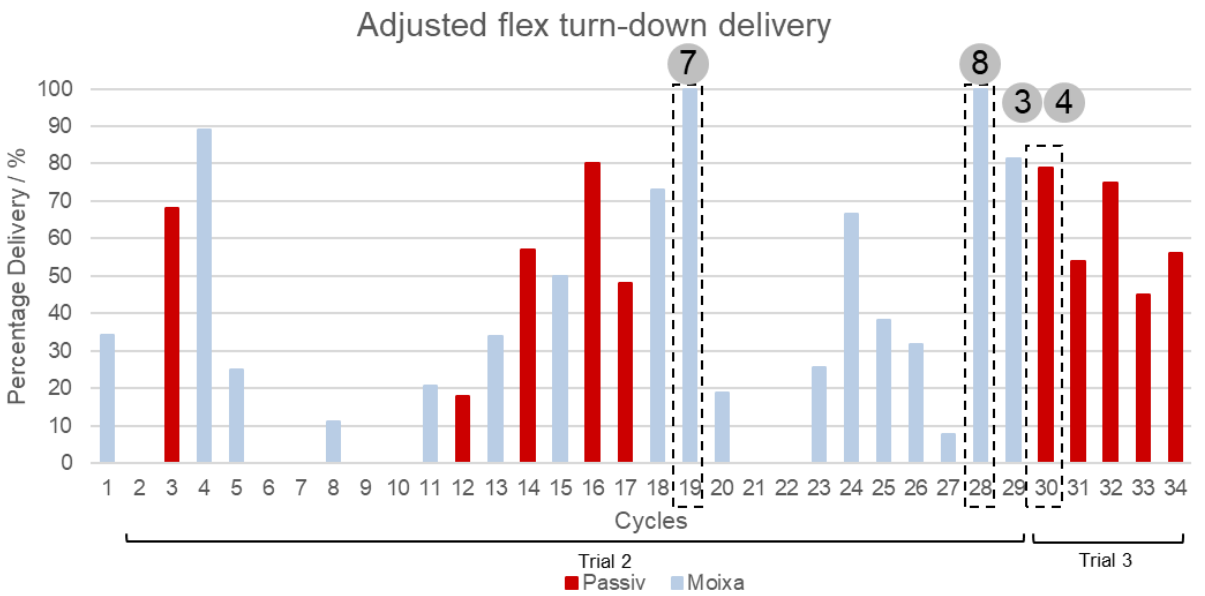

Figure 8-8 Reliability of demand turn down.

The reliability of an aggregator's response is calculated as an average across the half hourly periods in a given cycle. For each half hourly period the actual metered demand was compared against the D-Prognosis to establish the DSR delivered. This was then compared to the amount which was offered by the aggregator for the half hour to establish reliability percentage. Over delivery, where the response provided exceeds the offer, is ignored and shown as 100%. A significant improvement could be seen in the reliability of Passiv's response in Trial 3, following updates to forecasting algorithms for hot water tanks. For Moixa the turn down scenario proved more challenging, as this meant that the exporting battery had to compensate for any unexpected increases in the household's demand, which wasn't always possible.

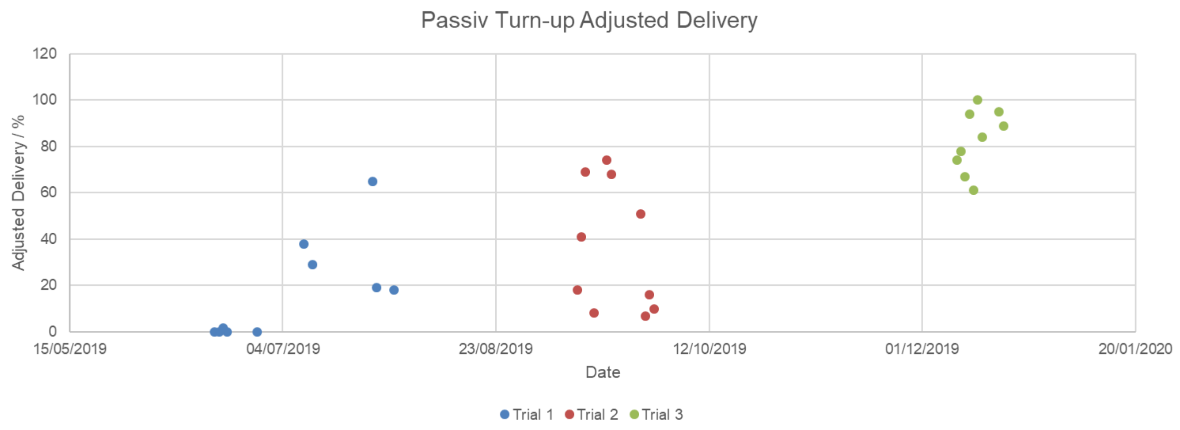

Figure 8-9: Turn up reliability (Passiv)

It is worth noting that given the small size of population, efforts were made to include every available asset in delivering flex. Thus, if any householder adjusted settings, or there was an environmental change that caused an opt-out[38], then delivery would be compromised. In a larger scale system, an aggregator would likely manage its risk profile differently, retaining a percentage of availability in order to balance the opt-out risk and thus delivery would usually be closer to 100% (although maximum flex available would be slightly lower). How the aggregator manages this risk will depend on commercial incentives.

In SEI, aggregators were not penalised for deviating from their forecasts outside of flex periods. However, if desired, this could be specified by the DSO and agreed between the Aggregator and DSO. Forecast accuracy metrics could apply to just flex orders or to the whole D-Prognosis.

In the case of D-Prognosis it would mean the aggregator having to actively balance their portfolio 24/7, which would be very challenging and would result in some households having flex constraints applied even when not in a flex order scenario.

8.6 PRICE OF FLEXIBILITY

Price was calculated by the aggregators taking into account the following factors:

Passiv: the price of flexibility only includes the extra energy cost to the consumer, but does not take into account the cost of running an aggregation system or other cost of an aggregation business. The cost to the consumer is based on a comparison of energy demand profiles before and after flex, the tariff the household is on and factors the availability of free/cheaper solar electricity. It did not consider the costs of operating an aggregation business. In a commercial model the cost of operating the aggregation business would depend on factors such as portfolio size, likelihood of flex utilisation, and contractual terms between the Aggregator and DSO/BRP. This was outside the scope of the project.

Moixa: a similar principle was applied. The battery aggregator used an optimisation tool to obtain the ideal battery behaviour in order to optimise cost for each individual household based on their predicted solar and consumption profiles. When a flex request was received, the same optimisation tool with additional constraints based on the flex request was used to obtain an alternative and sub-optimal battery behaviour that satisfies the constraints, and therefore, the flex request. The expected behaviour over the day for the whole household using each of the two battery plans was then simulated to compare the aggregated cost per PTU for each.

However, there is also an associated cost to flexibility: the incurred costs to a customer of having participated in a flex event, or the difference between the cost of the battery's plan for if it wasn't used to provide flex and the cost of the battery's plan to deliver the flexibility requested:

Cost to the customer of flex [£]=Cost of battery plan if device was not used to provide flex [£] – Cost of battery plan to deliver flex [£].

[38] This refers to an automated opt-out, where a home is removed from flex due to unexpected changes in demand, rather than a user opting out actively

Under a commercial arrangement, the customer would be rewarded for flex participation. This aspect was not considered in detail under SEI, although the participants were rewarded for trial participation.

The price ranges of flexibility offered by the aggregators was £3 and £50/ MWh for turn up and £7 - £115/ MWh for turn down for the heating assets, and £106 - £130 and 0 - 128£ for turn down for the batteries. For comparison, the price offered by WPD under the Constraint Management Zone scheme is £300/ MWh for demand turn down. However, it is difficult to conclude on this basis that domestic DSR is a cost-effective alternative to reinforcements / curtailment. The costs do not include the cost of running an aggregation business, or compensation and rewards for the customers (vouchers for participation were funded separately from the project's budget). These will depend on the scale of the aggregation business and the ability to design simple and easy ways to communicate value propositions for end users. Larger scale demonstrations, ideally with 500+ homes with a mix of equipment, incorporating elements such as commercial arrangements and value propositions for end users are needed to ensure the business model stacks up.

8.7 TRIALS: DISCUSSION AND CONCLUSIONS

DISTRIBUTED DOMESTIC ASSETS CAN COST-EFFECTIVELY HELP ADDRESS GRID CONSTRAINTS AND ALLEVIATE CURTAILMENT

The trials have shown that domestic and small commercial assets have the potential to provide demand response capacity to alleviate local network constraints at a reasonable price. While the price range was large (£0-130/ MWh) and did not include aggregator's operating cost, it is well below the current commercial value (e.g. £300/ MWh under WPD's CMZ).

To understand how the system would scale up, the amount of response delivered was compared to the total capacity of controlled assets. This is influenced by a complex set of variables, which are difficult to model reliably and might differ significantly in other locations. However, we believe the results are helpful in estimating the capacity of a scaled-up system on the Isles of Scilly. For example, to fully offset the curtailment of the 40 kW solar garden, approx. 61 participating homes would be required.

PORTFOLIO SIZE IS IMPORTANT FOR RELIABLE DSR PROVISION

The capacity to respond reliably is highly dependent on asset type and other influencing factors that are difficult to control (user behaviour, weather, etc.). With 20-25 households participating in the trials, the sample was small, and it was difficult to achieve high levels of reliability. The larger and more diverse the portfolio of assets providing flexibility, the more reliable the response becomes.

In particular, Moixa found that the small size of the battery portfolio, combined with the whole-home baselining approach, was challenging to manage. Typically, participating homes have varying levels of predictability and cannot both be predicted to the same level of accuracy. Moixa manages this by assigning a risk metrics to the properties associated with the level of unpredictability. This can then be used to determine which properties are safer to use for services. However, given the scale of the test in SEI, excluding homes based on this metric wasn't an option.

DNO FLEXIBILITY SERVICES COULD BRING ADDITIONAL INCOME TO IOS, BUT COST AND BENEFITS OF PARTICIPATION NEED TO BE BALANCED

Provision of flexibility services to the DNO could constitute an additional source of income for the community on the Isles of Scilly. However, the revenue potential of this scenario is limited (WPD only requires DSR during one month of the year). For example, if the system was scaled up to 1,000 homes, demand turn down of approx. 200 kW could be generated (based on Trial 3 average). Under the current CMZ scheme offered by WPD, this would generate a revenue of £1,346 over the month of April 2020[39]. These values seem low and is unlikely to be sufficient to compensate the scheme operator (IoS Community Venture) for the effort required, e.g. signing tenants up to the scheme and manually submitting the weekly declarations.

The CMZ revenue is calculated based on response level which needs to be declared in advance (a week ahead) and the revenue decreases if the response is lower than declared, with no payment if the reliability is lower than 60%. With a small portfolio of weather dependant assets, it is extremely difficult to respond to such a scenario, creating a high risk of even lower/no revenue. Bringing flex trading closer to real time, as per USEF, would help the aggregators to forecast more accurately.

A system such as USEF, which allows the aggregators to respond based on day-ahead or same day demand and generation forecasts would be more suitable. Therefore, to be able to build a compelling business case under current market arrangements, the aggregators would need to tap into other value streams, e.g. make better use of ToU tariffs in partnership with a supplier, or access ancillary services markets. The original concept of the Community Venture operating behind a Virtual Meter to balance demand and generation on the Islands, would have created much stronger incentives / larger savings. Unfortunately, it has proven impossible to implement under the current regulatory structure, as discussed in Chapter 9 .

IDEAL ASSET MIX IS USE-CASE DEPENDANT

The mix of generation (solar PV) and heating assets was not an ideal match from the point of view of the curtailment avoidance scenario. Heating devices were less able to provide demand turn up in the summer, when PV is at a higher risk of curtailment. Space heating was not utilised at the time. Additionally, most homes had rooftop PV, which meant they were already optimised to maximise self-consumption, leaving little scope for additional demand turn up. However, the system demonstrated a consistent ability to provide turn up in the winter. This ability could be more valuable in combination with a different mix of generation, for example for the purposes of avoiding curtailment of wind.

USER BEHAVIOUR CAN HAVE A SIGNIFICANT IMPACT ON THE AVAILABILITY OF FLEXIBILITY

Communication and user trust in the system are key to maximise the benefits. For example, if users choose to manually control their devices, rather than rely on pre-programmed settings, the ability of the aggregator to deliver reliable response is significantly reduced. Assuming the pre-programmed

[39] https://www.flexiblepower.co.uk/scheme/CMZ_T3B_SWE_0008/2020 [accessed on 07.02.2020]

settings reflect user requirements, this would not compromise comfort and result in a more efficient outcome for the user.

Prioritisation of user needs worked well: trial participants were not inconvenienced in any way and did not notice that their systems were providing flexibility services. No complaints were raised about the levels of comfort provided by the systems by the occupants in relation to flexibility trials and the data shows that temperatures and water availability were maintained within the user defined limits throughout the trials.

RELIABLE BASELINING METHODOLOGY IS KEY FOR COMMERCIAL VIABILITY OF DOMESTIC FLEXIBILITY

Developing effective baselining approaches for domestic and small commercial assets and commercial arrangements which provide the right incentives for aggregators will be key to their participation in flexibility markets. The Smart Energy Islands project did not implement the Settlement stage of USEF and it didn't explore these aspects in detail, but conclusions can be drawn based on the trial data analysis.

As discussed previously, the two aggregators interpreted the USEF baseline differently – Passiv provided the baseline on asset level and Moixa on whole home level. The latter found that the USEF baselining methodology when interpreted at the home level is challenging for an aggregator to work with.

USEF incorporates the aggregator's predictive capability into the baseline against which the aggregator will be assessed, so there is limited option for adding headroom into what is reserved, where the aggregator has no direct control over the household load. A fixed baseline, such as the CMZ baseline (average demand over three weeks preceding the provision of the service), allows the aggregator to manage headroom reserved at the point of declaration of available flexibility and hence manage the risk of non-delivery. This tends to be the standard in current commercial contracts.

The most appropriate baselining mechanism is to compare what the node would have done without flex with what it actually did with flex. This means the aggregator assumes the risk and needs to mitigate such risk and price it in when it generates flex offers. In a well-functioning and liquid market, aggregators that require high risk margins will be priced out. However, there are two potential problems with this approach:

- In a situation where the flexible assets are used to provide other services (i.e. are not idle when not delivering flex), only the aggregator is able to determine what the node would have done without flex and could use this information asymmetry to its advantage ('gaming' the baseline). While considering the participation in WPD's CMZ, it became clear in the discussions with the DNO that the fixed baselining methodology is not ideal and could be manipulated by an aggregator.
- At the same time, aggregators who provide an optimisation service to the household, may already be helping the grid by shifting demand in the desired manner (e.g. maximising solar self-consumption behind the meter reduces the home's export at times of peak generation). This value is difficult to recognise commercially if an optimised profile is taken as a baseline.

FLEX OFFER SCORING MECHANISM NEEDS TO BE TAILORED TO LOCAL CIRCUMSTANCES

A scoring mechanism was developed by Hitachi to evaluate flex offers including criteria such as magnitude, duration and price. Additionally, changes to demand profile outside flex periods were evaluated, but this was dropped in the course of the trial in the absence of information about network conditions. The scoring mechanism can be customised on congestion point level, giving the DSO an opportunity to reflect localised constraints. In a fully-fledged implementation of USEF, the definition of such criteria will be crucial to creating the right incentives for the aggregators.

8.8 USEF – LESSONS LEARNED

The project partners found the USEF framework to be well defined, providing the necessary guidance to ensure standardisation and interoperability between parties.

USEF provides one common standard that allows new market players such as aggregators, energy service companies and energy communities to integrate on a standard platform making it possible to participate in a cost-effective way. Projects built on common standards such as USEF will be rapidly connectable, accelerate innovation, integration, and scale-up in the market for smart energy products, services and solutions.

USEF identifies three levels of compliancy: protocol, process, and service compliancy. Protocol compliancy deals with the syntax and semantics of messages sent in a USEF implementation. This can be improved further to make it simpler from implementation point of view.

Process compliancy considers the processes in and interactions amongst the roles defined by the USEF market model. For example, in order to manage congestion effectively using local Flexibility, all parties in the market will depend significantly on the DSO and Aggregators forecast accuracy. Therefore, it is essential that the process of baselining, forecasting and associated request for flexibility is accurate. Service compliancy deals with the validation whether a service provider can provide the flexibility service according to the contractual arrangements.

The application of USEF is limited by the current market structure. The Smart Energy Islands project implemented a USEF based approach within the constraints of the current arrangements. We feel USEF could deliver more value if it became the basis for a market organization, rather than try to co-exist with other arrangements such as ANM-based curtailment based on the LIFO stack approach.

The baselining issue described above is in our view the most significant topic for further exploration in order to realise successful flexibility markets.

Trials with a significantly larger sample of homes (500+) and ideally greater variety of controlled devices are required to deliver a reliable evaluation of a USEF system. With only 20-30 homes the variability was very high, making it difficult to accurately forecast and deliver flexibility.

9 THE ISLES OF SCILLY COMMUNITY VENTURE

In 2017, the Isles of Scilly Community Venture was established as a not-for profit Community Interest Company. It was created with help from Hitachi and the Smart Islands Partnership to socialise the benefits arising from the Isles of Scilly's projects, including the Smart Energy Islands project.

Early in the process of developing the Smart Islands Partnership, it became apparent that a locally driven organisation would be needed to enable the community to fully benefit from the projects.

This organisation would ensure that the benefits and assets arising from the publicly funded projects could continue to be channelled into the community after the projects themselves had completed. Doing so through a locally coordinated, independent organisation would safeguard community trust and ensure local priorities were addressed.

The assets and technologies deployed in the Smart Energy Islands project were transferred to the Council in late 2019 and the revenue generating assets are due to be transferred from the Council to the Community Venture in 2020 if leases and other contractual arrangements can be agreed.

9.1 LEGAL, GOVERNANCE AND OPERATIONAL STRUCTURE

The Isles of Scilly Community Venture was established as a Community Interest Company in 2017. The Board of Directors was recruited from within the islands' communities and from further afield – to bring in specialist expertise whilst maintaining a close relationship with the islands' needs and culture.

Recruitment for the general manager received interest from across the UK and abroad which highlighted how innovative and interesting the concept was. The appointee moved to the Isles of Scilly in late 2017 and quickly became part of the community. Two additional members of staff were hired locally, creating three new jobs on the islands.

9.2 FUNDING

The Community Venture was supported with a European Regional Development Fund (ERDF) grant from the Isles of Scilly Voucher Scheme. This investment is made by the Cornwall and Isles of Scilly Growth Programme to lead to long term and sustainable business growth including, higher value job creation and an increase in GVA on the islands. The ERDF investment was match-funded by the Smart Islands' partners, including Hitachi Europe. This start-up funding allowed the Community Venture to launch, with the goal that it would become financially self-sustaining by 2021.

9.3 COMMUNITY VENTURE BUSINESS MODEL

The initial business case for the Community Venture indicated that the organisation could become financially self-sustaining, once it accumulated a sufficient asset base. Any surplus generated by the Community Venture would be distributed back to the community in the form of reduced energy costs – either through a lower-priced tariff or through discount vouchers.

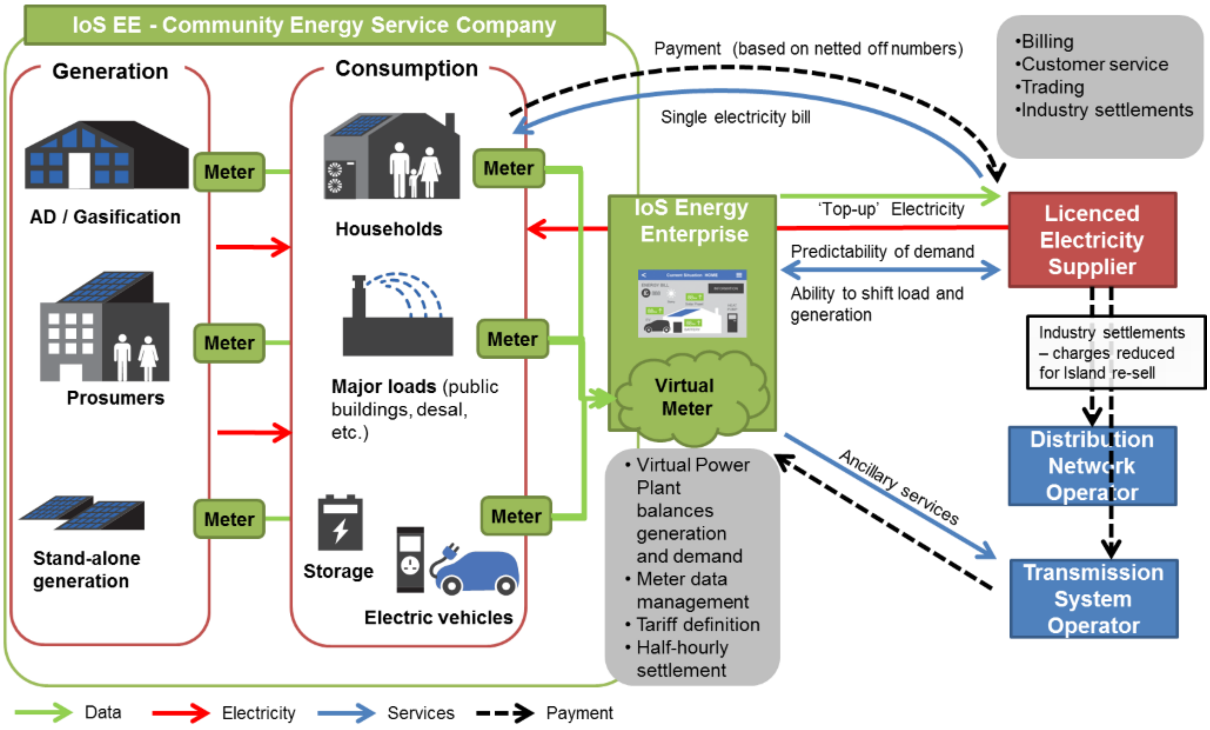

Figure 9-1: The original model envisaged

This initial operating model also included the operation of a wider asset base, such as energy from waste, district heating, and an electric vehicle car share scheme for example, but delays and re-evaluation of some projects have changed the asset base available to the Isles of Scilly Community Venture.

It remains the islands' ambition to reach 40 percent of energy generation from renewables by 2025. This is characterised on the islands as the 'missing megawatt' – once this additional generation is in place, the Isles of Scilly Community Venture would be able to be self-sustaining from asset income alone. To achieve the Island's ambition, the additional megawatt of generation will need to represent a mix of different generation types, such as wind, wave/tidal and/or anaerobic digestion.

9.4 KEY COMPONENTS OF THE SMART ENERGY ISLANDS MODEL.

VIRTUAL METER ARRANGEMENT / LOCAL NETTING

The initial ambition of the project was to create a Local Energy Market, which would incentivise investment in local generation and maximisation of self-consumption of electricity on the islands, resulting in cost reduction for the local community.

The concept of a 'virtual meter' was at the time being discussed by other community projects and SEI sought external specialist advice as well as engaged with Ofgem's Innovation Link and Elexon, who administrate the Balancing and Settlement Code (BSC), to further develop this idea.

As shown below, the average domestic electricity bill is made up of approximately 32 percent of electricity generation cost, while the costs of transmission and distribution networks, social and environmental programmes account for over 40%. Most of these costs are allocated on volumetric basis, i.e. per kWh of electricity consumed and included into business and domestic electricity bills by licenced suppliers.

On Scilly, a Virtual Meter Arrangement was envisaged, whereby settlement data from all participating meters (generation and demand) would be netted off before being entered into industry settlements, thus saving a significant portion of the non-electricity cost of the electricity bills.

A virtual meter could potentially provide a significant saving and incentives for the community to invest in more renewables and maximise self-consumption of the cheaper local power on the islands.

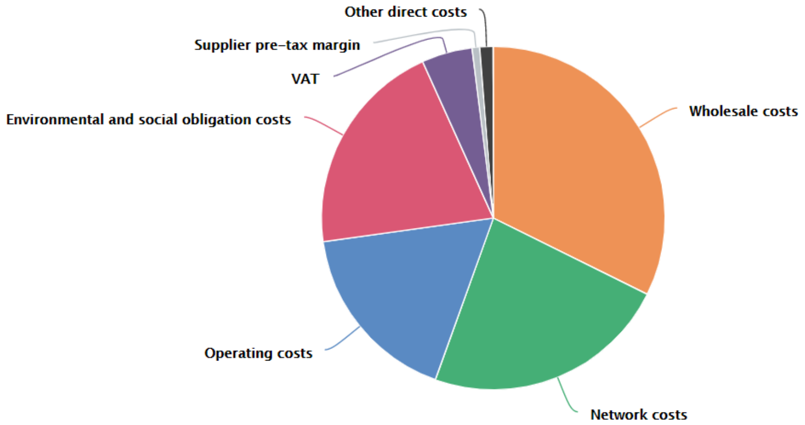

Figure 9-2 Typical break-down of a domestic electricity bill[40]

Following discussions with Ofgem's Innovation Link, it was deemed that the Virtual Meter arrangement was not feasible within the current regulation and derogations for the purposes of the trial could not be granted. This was due to wider equity concerns: if customers on Isles of Scilly do not pay for the network costs, somebody else will have to. This is a wider issue of fairness, which is currently being addressed by Ofgem as part of the ongoing Targeted Charging Review (TCR) launched in August 2017, a major review of charging principles. The outcome of the TCR will significantly change the way network costs are recovered in an effort to allocate them more fairly to all network users.

Instead, a Licence Exempt Supplier arrangement was proposed.

LICENCE EXEMPT SUPPLY

Electricity supply is a licensable activity and any supplier must go through a rigorous and costly process to be granted a supply licence and enter the market. This process ensures that suppliers have the required systems, processes and financial backing in place to function effectively in the market.

In discussions with Ofgem's Innovation Link it was concluded that the IoS Community Venture would act as a Licence Exempt Supplier under Electricity (Class Exemptions from the Requirement for a Licence) Order 2001[41]. Class A of this exemption allows small generators to supply customers

[40] Source: Ofgem (2019) https://www.ofgem.gov.uk/data-portal/breakdown-electricity-bill [accessed on 26.02.2020]
[41] https://www.gov.uk/guidance/electricity-licence-exemptions

directly, without a supply licence. The volume of supply is limited to 5MW, with no more than 2.5MW supplied to domestic consumers at any time. While this activity is not subject to licence, the supplier still needs to comply with certain requirements to ensure customer protection, such as change of supplier, customer contracts, customer information (including metering) and dispute determination.

As such, the Isles of Scilly Community Venture could supply electricity from the commercial PV installations directly to customers on the Isles of Scilly Energy Share tariff. Licence Exempt Suppliers are not under the obligation to levy some of the environmental and social costs, which constitute a part of the standard electricity bill. This saving could then be passed directly onto the customers or retained by the Isles of Scilly Community Venture. Therefore, as an Exempt Supplier, the IoS Community Venture could supply electricity from its generators, e.g. PV installations or wave/wind in the future, to local customers at a discount reflecting the avoided cost.

This arrangement is possible within the current regulatory structure, but still requires a back-up licenced supplier to process the billing and discharge other industry obligations. Metering and settlement issues related to Licence Exempt Supply are also complex and industry code changes[42] are now under way that will enable such arrangements in the future (BSC modification P379).

Although selected for its reliability and backing by the Scottish Government, Our Power, the SEI licenced energy supply partner went out of business in January 2019. Discussions with Elexon to enable a simplified version of the arrangement were at an advanced stage at the time.

POSTCODE-RESTRICTED ISLES OF SCILLY ENERGY SHARE TARIFF.

The benefits of Licence Exempt Supply could be channelled to the consumers through a tariff only available to the local community.

The Isles of Scilly Community Venture collaborated with a licenced electricity supplier, to provide a post-code restricted tariff, available only to customers on the Isles of Scilly. The Isles of Scilly Energy Share tariff was launched in the autumn of 2018 and enjoyed a rapid uptake, with more than 50 islanders switching, despite only word of mouth and social media advertising.

IoS Energy Share Tariff. **Energy share** is an **energy** deal that will allow us to supply locally generated electricity to local people. The Isles of Scilly Community Venture aims to develop projects that will help lower **energy** use, lower **energy** costs and increase locally generated **energy** for the Islands.

The role of the Isles of Scilly Community Venture in this model was that of a trusted intermediary ensuring that customers on the islands benefit from a fair tariff supporting the local economy.

Following Our Power going out of business the tariff was discontinued when customers were transferred to an alternate provider under Ofgem's safety net. However, the model for the

[42] BSC modification P379 *Enabling consumers to buy and sell electricity from/to multiple providers through Meter Splitting*. Retrieved from https://www.elexon.co.uk/mod-proposal/p379/

implementation of a community energy tariff was demonstrated for future consideration and the Isles of Scilly Community Venture is in the process of negotiations with a replacement licenced supplier.

BEHIND-THE-METER (BTM) BILLING AND POWER PURCHASE AGREEMENTS.

The households participating in the Smart Energy Islands project were asked to sign up to a billing agreement with the Isles of Scilly Community Venture and the response was very positive, with only three households opting out. The rate was set at £0.085/kWh, offering savings compared to the average market rate. This model relies on the ability to disconnect the customers who opt out or default on their payments to ensure fairness. The inverters in the homes that opted out from the tariff were locked.

The solar PV that was installed as part of the project was not eligible for Feed-in-Tariffs nor export tariffs based on the Smart Export Guarantee. The only option for the Isles of Scilly Community Venture was to charge the tenants at a reduced rate for generation consumed behind the meter (BTM).

Between September 2018 and January 2019, about 40 percent of the energy generated was self-consumed by the homes where solar PV was installed. The balance was exported to the Isles of Scilly energy grid and consumed by other homes and buildings on the islands – as no electricity is exported from the Isles.

For the larger rooftop installations at the other Council-owned buildings and the St. Mary's Airport solar garden, standard Power Purchase Agreements (PPAs) were proposed between the Isles of Scilly Community Venture and the licenced supplier. The supplier would then allocate the local generation to the local customer demand within its portfolio, creating a direct link between local renewable generation and the local tariff.

BTM and PPAs were possible to implement within the current regulation. The IoS Community Venture would bill the customers for BTM electricity as a Licence Exempt Supplier.

PPAs were seen as an interim step, before the Licenced Exempt Supply was launched.

The Internet of Things platform and optimisation functionality is valuable in implementing this model. By metering and increasing the BTM self-consumption of rooftop solar and avoiding curtailment of larger sites, the Community Venture is able to extract more value from the energy generation assets.

9.5 LESSONS LEARNED

The original business case for the Isles of Scilly Community Venture recognized that a range of revenue streams is needed for the organisation to be sustainable. It was established that the Community Venture could offer efficiencies in managing a variety of assets on the islands, such as energy from waste, district heating, and an electric vehicle car share scheme, for example.

The BTM revenue model was generally well received by households on the Isles of Scilly and is feasible to implement in this setting. The effort required to get customers on board, manage the billing and any debt issues is the make or break for such a model. Additional administrative effort was required to handle scenarios such as right to buy. Reducing the administrative effort relies on strong community buy-in.

It was unfortunate that the energy supplier selected to support the delivery of the community energy tariff, Our Power, went under. Calculations showed that the community energy tariff would have been able to generate sufficient revenue to cover its operating expenses, deliver benefits to the local community, and put aside reserves to invest in hardware maintenance, replacement and new renewable energy projects.

The total extent of value generated by a future community tariff will depend on a number of factors such as customer numbers, generation base and mix, availability of controllable load and ability to get a supportive licenced supplier on board. Different scenarios of tariff uptake, generation mix, generation roll-out speed and the resulting impact on customer bills were modelled. Generally, the speed of generation roll-out and uptake of the tariff needed to be in line to ensure that a significant benefit is offered to all customers.

The graph below summarises the results of the initial modelling. It shows that on average, a customer could save £188 a year just by switching from a standard EDF tariff to the local Our Power tariff. Further savings could be achieved by channelling the benefits of local generation to the local customers. If all domestic customers on the islands (1,122) signed up to the tariff, each of them could save £64 over and beyond this initial saving. However, if the uptake was lower, with only 25% of customers switching, the saving could be as high as £257 per household, as the same overall saving would be divided between a smaller number of customers.

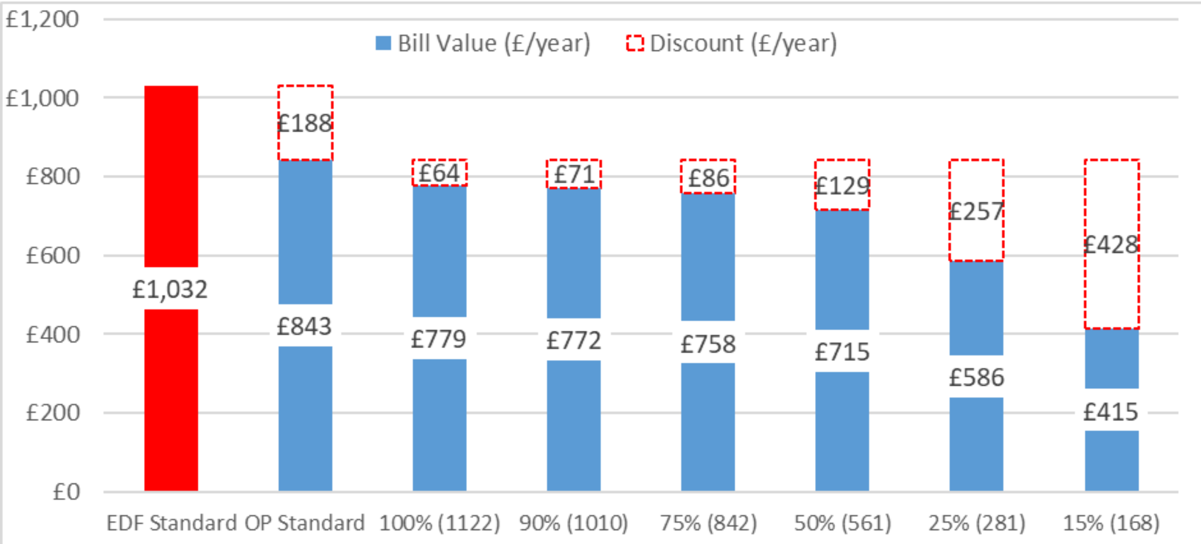

Figure 9-3 Potential benefits of a local tariff, depending on the rate of uptake

Key assumptions behind this model:

- All initially planned generation projects are commissioned and generating (477 kW of PV, 130 kW Anaerobic Digester, 550 kW Gasifier)
- The generators were publicly funded and gifted into the Community Venture
- The IoS Community Venture generates revenue via BTM and PPAs.

Some of the new generation projects were delayed and the vision has changed for others, creating a revenue gap for the Community Venture. However, the capacity built up in the organisation during the SEI project positioned it well to deliver other energy-related projects on the islands and branch out into other services. While the Community Venture's business model has evolved, it remains a vital element in supporting the assets installed as part of the project and driving the wider decarbonisation agenda on the islands.

Over time, as more PV and new types of generation continue to be installed (e.g. tidal or wave), and new flexible controllable assets become available (e.g. EVs or storage), the active managing of energy supply and demand on the islands (local balancing) will become ever more important and will enable the Isles of Scilly to connect more low carbon generation sources, increasing their capability to export energy to the grid.

The portfolio of projects has evolved, with new exciting opportunities emerging: innovative wave power, participation in the CMZ, replacement of the diesel-backup power station and perhaps an integrated energy system for the islands as a whole. The Smart Islands Partnership adopted a new vision in late 2019 to reflect the need to raise ambitions in the light of the climate emergency and areas such as energy as well as housing and transport will have improved strategies.

The regulatory considerations under this project reflect the wider industry discussion regarding the decentralisation and democratisation of the energy system. Supporting community generation and local energy systems is firmly on the Government agenda and this project helps to inform the discussion.

The model that was trialled aimed to ensure that the Smart Energy Islands project could meet its aims and that the Community Venture could be self-sustaining in the mid to long term and not reliant on public funding support once the ERDF investment ended. To this end, a number of other potential revenue sources for the Community Venture have also been identified, including the Go-EV electric car scheme Hitachi is also helping to deliver, which is in development on the island. The introduction of EVs to the islands will also add a new significant battery storage asset to the Island's energy storage and flexibility potential.

10 REPLICABILITY AND REGULATORY IMPLICATIONS

This section focuses on the replicability of discrete elements of the project within the current regulatory context, and points out potential barriers.

10.1 BEHIND-THE-METER SUPPLY AND BILLING

The model designed as part of the Smart Energy Islands project ensured that the Licence Exempt Supply requirements regarding customer communication and metering were met for the BTM supply. The BTM functionality of Hitachi's IoT platform provides the aggregation and validation of meter data and gives the IoS Community Venture the ability to generate reports as basis for customer billing.

The BTM charging model can be implemented within the current regulation. Replication considerations are commercial, rather than regulatory in nature. Smart Energy Islands has demonstrated that in locations with strong community ties, consumers are willing to pay for BTM self-consumption in the knowledge that their contribution benefits the community. Out of the 69 tenants approached, 66 have agreed to pay 8.5 p / kWh for the self-consumed electricity. Such an arrangement relies on the goodwill of the participants, as a community organisation might have limited recourse in the event of non-payment.

10.2 LICENCED EXEMPT SUPPLY FROM COMMUNITY GENERATORS

The second part of the model proved more challenging to implement. The purpose of direct supply from local community owned generators was to provide cheaper electricity to the fuel poor community, with any surplus reinvested by the IoS Community Venture into further generation. This exemption, which is relatively straight forward to implement for one generator and one offtaker, proved complex to apply in the case of a community generator supplying many domestic customers.

Once the initial Virtual Meter concept was discarded (see previous section), the Licence Exempt Supply arrangement was explored for the IoS Community Venture to supply the locally generated solar power to customers on the islands. This would allow to achieve the desired objective to some extent, as licence exempt suppliers are not responsible for the recovery of the policy costs[43], which jointly account for about 20 percent of the domestic bill.

While conceptually simple, practical implementation of this arrangement posed some challenges:

The licence exempt generation and supply volumes would still need to be entered into the industry settlement system to be made exempt from selected charges, which meant that a licenced supplier was needed to perform this function. Due to the nature of the generation (PV, with a small amount of batteries), the local generation was not able to cover 100 percent of demand for a group of customers. A back-up supplier was needed to supply the difference. A mechanism would therefore be required to determine what portion of an individual household's consumption was supplied by the local generator and what portion was a top up provided by the supplier. The former would be exempt from some of the charges and therefore cheaper for the consumer, while the latter would

[43] FIT, RO and Electricity Market Reform (EMR), which include Contracts for Difference and the Capacity Market. While FIT and RO exemption require only a notification to Ofgem, the EMR costs are managed by the EMR Settlement company and therefore a process for exempting volumes needed to be agreed with Elexon.

include all of the charges and be more expensive. The allocation mechanism chosen would have distributional consequences, as some consumers would potentially stand to benefit more than others.

Our Power, the partner licence supplier at the time, had agreed to facilitate this arrangement and offer a local tariff, which would incorporate an element of the licence exempt supply and a top-up supplied by Our Power. This would allow all the customers switching to the 'IoS Energy Share' tariff to benefit from cheaper and greener electricity, thanks to the local generation component. Effectively, a customer would be buying electricity from two suppliers, the licenced supplier and the licence exempt supplier, while receiving a single electricity bill.

However, separating out the volumes supplied to a single metering point by different suppliers for settlement purposes is not possible under the current 'supplier hub arrangement'. This market model sees the licenced supplier as the sole interface with the customer and the industry settlement systems and data flows reflect this principle. A licenced supplier is responsible for a customer's meter and all the volumes recorded by the meter are assigned to that supplier. The industry has recognised that this does not support innovative business models, such as licence exempt supply from a community owned generator or 'as a service' models, e.g. 'heat as a service'. Modifications to the industry systems are currently being discussed, that would allow them to disaggregate the electricity volumes provided to one customer and thus allow a customer to buy electricity from more than one supplier[44].

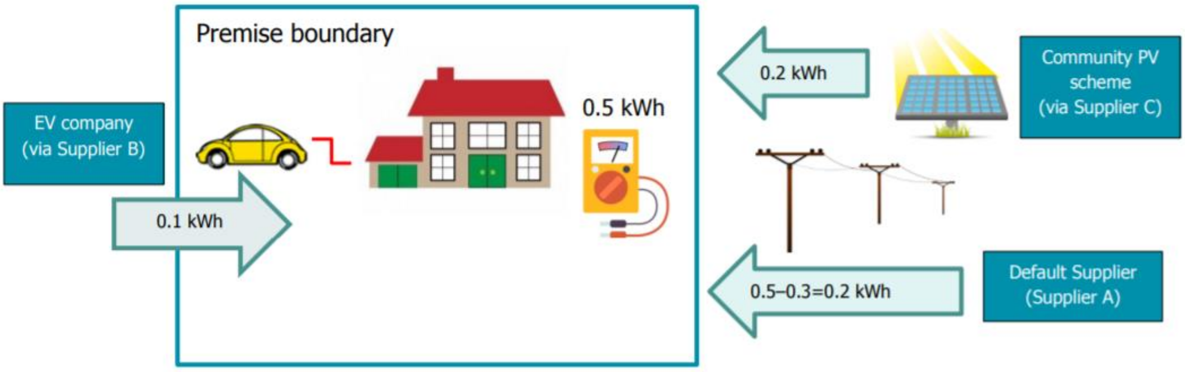

Figure 10-1 Enabling customers to buy power from multiple providers (Elexon 2018)

At the time of writing, this modification is still being developed by Elexon and a target implementation date has not been announced[45]. The Smart Energy Islands project and Our Power have engaged with Elexon and devised a simplified arrangement, which could have enabled the licence exempt supply by the IoS Community Venture, while the target industry solution is being developed. Due to Our Power going out of business, this approach was not implemented.

[44] P378 to the Balancing and Settlement Code. The concept was initially described by Elexon (April 2018): https://www.elexon.co.uk/wp-content/uploads/2018/04/ELEXON-White-Paper-Enabling-customers-to-buy-power-from-multiple-providers.pdf

[45] https://www.elexon.co.uk/mod-proposal/p379/ (Accessed 16.10.2019)

Once the proposed modification is implemented, small community generators like the IoS Community Venture will be able to share the benefits of generation more directly with local consumers, creating a replicable model and local incentives to maximise self-consumption. To enable this, cost efficient ways to provide transparency to the consumers and handle the complexity of multiple suppliers to one household will need to be developed.

10.3 OFFSETTING SURPLUS GENERATION BY DEMAND TURN UP TO REDUCE CURTAILMENT

Offsetting the curtailment of generators by turning up local demand was the primary flexibility use case the project has set out to demonstrate. As discussed in Section 7, SEI has shown that demand turn up from domestic heating and storage devices has the capacity to absorb the surplus generation, while challenges related to baselining, reliability of response and portfolio sizes remain.

Active Network Management (ANM) is defined as using flexible network customers autonomously and in real-time to increase the utilisation of network assets without breaching operational limits, thereby reducing the need for reinforcement, speeding up connections and reducing costs (ENA). Most commonly ANM is used by network operators to connect generators on constrained parts of the network. ANM connections allow generators to connect more quickly and at lower cost by including provisions for curtailing their output during constrained periods to avoid the need for reinforcement. From a DNO point of view, a reduction in generation on the same part of the network has the same effect as an increase in demand. Thus, increasing demand affecting the same constraint could theoretically be used to offset the surplus generation and reduce curtailment.

In commercial terms, such an arrangement could be facilitated by the DNO/DSO or through a bilateral agreement between the curtailed generator and the aggregator providing demand turn up. In the case of Smart Energy Islands this is simplified, as all the generators and the flexible assets are managed by the same entity, the Isles of Scilly Community Venture.

An approach to rewarding the customer, who ultimately pays the electricity bill, will also need to be developed. This additional level of complexity was not explored, as during SEI the customers were offered vouchers as a reward for trial participation. Voucher value was not linked to the value of flexibility provided. In the future, offerings such as ‘heat as a service’ are likely to make the flexibility aspect commercially invisible to the customer by offering a single price for the service, while exploiting asset flexibility in the background.

10.4 LAST-IN-FIRST-OUT (LIFO) APPROACH TO CURTAILMENT MANAGEMENT

The replication of the solution in a different constrained area with multiple generators subject to curtailment would need to consider the impact on all generators within the same LIFO stack.

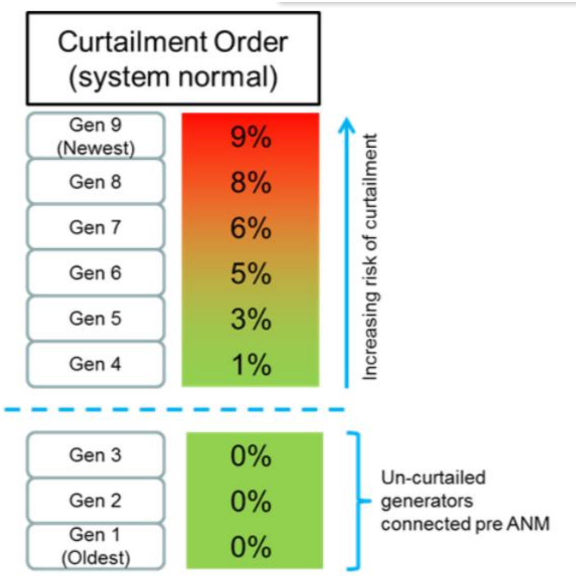

Figure 10-2 Curtailment under the LIFO approach (ENA)

Under the ANM system, WPD adopted the Last-In-First-Out (LIFO) approach to executing curtailment, where generators are curtailed in reverse order of connection applications. This means that generators who connected to the network first are not adversely affected by later connection of additional generation.

WPD's project SYNC completed in 2017[46] considered the commercial implications of matching customer load and generation on an ANM system and identified several potential issues.

It concluded that this approach is likely to provide unfair advantage to some of the generators, while negatively impacting the revenue of others. The underlying issue is that of baseline reliability and attribution of demand increase to a deliberate DSR action performed by an aggregator.

For example, in a hypothetical ANM zone with three curtailed generators, Gen1 being the first to have connected and Gen3 the last, Gen3 would be first to suffer from curtailment. Conversely, Gen1 would be the last to be curtailed and the first to benefit if demand increases. However, if Gen3 contracted a local Aggregator to turn up demand during curtailment events, Gen3 would benefit from the demand turn up first. Conceptually, this arrangement is quite simple. However, it relies on having a reliable baseline against which to measure demand response. The amount of demand turn up attributed to the Aggregator will directly benefit Gen3. Should this amount be overstated, Gen3 will benefit at the expense of Gen1. The SYNC project concluded that this would be difficult to achieve accurately and therefore a demand turn up matching scheme "has high risks of causing detriment to other customers limiting the potential for application".

As demonstrated by the Smart Energy Islands project, baselining demand from domestic heating assets and batteries, is indeed complex, especially where a portfolio of resources is relatively small. However, this problem is not unique to demand turn up matching schemes and applies to other flexibility markets and procurement schemes, such as WPD's Constraint Management Zones. Electrification of heat and transport will bring large capacities of flexible resources with complex demand patterns and granular control capabilities (not just on/off control) – these should not be ignored just because it is too difficult to baseline. While some level of error is inevitable, forecasting algorithms will become more accurate over time. As users' trust in automated controls based on pre-programme schedules increases, the level of manual intervention is expected to decrease. This, combined with AI learning algorithms, will make the demand more predictable. Indeed, over the

[46] https://www.westernpower.co.uk/innovation/projects/sync (T2) - Directly matching flexible load with flexible generation

course of the Smart Energy Islands trials, the accuracy of the day ahead forecast has improved significantly as the system stabilised.

Finally, a more comprehensive approach to flexibility management, such as that suggested by USEF, could counteract double-counting issues, by introducing data verification mechanisms to make sure flexibility offered by the aggregators is measured as accurately as possible.

Further work and larger scale trials are required to develop reliable baselining approaches and better network monitoring capabilities that will allow for flexibility mechanisms to function.

11 NEXT STEPS

The project has delivered direct and lasting benefits for the islands, developed valuable learning and replicable technologies for the delivery partners, and has informed the wider energy market transition agenda. The project was also included as one of twelve case studies on future energy innovations in the Government's Industrial Strategy published in November 2018.

On the islands, the IoS Community Venture continues to operate and leverage the experience gained during the project to provide first line support for the households with SEI equipment. It is also in the process of taking over the community assets (Solar PV equipment and batteries) in order to be able to generate a sustained revenue stream from BTM self-consumption on those sites and PPAs where applicable. The Venture is also leading the delivery of the follow-on Go-EV project on behalf of the Council of the Isles of Scilly, which addresses the strategic objectives of decarbonising transport on the islands and reducing the overall number of vehicles.

Go-EV will install 27 EV chargers across the islands, 10 of them with V2G capability, deploy a fleet of electric vehicles and a car share scheme, as well as additional PV. The project builds directly on the legacy of SEI. Hitachi and Moixa are both involved as project partners and will leverage the technology platforms developed under SEI to optimise charging and test V2G capabilities. The project will investigate the value of energy optimisation based on smart charging and V2G in the context of a car share scheme.

Go-EV contributes directly to one of Hitachi's strategic priorities in the area of mobility, which is to accelerate the transition of fleets to low carbon, including electric. Hitachi is already delivering Optimise Prime, the world's largest corporate EV trial project, in collaboration with UKPN and SSEN, who operate the electricity distribution networks in London and the South of England. Optimise Prime focuses on enabling quicker and smarter, optimised network connections for EV chargers, particularly in areas with network constraints. Go-EV will contribute learning on the value of optimising charging patterns to reduce electricity cost and the potential to generate additional revenue from grid services.

Hitachi has also actively engaged with the USEF foundation to contribute to the further development of the framework and has links with the FUSION project[47], led by Scottish Power Energy Networks (SPEN), another UK DNO, which looks to deliver a larger trial of USEF and make recommendations on its applicability to the UK market.

More broadly, this project has highlighted improvements and further work needed to make domestic flexibility a reality and enable wider market access for aggregators and flexible device owners. Challenges identified include: fair and auditable/verifiable baselining approaches, forecasting accuracy and its dependence on portfolio size and the nature of the devices controlled. The administrative cost of running a DSR scheme with many small assets and complex commercial arrangements, as well as building customer trust and acceptance of automation are also important aspects to be considered in any scheme.

[47] https://www.spenergynetworks.co.uk/pages/fusion.aspx (Accessed on 20.02.2020)

Some of the challenges identified are already being addressed by other projects, for example SPEN's FUSION and WPD's Intraflex[48], which is exploring bringing flex trading near to real time, reducing the risk of forecasting inaccuracies for aggregators. The Hitachi team will continue to look for ways to contribute to projects, schemes and support policies to help overcome these challenges and enable our future flexibility market design to truly contribute to the net-zero target.

[48] https://www.westernpower.co.uk/projects/intraflex (Accessed on 20.02.2020)