Heat Smart Orkney (HSO) Project

2016-2018

Final Output Report

(for the Local Energy Challenge Fund)

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1 Executive Summary

The Orkney Islands generate 115% of their energy needs through the Islands' 23 wind turbines; any excess generated energy is transported to the Scottish mainland via a subsea transmission cable. In reality, generation from Orkney's wind turbines is far higher. When the capacity limits of Orkney's grid network are reached, wind turbines are switched off - known as being curtailed. Turbine curtailment not only reduces renewable generation; it also threatens the financial viability of wind generation on the Islands. This is a concern, as many turbines in Orkney are community-owned and in addition, an estimated 63% of households in Orkney live in fuel poverty.

The Heat Smart Orkney (HSO) project was developed to address the curtailment of the community-owned Rousay turbine. In the Financial Year 2016-17, Rousay faced a 30% loss in production (~0.7 GWh) and ~£110k loss to its local economy. Funded by the Scottish government's Local Energy Challenge Fund, the HSO project developed a small-scale community pilot, in which curtailment of the Rousay turbine was avoided through smart-grid technologies that intelligently control domestic heating devices.

As part of the project, 108 electric heaters and water immersion heaters were installed in 72 households on the Orkney Islands. During curtailment events, these heating devices were switched on - activating a Demand-Side Management response to reduce curtailment and increase generation payments to the community-owned turbine.

The project avoided 15 MWh and 3.3 MWh of marginal curtailment of the Rousay turbine in 2018 and 2019, respectively. Customer retention and satisfaction throughout the project were incredibly high - reaching over 98% customer retention, and with ~1 in 4 customers reporting a reduction in their fuel bills.

The project is now in its Legacy phase, seeking to integrate other generators in the Orkney grid, and to demonstrate it can generate sufficient income to cover its operational costs. An analysis of projected earnings for the HSO model at-scale, expects break-even to be achieved with roughly five turbines and 800 heating devices installed.

The HSO project has had an impact far wider-reaching than its original objectives. It has developed resources and built relationships with local grassroots organisations working to address fuel poverty in the local community, and has created the foundations on which the Smart Islands Energy Systems (SMILE) and Responsive Flexibility (ReFLEX) projects have been built on.

Led by REWDT (Rousay Egilsay & Wyre Development Trust), the project was delivered by its subsidiary HSO Ltd. - together with its project partners REWIRED (Rousay Egilsay & Wyre Islands Renewable Energy Development), CES (Community Energy Scotland), VCharge (now, Kaluza), Catalyst, and other Orkney-based Development Trusts.

2 Preface

2.1 Contents

2.2 Abbreviations

Abbreviation	Meaning
ACP	Aggregating Controller Platform
ANM	Active Network Management System
CES	Community Energy Scotland
DNO	Distribution Network Operator
DSM	Demand Side Management
HSO	Heat Smart Orkney
LECF	Local Energy Challenge Fund
LIFO	Last-In First-Off (curtailment principles of access)
Ofgem	Office of Gas and Electricity Markets
PNDC	Power Networks Demonstration Centre
REWDT	Rousay, Egilsay & Wyre Development Trust
REWIRED	Rousay, Egilsay & Wyre Islands Renewable Energy Development
RPZ	Registered Power Zone
SCADA	Enercon turbine Supervisory Control and Data Acquisition system
SGS	Smarter Grid Solutions
SHEPD	Scottish Hydro Electric Power Distribution (subsidiary of SSEN)
SSEN	Scottish & Southern Electricity Networks
VCCC	Software application running in the 'cloud'
VScon	VCharge Supervisory CONtrol and data acquisition device

2.3 HSO Ltd Acknowledgements

HSO Ltd would like to thank the numerous REWDT Board members who over the years have supported the development of the HSO Project and, who have agreed to allow HSO the use of their assets for another year - enabling the project to expand into its Legacy phase, and to prove the concept to other generators within the Orkney grid.

HSO would also like to thank its project partners and contractors for their hard work in getting the scheme to work and for supporting all our efforts in making this a success. And finally, a thank you to the Scottish Government for providing the finances to make this happen and who without their support the project would never have been started.

3 Introduction

This report is the final project report of the Heat Smart Orkney (HSO) project, part of Phase 2 of the Local Energy Challenge Fund (LECF) and funded by the Scottish Government from April 2016 – October 2018. The report aims to provide an evaluation of the project, its achievements, an insight into its key deliverables and objectives, as well as looking at how the project's legacy and post-LECF funding future looks to build on the progress made by the project, which was achievable in thanks to the LECF's funding and support during both Phase 1 and Phase 2 of the LECF. The HSO project has been a collaborative project using the expertise provided by Rousay, Egilsay & Wyre Development Trust (REWDT) and its subsidiary, Rousay, Egilsay & Wyre Islands Renewable Energy Development (REWIRED) Ltd., Community Energy Scotland (CES), VCharge (now Kaluza, an OVO Energy company), Catalyst, and various other Development Trusts within Orkney which supported the work being undertaken as part of the project.

The project sought to minimise curtailment of the Rousay, Egilsay and Wyre community turbine, and to divert this excess energy to new heating load. This created value for the community by delivering efficient and effective supplementary heating and hot water, with significantly discounted energy that otherwise would not have been generated - thus, helping to counter the high levels of fuel poverty within the islands. This supplementary heating and hot water was provided by means of installing new Dimplex Quantum storage heaters, Heatrae Sadia Megaflo Hot Water Cylinders, MacGregor Copper Cylinders and Heatrae Sadia Flow Boilers to be controlled via a DSM system implemented by VCharge. The need for demand side management (DSM) stems from underutilised existing community wind turbines throughout the Orkney Islands as they suffer from curtailment due to grid limitations. This concept shares several similarities with the ACCESS project; a LECF project based in Mull, sharing several of the same partners with the HSO project, however there are distinct differences between the projects;

- HSO demonstrates integration of DSM to improve the operation of multiple generators within an existing ANM zone - ACCESS established a standalone Demand Side Management system for a single generator, without an existing ANM system.
- HSO mitigates curtailment for existing renewables suffering from multiple points of constraint on the distribution network - ACCESS provided a route to grid access for new renewable generation facing a single transmission constraint.

3.1 Heat Smart Orkney: an introduction

Rousay, Egilsay & Wyre is a three-island group within the Orkney Islands, with a population of c. 260. The larger Orkney Islands lie 6 miles off the North Coast of Scotland, comprising 20 inhabited islands, with a population of 22,000. The islands have the highest rate of fuel poverty in Scotland and the United Kingdom, with most recent figures showing that 57% of households are classed as being in fuel poverty, with the number regularly sitting around 60% over the past decade. Fuel poverty is defined as a household where fuel costs are more than 10% of their net income. 23% of households were classed as being in extreme fuel poverty, where over 20% of their household's net income goes towards fuel costs. 85% of retired households are also defined as being in fuel poverty.

Despite this, since the early 2000's, when the first modern large scale wind turbines were installed in the islands, there has been a steady increase in local renewable energy generation. It is estimated that large scale wind generates approx. 161 GWh per year, while small scale wind generates approx. 19 GWh per year. Export to mainland Scotland occurs via 2 x 33kV submarine cables. Since 2012 however, Scottish Hydro Energy Power Distribution (SHEPD) imposed a moratorium on all new generation in the islands due to grid constraints relating to the export of energy via these submarine cables.

Since 2009, an Active Network Management (ANM) system has been in operation across Orkney, to allow generators to connect and export to the limited grid system without the need for substantial upgrades to the network capacity. This however has introduced the risk that their generation may be limited due to the grid constraints. The ANM monitors power flow through several pinch points on the grid network and power flow from a number of renewable energy generators to be controlled in order to reduce their output to match available network capacity. This results in what is known as the 'curtailment' of generators. Before the ANM came online in 2009, several more important milestones were reached:

- 2004 – DTI funded study establishing the benefits of the ANM, details of a technical solution to generation on the local grid.
- 2005 – RPZ (Registered Power Zone) application to OFGEM, setting out barriers to connection and innovative grid solutions
- 2006 – ANM scheme trial
- 2009 – Connection of first ANM generators

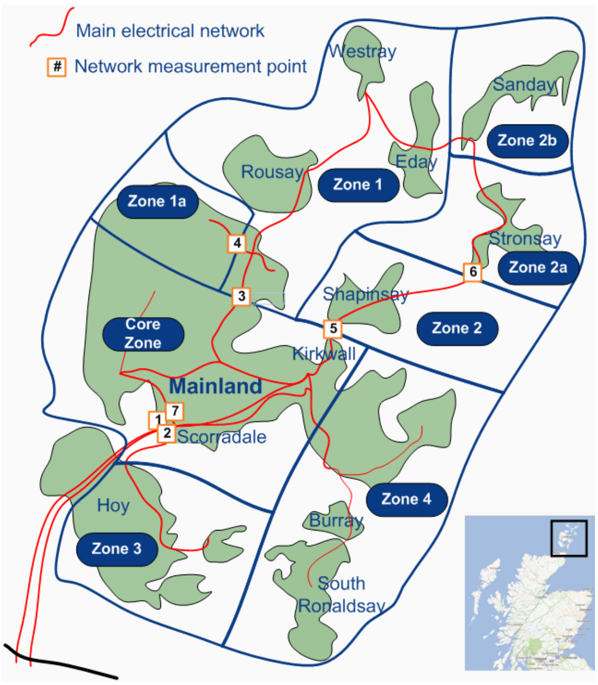

Fig. 3.1 *- The Orkney ANM, showing the various zones of the local network*

Before the introduction of the ANM and latterly, the moratorium, several local development trusts and community groups were able to receive grant funding and raise capital to install their own renewable energy generators. REWDT oversaw the commissioning of their 900 kW Rousay wind turbine in 2011, 2 years after the introduction of the ANM system, and as such, the turbine is managed on a non-firm grid connection.

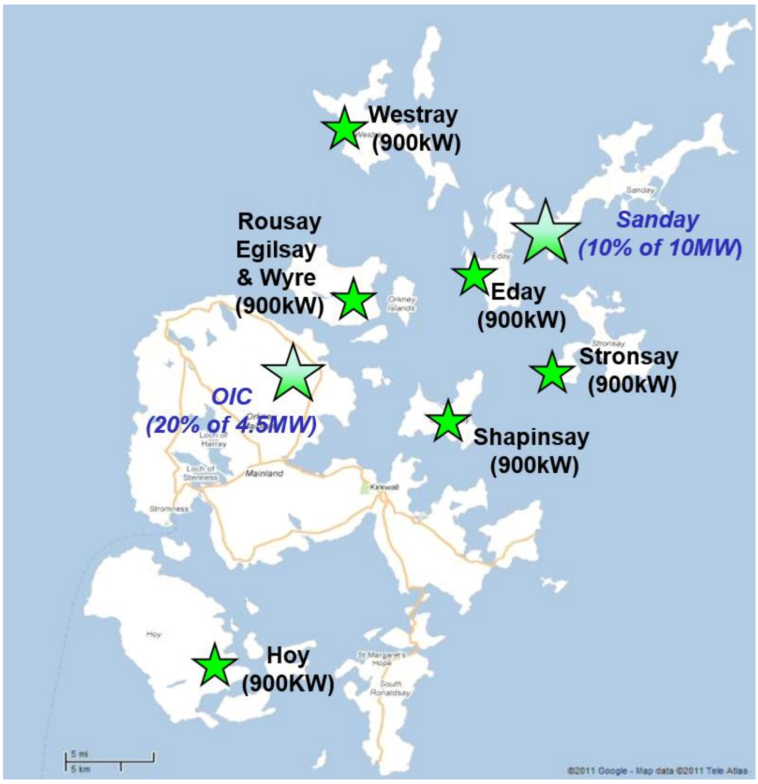

Fig. 3.2 – *The Rousay, Egilsay and Wyre community turbine, alongside other large scale community owned renewable energy generation. Total installed: c. 7.3MW*

Through the Principles of Access (PoA) mechanism used in the ANM, a Last-In First-Out (LIFO) system meant that many of these community owned turbines were connected as new non-firm generation, after many other generators across the islands had been installed. As new non-firm generation, these turbines were not guaranteed unrestricted access to export to the grid, and would be subject to control from the ANM, and as a result, curtailment. These generators were in contrast to those connected to the Distribution Network Operator (DNO) earlier and marked as firm generation, where they would receive priority to access the grid. This is known as the priority stack, where generators further down in the stack (and therefore the last the be connected to the DNO) are given less priority to access the grid, meaning many of the later generators were subject to more restricted access and undergo more frequent curtailment and reduced generation as a result.

Under the Last-In First-Out (LIFO) system, the last connected to the grid are the first out in the event of grid restrictions and curtailment. Each of the ANM zones containing new non-firm generation will be subject to a priority stack and curtailment. The table below (table 3.1) shows a theoretical example of how the ANM priority stack would work on seven generators within the same grid zone, and is not based on accurate details of a generators position in the stack or levels of curtailment experienced. It does not represent the actual Orkney priority stack and any similarities to existing generators are coincidental.

Table 3.1 - *Example of Orkney ANM priority stack within a single ANM zone*

Date of Connection to DNO	Position in the ANM stack	Wind Turbine	% of time spent 'curtailed'
Oldest	1	WTG A	0
	2	WTG F	0
	3	WTG D	10
	4	WTG B	30
	5	WTG C	40
	6	WTG G	60
Newest	7	WTG E	70

As a result of the priority stack and the LIFO principle, at times of peak potential generation, it is likely that generators further down the priority stack will be curtailed, due to the existing high level of generation exporting to the grid during optimal generating conditions. This causes a significant problem for lost income from generation for many turbines across various zones. In the financial year leading up to the HSO project, curtailment of the Rousay, Egilsay and Wyre community turbine resulted in a 30% loss of production (approximately 700,000 kWh), amounting to a loss of £110,000 to the island economy, while the turbine had an estimated constrained output of 366 kW, significantly lower than the 900 kW rating of the turbine. The following figure (Fig. 3.3) shows the generation and curtailment of the REWDT turbine over the period from 2012 - 2018.

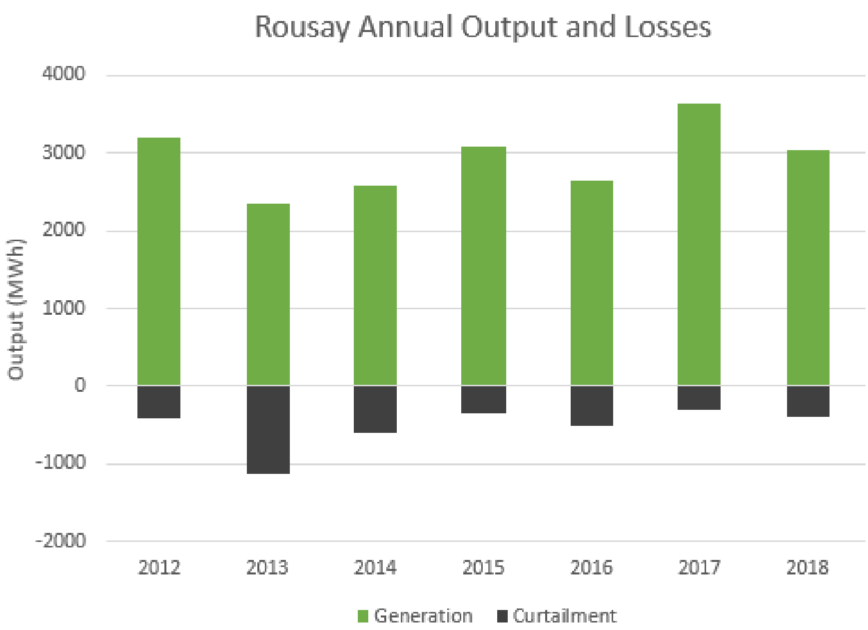

Fig. 3.3 - *Rousay turbine generation and curtailment 2012 - 2018*

The following figure (Fig. 3.4) shows a month by month generation and curtailment comparison of another project partner, the Eday community turbine, which is also located within Zone 1 of the Orkney ANM. Note these outputs are by month and in kWh, while the previous figure (Fig. 3.3) shows by year and in MWh.

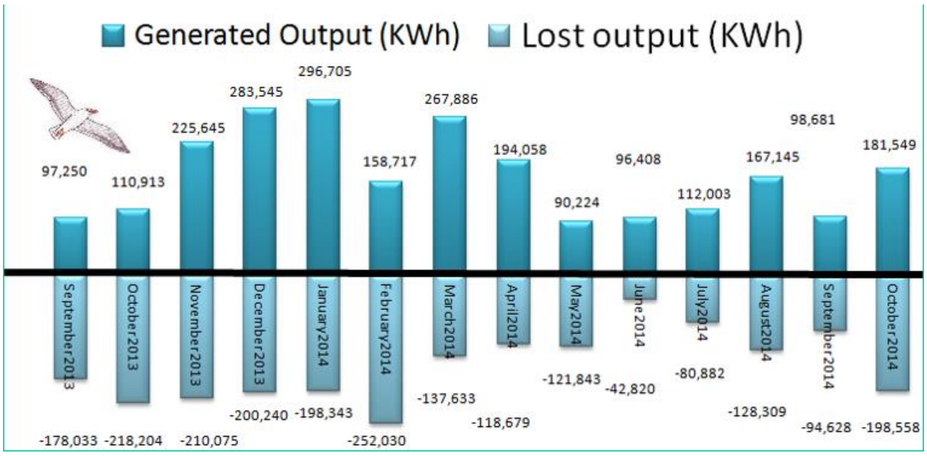

Fig. 3.4 *- Eday turbine generation and curtailment from Sep 2013 – Oct 2014*

The results of such significant curtailment proves to be a problem for the development trusts and their turbine trading subsidiaries, who in the worst case scenario, can struggle to meet their loan repayments remaining from the financing and installation of their turbines, while also struggling to tackle the issues experienced within their communities, that could otherwise be addressed by the excess income generated through increased export to the grid, such as island depopulation, high fuel poverty, old existing housing stock and a lack of employment opportunities.

To address the issue of fuel poverty, the project sought to use its supplementary heating systems of parallel electrical flow boilers, hot water immersion heaters and cylinders, and intelligent Quantum electric storage heaters to reduce participating properties' reliance on their older, less efficient and often fossil-fuel based primary heating systems. These modern, energy efficient devices were each installed along with their own VCharge 'Dynamo' controller, which through communication with the VCharge 'VScon' unit installed in the community turbine, would send commands to turn on/charge the heating devices during periods of marginal curtailment – where the Rousay generator is the turbine in the priority stack that is being instructed by the ANM to reduce its output. The secondary function of these heating devices meant they were mitigated against a lack of wind or lack of curtailment, but during optimal times of curtailment, provide efficient and locally generated background heat in a property, reducing the households' reliance on their primary heating system, using less fossil fuels and reducing carbon emissions.

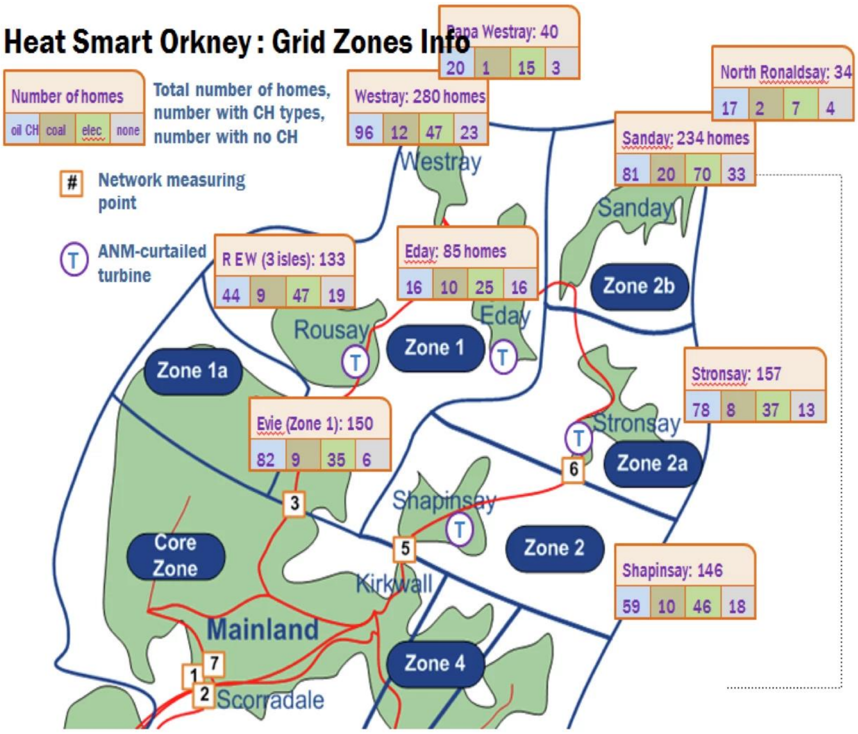

Fig. 3.5 *- Number of homes within Zone 1 of ANM, and their existing heating types*

3.2 Project objectives

The primary objective of this project is to develop a community-scale pilot to develop a commercial local energy solution that is fully integrated with the Distribution Network Operators' (DNO) existing grid control infrastructure and regulatory process.

The key deliverables of this community-scale pilot are to:

A. Provide measurable, verifiable, and statistically significant electrical demand which addresses fuel poverty, geographically adjacent to an actively managed renewable energy source;

B. Prove a commercially scalable model for supplemental grid-smart heat, while respecting the existing commercial arrangements of the Orkney ANM system, the load profiles of pre-existing load, and not affecting the national demand side management systems for off-peak heating;

C. Respecting the technically sensitive nature of the island grid, focus on using aggregation technology deployed in a prudent, passive manner in order to effectively decouple demand side management actions from critical network management.

D. Share knowledge with HSO's existing 'knowledge partners', to: address fuel poverty; develop the wellbeing, resilience and self-sufficiency of local communities; and reduce domestic carbon emissions from fossil fuels. HSO's knowledge partners include an existing consortium of small grassroots and socially-responsible organisations in the Orkney Islands.

3.2 Project timescales

The HSO project can be broken down into 3 phases; Phase 1 (Development), Phase 2 (Capital Demonstration Project), and the HSO 'Legacy'. As an outcome of Phase 2, this report primarily details the Capital Demonstration Project, while touching on the background of the project in Phase 1, and outlines the future of the project in the Legacy phase. The Capital Demonstration Project was funded from April 2016 – October 2018, the duration of the project.

Phase I was run by REWDT, prior to the set-up of HSO. This initial stage provided an opportunity to:

- design the VCharge algorithms for determining and monitoring curtailment events;
- build analytics for identifying patterns, durations and frequency of curtailment events;
- demonstrate the technology concept at a small scale;
- identify the scale of potential customer take-up;
- collect the necessary data to build cost estimates for Phase II; and,
- identify any implementation and logistical challenges.

Following on from earlier trial projects funded through CARES IIF, in 2014, REWDT were awarded funding through the LECF to develop the HSO concept further, and secured c. £200,000 of funding to develop and undertake a series of trials to look at mitigating the effect of curtailment and addressing fuel poverty within the local community. The outcome from these trials resulted in the development of the HSO Project and subsequent application to the Scottish Government for funding from the LECF.

The development work included the testing of smart grid technologies to show ANM curtailment signals, and how the signals could be used to control heating devices. REWIRED funded the VCharge communication, hardware and software upgrades at the community turbine, allowing the curtailment signals to be read and intercepted and allowing real-time data to be continuously collected, saved and correlated providing a quantifiable loss of energy during a curtailment event.

This allowed for a small-scale trial of six households on Rousay to provide REWDT and REWIRED the opportunity to test the feasibility of the VCharge technology and the communications between the VScon at the turbine and the Dynamos controlling the heating devices. The trial also provided the basis on which to build costings for a full-scale project, establish financial parameters to meet potential take up and identify logistic issues associated with rolling the project out to the wider project area, procuring services, and staffing etc.

3.4 Project funding

Phase 2 of the HSO project was funded through the Scottish Government's Local Energy Challenge Fund in 2016. The total project cost for the year was £1.6m, with £1.2m provided in grant funding from the Scottish Government, with the additional £400,000 covered by the Rousay, Egilsay & Wyre Development Trust. Initially, the HSO project had hoped to receive a portion of this £400,000 as match funding from the National Innovations Allowance, however in March 2017, the project was informed that this funding was not going to be awarded.

Prior to the phase 2 project funding, the HSO concept was developed through various different funding streams over a number of years, providing the building blocks that allowed the project to form. These include:

- CARES Infrastructure and Innovation Fund (IIF) – REWDT had benefited from CARES IIF grant awards for individual projects including Demand Side Management, Electric Vehicles and EV Grid Smart Charging projects.
- Phase 1 of the LECF Funding in 2014 – REWDT was awarded £29,488 to develop the Phase 2 application.
- REWDT invested £120,000 of funding awarded by the Big Lottery Fund, bringing this work together with a communications trial in order to support the application for the HSO project.
- REWIRED Ltd invested £10,000 in VCharge data capturing equipment, allowing access to further data relating to curtailment.
- REWDT also benefited as a project partner of a further CARES IIF project awarded to the Hoy Development Trust.

3.5 Project partners

The HSO Project has been a collaboration between numerous partners - the Rousay Egilsay & Wyre Development Trust (REWDT), Rousay Egilsay & Wyre Islands Renewable Energy Development (REWIRED) Ltd, Community Energy Scotland (CES), VCharge, Catalyst, as well as other Orkney-based Development Trusts. An introduction to each partner and their role in the HSO project is provided below.

REWDT

- A Development Trust serving a population of 260 from the three islands of Rousay, Egilsay and Wyre. It aims to sustainably improve the quality of life for its island inhabitants and is the Lead Partner in the HSO project.
- In 2011, it oversaw the commissioning of the Rousay turbine.
- Secured ~£200k to develop the HSO project and invested 3 years in groundwork for the project - including grid investigations on enhancing turbine output, and testing how curtailment can be mitigated using domestic heating units.

REWIRED

- A subsidiary of REWDT whose role is to operate the 900 kW community-owned Rousay turbine.

- During the project, REWIRED met all costs needed to upgrade the communication, hardware and software of the turbine - enabling real-time curtailment data to be collected.

CES

- An independent social enterprise and charity aiming to build confidence, resilience and wealth at a community-level in Scotland, through sustainable energy development.
- CES develops community energy projects, assists with project and infrastructure-related issues, assesses project impacts on fossil fuel reduction, and looks at maximising ownership and the local economic value of such projects.
- During the HSO project, CES provided support and expertise from conception to commissioning, and assisted with tackling project issues throughout.

VCharge

- An American company with a history of building software and hardware to coordinate distributed electrical load to respond intelligently to changing grid conditions.
- The company had prior experience in using night-time storage heaters to reduce heating costs, and providing grid balancing services in the US energy markets.
- During the HSO project, VCharge developed the load switching technology for the household devices and turbine.
- In 2016 VCharge was bought by OVO Energy, and as of 2019 was rebranded as Kaluza.

Catalyst

- An electrical engineering company based on Hoy, with connections to Hoy Development Trust and Hoy Energy Ltd.
- Throughout this project Catalyst acted as an adviser and contractor for equipment installation.
- Catalyst also engaged with installations and hardware monitoring during early testing, and ensured that VCharge equipment complied with UK standards and regulations.

Other

Other Development Trusts (DTs)

- Whilst not active participants, DTs have supported the project by helping to promote the scheme to prospective households.

3.6 HSO Setup

HSO Ltd was registered with Companies House in May 2016 following the announcement of grant funding from the LECF for the HSO Project. HSO Ltd, set up as a subsidiary of the REWDT and was formed to administer and manage the customer engagement side of the project.

Board members for HSO Ltd were elected from volunteers of the REWDT Board, Project Manager (PM) and two community representatives. Articles of Association were drawn up and these are lodged with Companies House.

Under the remit of the REWDT to promote island growth and economic development the vacancies for Project Officer (PO) and Project Assistant (PA) were advertised in the local Rousay, Egilsay & Wyre Review (REW Review). Several applications were received, and three members of the community were appointed with the PA's role split to accommodate job share applicants. These staff were employed on fixed term contracts with the proviso that should the HSO Project cease they would no longer be employed. The team took up their posts in August 2016 and are still employed by the company ensuring continuity of service in the legacy year.

The HSO Project was launched at the REWDT Annual General Meeting in November 2016 with HSO Ltd staff providing a presentation and issuing information packs. Contact details about the project and how to get a pack were also covered in the REW Review.

For additional information on the HSO Setup and launch, please see appendix 2, 2.1 and 3.2

4 Project implementation

This section provides background information on the implementation of the Heat Smart Orkney project, namely its commercial and technical elements.

The commercial implementation (section 4.1) discusses the customer journey for households recruited in the trial, together with the underlying rebate system used to distribute the value created through curtailment mitigation to the trial participants. The technical implementation section (section 4.2) focuses on: how the technology has been designed to meet Orkney's unique requirements; the heating systems used; and how the VCharge-designed technology facilitates control of residential heating systems during curtailment events.

As referenced in the Introduction, The HSO project has been split across three phases: Phase I, Phase II, and the Legacy Phase. Phases I and II include the HSO project work conducted to date - including the technology development and implementation, recruitment of trial households, and the first demonstration of how intelligent control of electric demand can mitigate a marginally curtailed generator. Phase I involved an initial small-scale trial; Phase II progressed to a larger scale trial.

The Legacy Phase concerns the next stages of the HSO project - transitioning from a pilot-scale trial, to a sustainable business model, with the opportunity for expansion across a broader portfolio of households and other zones within the Orkney grid. This section (section 4) refers only to Phases I and II of the project. Forward-looking details on the Legacy Phase are discussed in section 6.

4.1 Project implementation: commercial aspects

4.1.1 Customer journey for trial participants

The selection of customers recruited in the trial was governed by certain eligibility criteria - in particular, households required:

- a connection to the electrical grid;
- a primary heating source that used either electricity, coal, of LPG;
- a broadband connection (either landline, satellite or mobile).

Furthermore, households were required to lie within Zone 1 of the Orkney grid - covering the islands of Rousay, Egilsay, Wyre, Westray, Papa Westray, Eday and the northeast of West Mainland. The islands represented by REWDT were particularly targeted (Rousay, Egilsay and Wyre).

During phase 1 of the project, REWDT identified a potential client base of 700 households, of which six were recruited for the initial small-scale pilot. The selected participants consisted of properties with a variety of heating solutions, broadband providers and connection speeds.

For phase 2 of the project, a total client base of 100 participant households was sought after - aiming for an uptake of 15-20% of the potential 700 households. HSO Ltd engaged with 189 households during the customer recruitment stage. Of these, 78 properties (41.2%) were invited to participate in the project, of which 72 (38.1%) were enrolled. A summary of the customer recruitment process, from phase 1 identification through to project end, is summarised in Fig. 4.1.

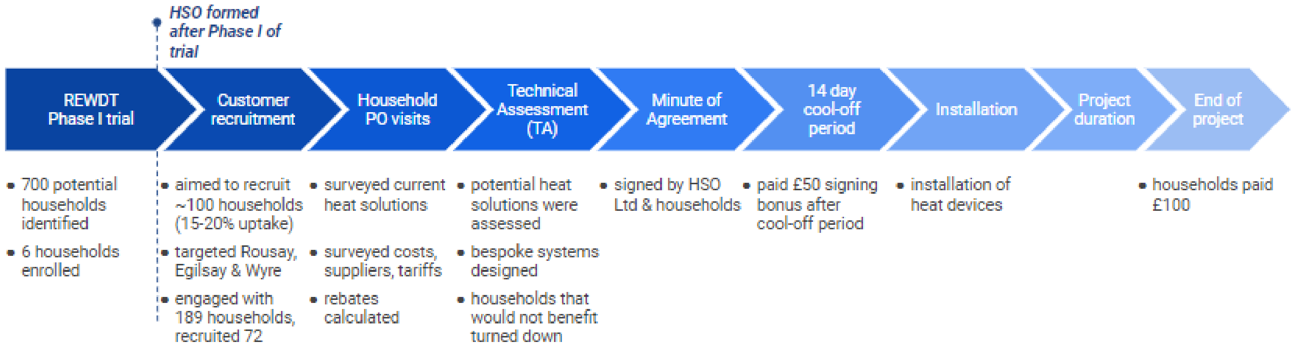

Fig. 4.1 *Customer journey for recruitment of households in Phase 2 of the HSO trial.*

As outlined in Fig. 4.1, the key stages of customer enrolment involved: household project officer (PO) visits, technical assessments (TAs), signing of a Minute of Agreement (MoA) and the subsequent installation of heating units. At the end of phase II, all participating customers were invited to take a survey to understand their experiences of the trial.

The requirements of each stage in the customer journey are outlined herewith.

Household PO visits

PO visits were used during customer recruitment to both gather data on the current energy systems in prospective households, and ensure these households met the required eligibility criteria.

The following data items were gathered:

- how households heated their home and hot water;
- what fuels were used and at what cost;
- their electricity supplier, including unit cost price, standing charges, tariffs;
- annual household consumption.

This information was used to determine rebates, compare fossil fuel use pre- and post-installation of HSO heating devices, and to assess the additional load that would be placed on the distribution network (in the context of any impact to grid reinforcement requirements).

PO visits were also used to clarify to prospective households that any devices installed as part of the project would be secondary to primary heating and hot water equipment.

PO visits initially targeted households on the islands of Rousay, Egilsay & Wyre. As the required numbers of properties were not met from these islands, participants were subsequently recruited from the more northern islands.

For more information on Project Officer Visits and household data gathering, please see Appendix 4, 4.1 and 4.2

Technical Assessments
Technical assessments (TAs) were carried out on all potential properties satisfying the PO visit. This involved discussing the potential heating units to be installed, documenting existing fuse boxes and meters, checking the broadband signal, and the potential additional load requirements on the grid. During the TA visits, households were turned away if the proposed heating units would have added to their energy costs without benefiting existing heating and hot water needs.

A bespoke heating solution was then designed for each household, based on the available heating systems (section 4.2.2). Upon completing the TAs, SHEPD was informed about the households considered for the project, and the associated loads that would be added to the network.

TA visits were run by Catalyst - chosen due to their prior experience in working with VCharge on the configuration, technical specifications and communication links between their equipment.

For more information on Technical Assessments, please see Appendix 5 and 6.

Minute of Agreement
A Minute of Agreement was issued to participant households, following completion of the TAs. These were signed by both households and HSO Ltd prior to the start of installations.

Customers were given a 14-day cooling off period after signing the MoA, to leave the trial if desired. Participants were paid a sign-up bonus of £50 if they signed and returned the Agreement, without dropping out during the cool-off period. In addition, householders were paid £100 at the end of the project - an incentive to encourage continued project participation.

The MoA was drawn up in a collaboration between HSO, CES and a solicitor, and was based on an Agreement used in earlier trials (REWDT phase 1, ACCESS project). Additional details were added to include pay-as-you-go 'key card' electricity customers, and those who were supplied with a broadband solution by the HSO Project.

Please see Appendix 1 for more information on the Minute of Agreement

Installation and commissioning
Installation of the Dimplex heaters and Megaflo boilers was financed by HSO Ltd. A dedicated installation team was set up for the HSO Project, consisting of two electricians and two plumbers (one apprentice, and one certified).

Devices were brought online during the installation process and installed in discreet locations within participant houses. Participants were issued with an operating manual, were shown how to programme the device, and the device set-up was configured as desired by the households.

Following installation, devices were connected to the VCharge cloud-based aggregating controller platform (ACP), and then commissioned by VCharge. Further details on the VCharge ACP are provided in section 4.2.3.

As outlined in the eligibility criteria, a broadband connection was required to enable the ACP and dynamos to communicate. Unifi Enterprise Security Gateway hubs (specified and supplied by VCharge) were installed during the installation process. Where necessary, additional unifiers and Wi-Fi boosters were installed to ensure households maintained a sufficient connectivity.

All installations were conducted by R S Merriman. This contractor was selected via a competitive process run by a User Intelligence Group, as specified by the Scottish Government procurement process. R S Merriman staff were provided with training by VCharge for the installation and connection of VCharge in-home devices (Dynamos - see section 4.2.3), and by Glen Dimplex for programming of the storage heaters used (see section 4.2.2).

During the installation process, it became clear that 3 of the properties would require alternatives to the Megaflo cylinder (see section 4.2.2), which could not be used with solid fuel boilers without the installation of an expansion vessel, costing an additional £800 per property. R S Merriman sourced a copper cylinder from MacGregor cylinders, which was a suitable alternative to the Megaflo cylinder within a similar budget.

4.1.2 Final customer recruitment numbers

A total of 72 properties were deemed suitable for receiving equipment for the HSO project, in which a total of 108 devices were installed. Of these, 19 households (26%) solely used electricity for their hot water and heating needs; whilst 53 households (74%) used fossil fuels.

A summary of device numbers installed by location are summarised in Table 4.1. Further details on the device types are provided in the technical background section (section 4.2).

Table 4.1 *Summary of installed device count by location.*

	Installed (for project)			**Adopted (prior)**
Location	Storage heaters	Megaflo cylinders	MacGregor cylinders	Immersion elements
Rousay	36	29	-	2
Egilsay	2	2	-	-
Wyre	-	1	-	-
Papa Westray	-	3	-	-
Westray	-	14	-	1
Eday	1	2	1	-
N.E. of West Mainland	3	12	2	2
Total	**42**	**63**	**3**	**5**

4.1.3 Value creation for HSO households

Value was created for HSO-participating households through two ways:

- Firstly, all electricity supplied to HSO devices by avoiding curtailment received a rebate payment (as a result of the increased revenue from higher turbine output) - effectively reducing the cost of electricity consumption.
- Secondly, the HSO devices had higher energy efficiencies relative to older devices (typically 20% more efficient) - thus reducing household consumption. For a 1 kWh consumed by HSO devices, householders could save 1.25 kWh from an older device

Rebate payments

Rebate payments were based on monitoring HSO device consumption during avoided curtailment events, through using meter readings collected by REWDT. These meter readings were taken in line with the periodicity of suppliers' electricity meter readings.

CES developed a tool for calculating rebate payments, based on the Sutherland Tables and in collaboration with the Energy Savings Trust Scotland. The Sutherland Tables are a quarterly publication of home heating costs in the UK and Ireland, compared across various fuels and types of dwelling.

Rebates were calculated as follows on a per household basis:

1. The *current cost per kWh* of heating and hot water was determined from combined energy bills and system usage over the previous year
2. A *target price per kWh* for the consumption through the HSO-installed devices was identified by applying a 10% reduction to the *current cost per kWh*
3. A *pre-VAT rebate payment* was determined from the difference in the current cost per kWh (step 1.) and the target price per kWh (step 2.)
4. To cover VAT costs passed onto households, the pre-VAT rebate payment was increased by 5%.
5. For households whose *target price* was higher than their *latest energy bill* (e.g. if on s standard rate tariff), the HSO project rebated a 10% reduction from this latest bill, ensuring that households consistently received a 10% reduction.

The following table provides an example of how a rebate is calculated:

Table 4.2 *Example rebate calculation.*

Current cost: Using the information gathered, calculate the *current cost* per kWh from the properties combined energy bills (electricity, oil, gas, coal etc.)	£0.1681 / kWh
Target price: We work out the *target price per kWh* for the electricity used in our new devices, by applying the 10% reduction to what your current costs are	£0.1513 / kWh
Latest energy bill: We take the cost of your electricity from your latest bill (e.g. your Standard Rate tariff)	£0.1650 / kWh
Pre-VAT rebate: We deduct the *target price from the latest energy bill to obtain the rebate payment (p/kWh)*	£0.0137 / kWh
VAT top-up: We will then include a 5% top-up to compensate for additional energy costs associated to VAT	£0.0007 / kWh
Final post-VAT rebate:: So for every kWh in an HSO device, the rebate is	**£0.0144 /kWh**

This process of determining rebate rates were run and adjusted accordingly as each household electricity bill was received.

4.2 Project implementation: technical aspects

This section provides background to the technical implementation of the project. Within this, Orkney's unique network requirements, its existing curtailment systems, and commercial agreements are outlined. Technical details on the HSO heating units installed, the VCharge communication and control architecture between the turbine and heating units are also provided.

4.2.1 Designing technology solutions to meet Orkney's unique requirements

The project objectives (section 3.2 - objectives B and C) required the technology developed to respect existing commercial arrangements of the Orkney network, the load profiles of pre-existing load, and not affect national demand side management systems for off-peak heating (objective B). In addition, the project was required to respect the technically-sensitive nature of the island grid system, focusing on aggregation technologies to effectively decouple demand side management from crucial network management (objective C). This section outlines Orkney's commercial arrangements, and the design principles used to define the optimisation of heating units.

As introduced in section 3, the Principles of Access (PoA) mechanism used in Orkney is the Last-in-First-off (LIFO) method. PoAs are commercial arrangements that are put in place, aiming to ensure fair allocation of renewable generation when generation is limited by the network. Orkney's LIFO method bases the decision to curtail a turbine on the date the turbines were commissioned - that is, the last generator to be connected is restricted before the first. This hierarchy of curtailment is referred to as the "priority stack".

In practice, network constraints can occur anywhere on the network - wherever the power generated exceeds the network capacity. SHEPD has divided Orkney's distribution network into zones that represent the points of constraint. These constraint points are based on generation, load, and network capacities. When a particular zone is overloaded from excess generation relative to local load, the generators in that zone are curtailed (following the LIFO PoA mechanism).

In addition to the internal constraints within zones, all zones within the Orkney grid are limited by the Core Zone, which connects the Orkney grid to the Scottish mainland. The Rousay turbine, and all turbines managed by REWDT, lie within Zone 1 of the Orkney ANM. To ensure the project did not encroach into other ANM zones, the SHEPD provided HSO with the ANM zone boundaries and list of properties in Zone 1 (based on data from feeders in the Burgar Hill substation located in Zone 1). This enabled the HSO team to only select households in the catchment area, as shown in Figure 4.2.

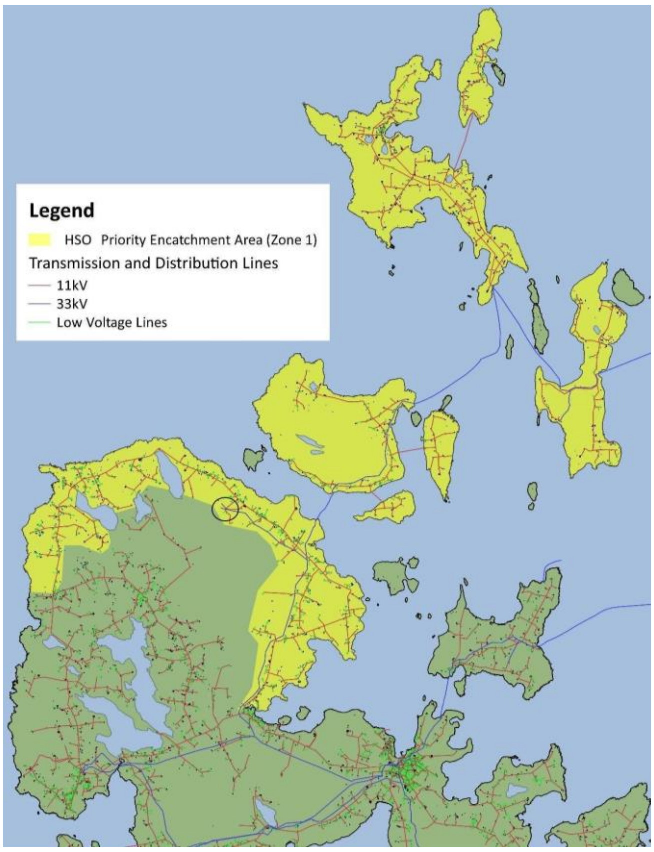

Fig. 4.2 *Detail of grid network within Zone 1 of the Orkney ANM at 33kV, 11kV and LV levels. The Burgar Hill substation feeding the yellow area is circled.*

Curtailment of the 900 kW Rousay turbine is controlled using a dynamic set-point signal. This set-point indicates the maximum power output allowed from the generator, at any point in time. It also allows the generator output to be trimmed (marginally curtailed), rather than being fully disconnected (fully curtailed).

The set-point signal is generated using Active Network Management (ANM) equipment installed at the zone's network constraint points. When the ANMs detect excess generation for the network constraint points, generators are curtailed. The ANMs sit at the zone boundary measurement point, sending commands to unique ANM Connect devices that control each individual turbine. As a result of the LIFO PoA mechanism, the order that generators are curtailed is based on their position in the priority stack. Thus at any time, only one generator will be marginally curtailed, with any others at lower positions in the priority stack being fully curtailed. The marginally curtailed generator is the first to be affected if either the network load or generation volume change.

This ability to manage the connection of a generator to a distribution network is termed a non-firm connection; a firm connection enables a generator to export power to the network without restriction.

As a consequence of Orkney's commercial arrangements and the requirement to not influence existing load profiles, or demand side management of off-peak heating, the following design decisions were made for the VCharge optimisation:

- heaters cannot work when they are offline, and not under VCharge management;
- heaters will only be charged by VCharge when a curtailment event occurs;
- heaters are set up to always call for heat, if a curtailment event occurs;
- heating provided from HSO devices can only be used for supplementary heating;

- customers cannot set comfort settings on the devices, and VCharge is not responsible for the customers' room / heater temperature.

Discussions with SHEPD began during Phase I of the project, during which grid impact studies were designed so as to assess the potential effects of the project on the local network, including the impact of additional load, costs to the network, and any areas of the grid requiring grid reinforcement.

4.2.2 Smart heating and boiler systems

A series of heater types were installed in participant households to create Demand Side Management (DSM) loads. These included: hot water immersion heaters, and stand-alone intelligent electric heaters. These were installed both in properties with and without pre-existing electrical heating systems. Originally, parallel electrical flow boilers were also considered as potential devices for installation; however, no suitable properties were identified, meaning none were installed. However, an existing flow boiler install was adopted from a REWDT communications trial project, and integrated into the project. The average load of the immersion heaters and electric heaters, on a per device basis, was 2.3 kW.

Hot water immersion heaters

A combination of direct and indirect, and vented or unvented Haetrae Sadia Megaflo hot water cylinders (ranging from 210 - 300 litres in size) were selected for installation. In varying forms, these devices use immersion coils held within water tanks and heat the water with electricity until the desired temperature on the thermostat is reached.

These heaters were selected for the HSO project due to their:

- high efficiency;
- good insulation properties and ability to act as a thermal store (thus maintaining heated water temperatures for longer);
- good performance in hard water areas, from their internal titanium coatings (advantageous given Orkney has hard water);
- reputation for quality;
- prior successful experiences of using these heaters in both the ACCESS Project and a small trial with solar panels on Hoy.

Whilst the immersion heaters were linked to marginal curtailment and could only charge at these periods, a "boost" override mode was enabled. This allowed households additional flexibility to immediately call for hot water during times with no marginal curtailment. All heating costs attributed to this feature would not be covered by the rebate - instead these would be charged at the household's standard rate energy tariff, with all costs met by the homeowner. All device consumption attributed to VCharge instructions from avoided curtailment were separately metered.

As previously mentioned in section 4.2.1, 3 properties required alternatives to the Megaflo cylinders, in order to integrate with the properties' existing solid fuel boiler. MacGregor copper cylinders were recommended by the installer, R S Merrimans.

Electric heaters
A range of Dimplex Quantum electric heater models were selected for installation, including the following: QM50, QM70, QM100, QM125, QM150 (power ratings ranging 1.02 - 3.3 kW).

Dimplex heaters consist of electric heating elements held between bricks, surrounded by insulation. As electric power flows through the device, the heating elements turn on and heat the bricks. A thermocouple held between the bricks and the insulation reads the brick temperature. Once the temperature reaches its heating limit (205 °C core sensor reading, equivalent to 700 °C brick temperature), the element is switched off. The insulation then enables the bricks to store heat until the room is desired to be heated, after which a fan and vent system enable the bricks to release the stored heat into the room. A diagram of the Dimplex heater internals is shown in Fig. 4.3.

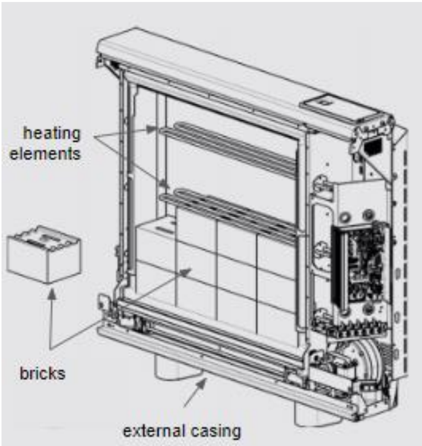

Fig. 4.3 *Illustration of the Dimplex Quantum internal components (sourced from Dimplex website)*

Dimplex Quantum heaters were selected for the HSO project due to their:

- ease of programming and control;
- efficiency to run;
- ease of use;
- ability to deliver heating load when desired by the householder;
- prior use in similar projects, such as ACCESS, and known knowledge and support of DSM projects by Glen Dimplex.

As with the hot water immersion heaters, the Dimplex heaters had a "boost" override mode enabled, which allowed households to charge their heaters in periods outside of marginal curtailment. Likewise, all heating costs attributed to this feature were separately metered, and not covered by the rebate. For Dimplex devices, households were allowed to boost for a period of up to 1-4 hours.

Dynamos
Both the Megaflo cylinders and Dimplex storage heaters were installed with a VCharge Dynamo 2-T controller. The Dynamo was used to control the switching on and off of heating for curtailment mitigation. All electrical consumption through the devices was metered using the Dynamo's in-built metering chips.

The Dynamos were tested prior to installation to satisfy DNO, grid security and project eligibility requirements. The dynamos are fully 'Conformité Européene' (CE) approved, and compliant with the ‘Restriction of the Use of Certain Hazardous Substances’ (RoHS) in Electrical and Electronic Equipment (EEE) Directive.

Further details on how the dynamos played a role in the turbine and DSM load control architecture is provided in section 4.2.3.

4.2.3 VCharge curtailment mitigation control system

Communication and curtailment mitigation between the Rousay turbine and household heating devices was facilitated through a variety of VCharge technologies - namely a VCharge Supervisory Control and data acquisition connect devices (VScon), the VCharge cloud-based Aggregating Controller Platform (ACP), and the VCharge Dynamos.

The VScon forwards real-time turbine generation data (from the Enercon SCADA, Supervisory Control and Data Acquisition system) and the ANM status details (from the SGS Connect) to the ACP. The ACP determines when the turbine is approaching curtailment, and its algorithms determine what volume of heating load from participating properties need to be activated to prevent marginal curtailment.

Each property has a VCharge dynamo and hub controller that links the Dynamos to the Vcharge ACP via an internet connection. When the turbine is marginally curtailed the ACP sends commands to the VCharge Dynamos, introducing electrical demand on the system. The Dynamos both switch and meter DSM loads, reporting load status back to the ACP at minimum once a minute, and more frequently upon activity (like heater temperature increasing due to it being turned on). The VCharge system was designed to respond to a curtailment event with no minimum duration, such that the end-to-end response time of the VCharge system to a curtailment event was less than 1 minute.

The ANM system is agnostic, meaning it cannot tell the difference between turning the generator down, or additional load. The increased electrical demand from these heating devices thus prevents the network safety margins from being encroached, mitigating curtailment and increasing renewable generation. At the end of a curtailment event, the ACP deactivates the Dynamos. The charging of these secondary heaters during periods of curtailment results in heat being stored in the heaters. This can later be released to supplement the primary heating system when needed.

The VCharge Dynamo and VScon system were successfully tested at the Power Networks Demonstration Centre (PNDC), as part of the ACCESS project. This also included a trial of their performance and network impact while performing DSM services.

A summary of the VCharge controls and communication process is shown in Fig. 4.4.

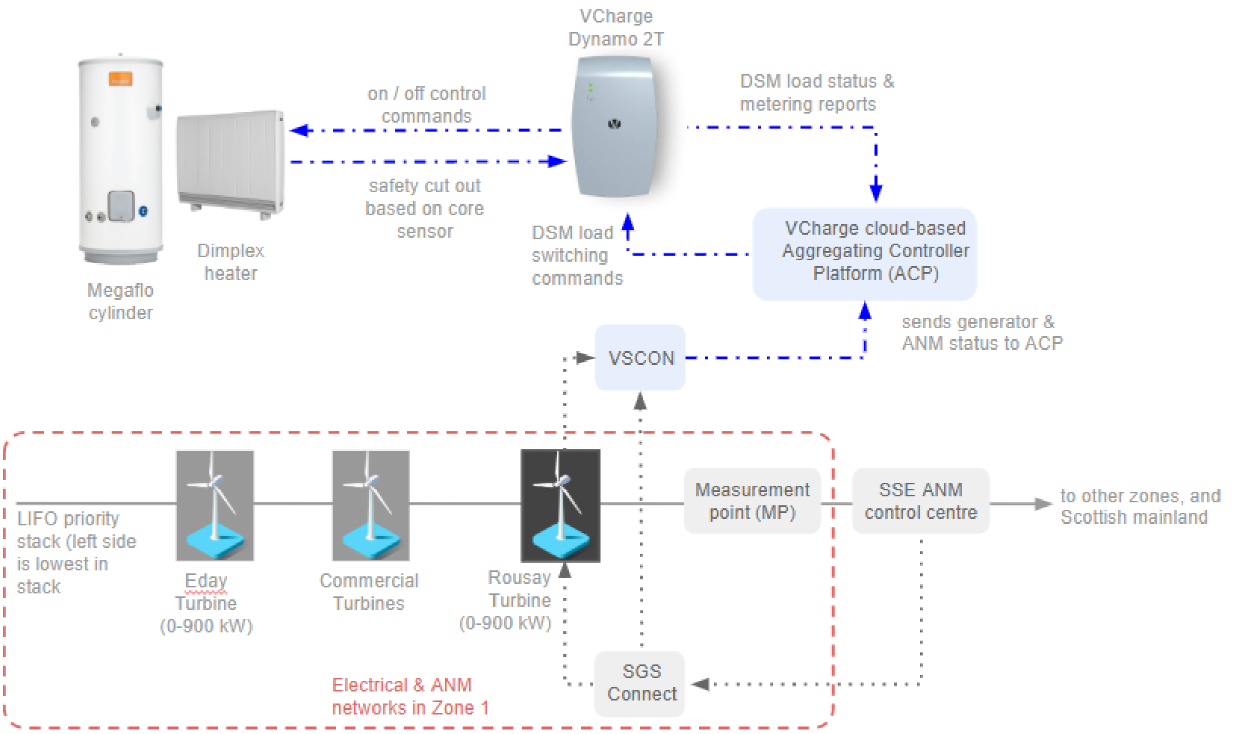

Fig. 4.4 *Illustration of the VCharge communication and control logic via VCharge VSCON with Rousay turbine ANM, VCharge Dynamo, and household storage heaters and water cylinders.*

5 Results

The Rousay turbine suffered roughly 93 MWh of marginal curtailment in 2018, and 40 MWh in 2019, based on data from the turbine's Enercon SCADA system. In addition to this, the HSO project is estimated to have avoided a further 15 MWh and 3.3 MWh of marginal curtailment which would otherwise have occurred in 2018 and 2019, respectively. This will have created £2,300 and £510 in additional generation payments each year.

Customer retention and satisfaction throughout the project were incredibly high - reaching over 98% retention, with only one of 72 households dropping out during the trial's Legacy phase. Customer surveys showed that ~ 1 in 4 customers reported a reduction in fuel bills, and felt their home temperature increase. In addition, 93% of customers felt that participating in the trial was valuable, with 78% believing the scheme has potential to tackle fuel poverty in the future.

Considering the system's effectiveness; of a maximum theoretical reduction in marginal curtailment of 67%, a 15% reduction was achieved in 2018 and an 8% reduction in 2019. The decline in 2019 resulted from communication issues throughout September - which unfortunately coincided with the month of greatest curtailment (>50%). Considering dispatch load efficiency (how much dispatched load coincided with marginal curtailment events), this was 74% in 2018, and 50% in 2019. This decline is primarily attributed to communications issues in the VScon.

The following sections (5.1 - 5.7) provide further details on the results from this trial.

5.1 The curtailment opportunity

The HSO scheme has been operational since spring 2018, during which operational data on turbine curtailment and load dispatch was continuously recorded by VCharge.

To provide background context for the system performance results (sections 5.2 and 5.3), this section introduces the "opportunity" for curtailment mitigation of the Rousay turbine, for the period 2018-2019. This includes the total device count and dispatchable load enrolled in the trial, together with the total system curtailment throughout the year, the proportion of marginal and full curtailment, and the monthly distribution of curtailment.

5.1.1 Installed devices and maximum dispatch loads

In 2018, across the 72 participating households, 113 individual heating devices were active (as noted in section 4.1.2). With an average per device load of ~2.3 kW, these were able to achieve a peak dispatch of ~250kW.

5.1.2 Curtailment over 2018-2019

Curtailment of the Rousay turbine has averaged ~80 MWh per year over the last four years. For the 2018-2019 period, during which the HSO project has been active, curtailment has overall been lower than in previous years - most notably, in 2019 (see Fig. 5.1). This has been due to other generators in zone 1 undergoing planned downtime for maintenance works in Q1 and Q2 of 2019. This resulted in a temporary drop in generation within zone 1, and thus a reduced stress on the grid, and hence a lower than usual constraint and curtailment of turbines within zone 1.

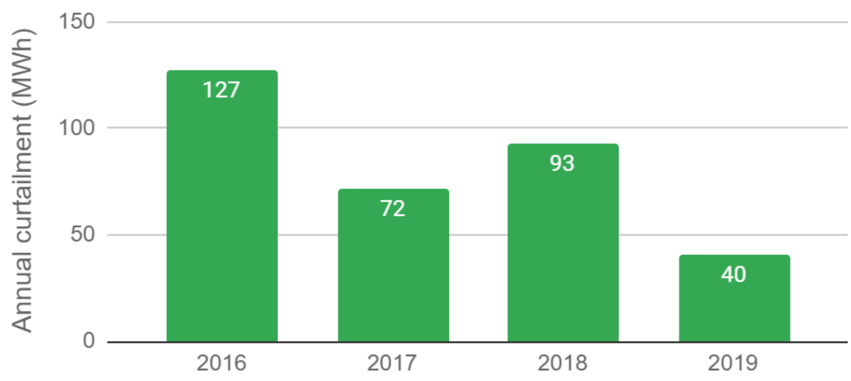

Fig. 5.1 *Total annual curtailment of the Rousay turbine from 2016-2019, based on data from the turbine's Enercon SCADA system.*

Focusing on the last two years, the proportion of operational time under curtailment has approximately halved in 2019, relative to 2018. The relative ratios of marginal curtailment to fully curtailed (2:7) have, however, remained the same. The proportion of time the Rousay turbine has spent in each curtailment state in 2018 and 2019 is shown in Fig. 5.2.

The HSO system can only dispatch DSM loads to directly benefit the Rousay turbine if it is marginally curtailed. If the Rousay turbine is fully curtailed, the benefit will be felt by turbines that are being marginally curtailed higher up the priority stack. Figure 5.2 highlights how over the last two years, the Rousay turbine has been marginally curtailed only 2-4% of the time.

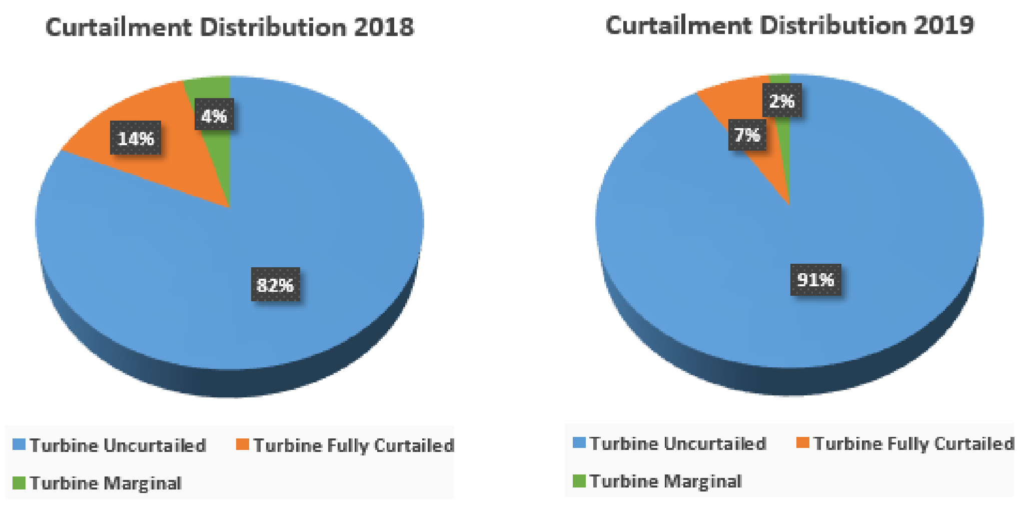

Fig. 5.2 *Proportion of curtailment states for the Rousay turbine in 2018 and 2019.*

As shown in Fig. 5.1, the total marginal curtailment experienced by Rousay in 2019 was lower than expected. Figure 5.3 highlights how the volume and duration of marginal curtailment was distributed throughout the year, on a monthly basis.

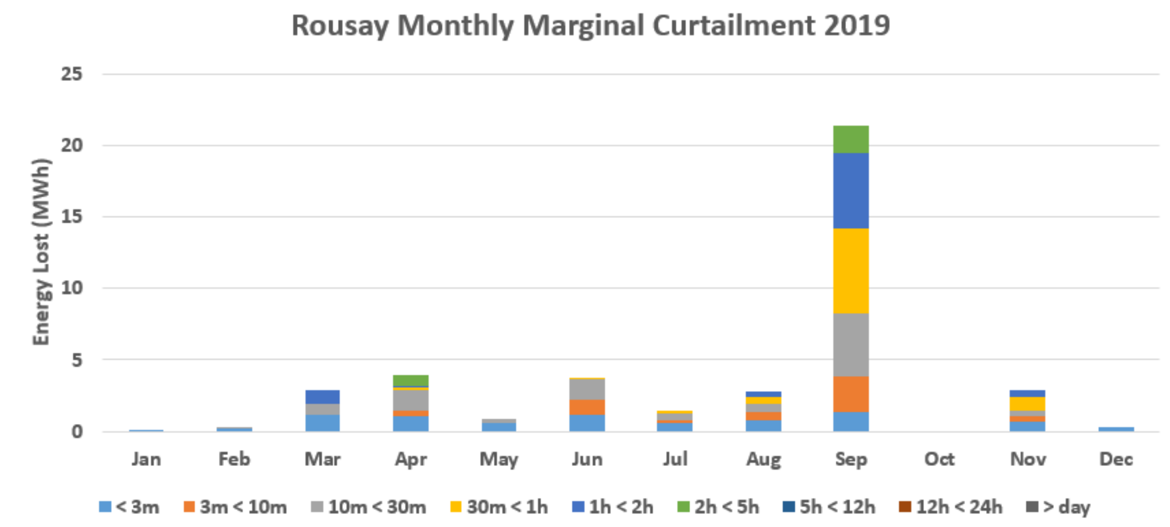

Fig. 5.3 *Distribution of marginal curtailment for the Rousay turbine, on a monthly basis in 2019.*

As a result of the low curtailment in 2019 - and in addition its skewed spread throughout the year - the HSO system spent significant periods of 2019 idle.

September showed significant curtailment volumes, equivalent to roughly half the total annual curtailment (~21 MWh). Unfortunately, this was not captured by the HSO system and translated to DSM load, due to a communications issue with the VScon. This was resolved in October.

5.2 Curtailment mitigation system effectiveness

Over the course of the scheme, CES conducted two independent analyses of system performance. The results were used by VCharge/Kaluza to inform system optimisation, with analysis being conducted over the operational periods covering Q2-Q4 in 2018, and Q3-Q4 in 2019.

These Analyses of system performance and effectiveness excluded the periods Q1-Q2 2019. Instead, during Q1-Q2 2019 the project partners conducted a series of load tests on the Rousay turbine, rather than normal operation. This was due to the expected low curtailment over this period, resulting from the planned maintenance of other generators in zone 1. [1]

This section provides an overview of the system performance, specifically covering: an illustrative demonstration of curtailment events, the annual volume of DSM load dispatched, and the system efficiency in matching load dispatch to curtailment. The results provided in this section are based on analysis conducted by CES, with some support from Kaluza (formerly VCharge). Further details are provided in the original CES FACT reports in the Appendix.

1 Note, these Q1-Q2 2019 exclusions mean that the data collected during this period obscured the system performance measurements due to the load tests on the Rousay turbine. As a result, the figures provided from the VCharge system for curtailment mitigation (Fig. 5.5, Fig. 5.7) add up to a slightly lower total than the annual curtailment figures provided from the turbine's SCADA Enercon system (introduced at the start of section 5, and presented in Fig. 5.1).

5.2.1 Demonstrating response to curtailment

One of the core objectives of the project (section 3.2, objective A) was to provide electrical demand that addresses fuel poverty, adjacent to an actively-managed renewable energy source. Figure 5.4, below, demonstrates the deployment of heating load to the HSO devices, in response to curtailment events from the actively-managed Rousay turbine - from March-October 2018.

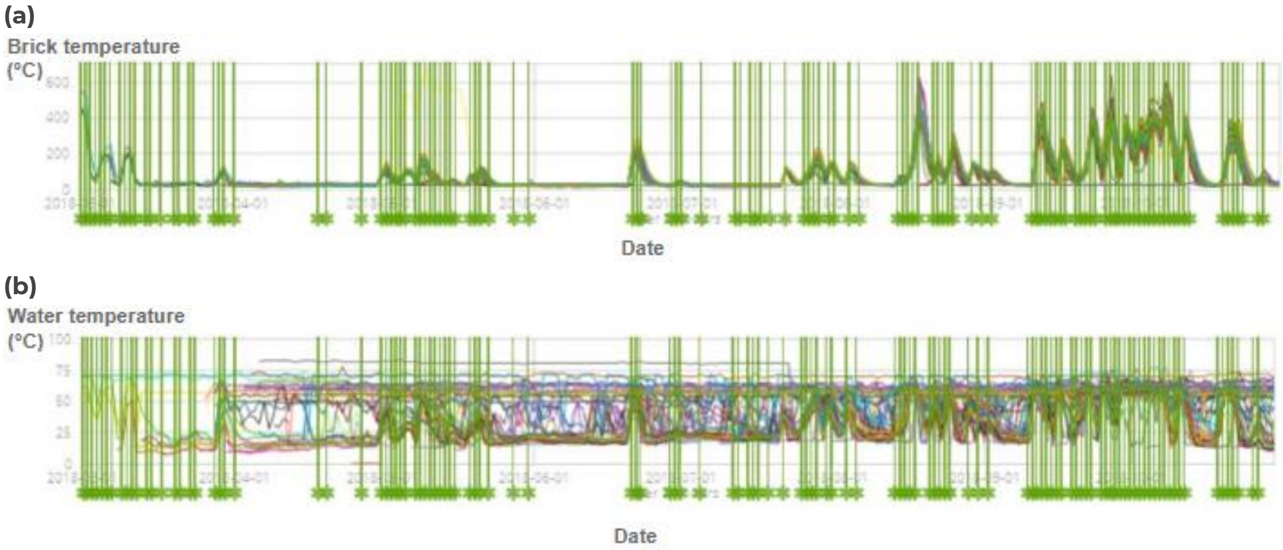

Fig. 5.4 *Snapshot demonstrating the DSM device portfolio response to curtailment events between March - October 2018. For both (a) and (b), the vertical green lines denote unique curtailment events over time; the coloured lines over time denote the DSM device temperatures over time.* ***(a)*** *brick temperature in Dimplex DSM devices,* ***(b)*** *water temperature in DSM Megaflo devices.*

The chart shows that at the onset of curtailment events, brick temperature in the Dimplex storage heaters and water temperature in the Megaflo heaters is elevated. This validates that the project has delivered a measurable, verifiable and statistically significant electrical demand, with supplementary heating to participants' homes. Further, this additional heating provided through mitigated curtailment has delivered rebate payments to participating customers, and increased the energy production (and thus PPA payments) from the community-owned Rousay turbine.

5.2.2 Curtailment mitigation system effectiveness

The effectiveness of the HSO system for mitigating curtailment can be measured based on the following metrics: (i) the efficiency in correctly detecting marginal curtailment, and matching this with DSM load, and (ii) the efficiency in only dispatching DSM load during periods of true marginal curtailment.

Efficiency in detecting marginal curtailment, and matching with DSM load

The ability to fully match detected marginal curtailment with DSM load is not only limited by accurate detection of marginal curtailment, but also by the total DSM load (in kW and kWh) that can be dispatched, and the efficiency of the load dispatch algorithm.

As outlined in section 5.1.1, the peak dispatchable load across all installed HSO DSM devices was ~250 kW. In comparison, the Rousay turbine has a maximum output of 900kW and an average constraint level of 366kW. Fully efficient (100%) mitigation of all marginal curtailment was thus not achievable, as constraint levels would sometimes exceed the maximum load available. Instead, the theoretical maximum efficiency achievable was around 68% (250 kW / 366 kW), based on the average turbine constraint level. In practice the maximum achievable efficiency will be significantly lower due to constraints in: the thermal capacity of heating systems; residents' actual heating needs; periods with different turbine constraint levels; and system downtime created by communications errors (at individual heaters, or between the heaters and the turbine).

The chart in Fig. 5.5 summarises the states of marginal curtailment mitigation for 2018 and 2019. These states are categorised as either (a) detected and not mitigated, (b) undetected and not mitigated, (c) detected and mitigated.

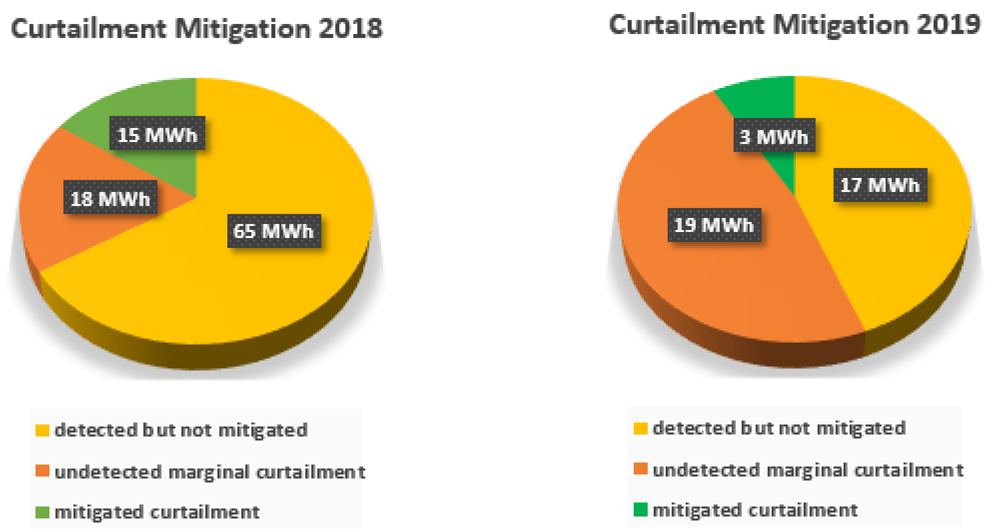

Fig. 5.5 *Marginal curtailment categorised by undetected, and detected mitigated or unmitigated load, for the Rousay turbine in 2018 and 2019, based on data from VCharge.*

Figure 5.5 shows that of a total calculated 98 MWh marginal curtailment in 2018, 15% (15 MWh) was mitigated, with 83 MWh remaining as marginally curtailed. This dropped to 8% in 2019 (3 MWh, of a total calculated 39 MWh), with 36 kWh remaining marginally curtailed. This decline in system response is attributed to a growth in undetected marginal curtailment (increasing from 18% to 49% from 2018 to 2019).

We have identified reducing undetected curtailment as the first step towards increasing the efficiency of load and curtailment matching. If undetected curtailment were eradicated, matching efficiency would have been 19% in 2018 and 15% in 2019.

Undetected curtailment arises when communications are down between the VSCON device and the main VCharge control system. We believe that the two main causes of undetected curtailment have been:

a) Communications issues with the VSCON, and
b) Downtime on the BT private wire used by the VSCON to export data

The increase in undetected curtailment in 2019 compared to 2018 largely arose from communications issues between the main system and the VScon device, in September. During this time, the VScon did not pass on any curtailment information from the turbine.

This unfortunately coincided with 2019's month of highest curtailment for Rousay (~21 MWh curtailment, ~53% of annual curtailment - see Fig. 5.3), exacerbating the issue.

Action is being taken to address both issues. Kaluza has developed a second generation VScon, which has been deployed in Rousay and Eday. Meanwhile, a more robust communications link has been commissioned to replace the BT private wire, which posed a lightning risk to the control equipment. Should both measures prove effective, we hope that undetected curtailment can be reduced below 5%; although early indications show some communications errors appearing to persist.

CES and Kaluza are also working on improvements to the load dispatch algorithm, which may be required to achieve further increases in curtailment matching efficiency.

Dispatch load efficiency

An alternative measure of efficiency can be found by examining how much dispatched load is directly matched to a curtailment event.

Load dispatch that was not matched to a curtailment event fell into two main categories, which were labelled "overspill" or "zombie" loading:

- Overspill occurred when loads stayed on for a short time after curtailment events finished.
- Zombie loading occurred when small numbers of loads were activated (often for long periods of time) at times when no marginal curtailment was detected.

Zombie loading was not expected, and assumed to be undesirable; but an overspill of circa 10% of total dispatched load may help to maintain hysteresis on the system. Thus the project partners had hoped to achieve ~90% dispatch efficiency. Figure 5.6 presents the load dispatch in 2018 and 2019, categorised as either matching curtailment, overspill, or "zombie" load.

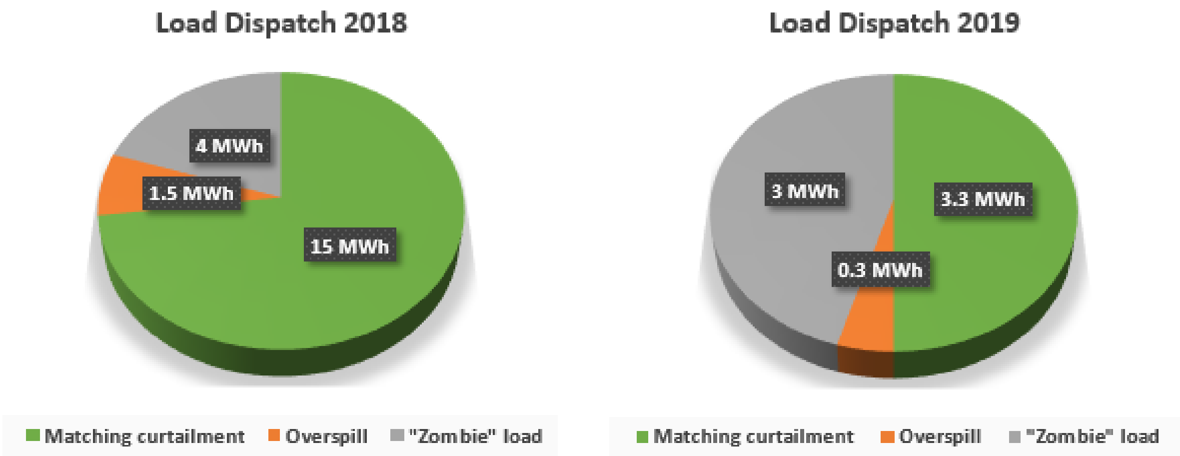

Fig. 5.6 *DSM load dispatch categorised by load matched to curtailment, overspill, and "zombie" load, for the Rousay turbine in 2018 and 2019.*

Considering Fig. 5.6, a total load of 20.5 MWh was dispatched in 2018, and 6.6 MWh in 2019. In 2018, 74% dispatch load efficiency was achieved, falling to 50% in 2019 - corresponding to 15.1 MWh and 3.3 MWh of avoided curtailment, respectively. This reduction in dispatch efficiency was driven by similar volumes of "zombie" load, combined with the low levels of curtailment in 2019.

Ignoring zombie loading, the target of 90% load matching curtailment was achieved in both 2018 and 2019. Thus, pinpointing and eliminating the cause of "zombie" loading was identified by project partners as the key task required to achieve dispatch load efficiency. A number of possibilities were examined, including poor communications and inaccurate data reporting. At the time of writing, it appears that a significant proportion of "zombie" loading may in fact be attributable to customers using the 'boost' feature installed on storage heaters and immersion elements to override the VCharge controls.

Use of the override is not necessarily negative, as long as the customers in question understand that they will not be rebated for energy consumed in this way. Instead, it indicates that the new heating devices installed during the project, although intended as secondary heating sources, may be being used by some residents to provide primary heating.

Being outside of the control of the VCharge flexibility platform, use of the override function should not be taken to imply a failure of the VCharge dispatch algorithm. However, the fact that the platform cannot distinguish load dispatched due to a user override from load which may have been incorrectly dispatched by the platform impedes accurate reporting on system performance. Future projects should design data capture processes which include visibility of any user override functions, to avoid repetition of this problem.

5.2.3 Improvements to system effectiveness

Based upon system performance monitoring in 2018, the following three key recommendations were made to improve performance, to prepare for commercialisation:

1. ***Boost utilisation of the flexibility assets by incorporating additional turbine(s) into the system:***
    - adding turbines would increase the length and number of marginal curtailment periods during which the HSO system can act;
    - this would allow dispatch of more heating load and curtailment of more generation, without substantially increasing costs.

2. ***Improve reliability of the VScon link to the turbine:***
    - increasing VScon reliability would drive an immediate performance boost by removing or eliminating undetected curtailment;
    - systems operations and maintenance practices should be reviewed and improved to combat reliability issues.

3. ***Investigate non-communicating household devices and eradicate 'zombie' load, to eliminate dispatch of load outside of curtailment periods:***
    - operations and maintenance practices should be reviewed and improved to reduce dispatch outside of curtailment periods - specifically, by designing stronger failsafe controls, tighter monitoring and faster remedial action.

Significant progress has already been made on recommendations 1, with works beginning to incorporate the Eday turbine into the system, and the initiation of the TraDER project offering to significantly expand the reach of the system by facilitating delivery of services to any generator on Orkney (see section 6).

A solution is also underway for recommendation 2, with the design by Kaluza of a second generation VScon, and the installation of reliable radio communications to replace the BT private line at Rousay. Recommendation 3 has not yet been fully addressed, however early troubleshooting analyses by the CES and Kaluza teams have begun. This remains a priority for action.

5.3 Impact to the local distribution network

Core requirements of this project required technological solutions for grid-smart heat, that did not influence the load profiles of existing loads, and effectively decoupled demand side management from critical network management (objectives B, C - section 3.2).

Continued discussions with SSE throughout the trial demonstrated that as the project progressed, the grid could take the additional demands placed on it. The scheme's demand side management system was shown to work with no ill effects on the existing commercial arrangement of the Orkney ANM system, the load profiles of pre-existing load, and to not affect the national demand side management systems for off peak heating.

Further, in instances where significant DSM load was dispatched, HSO was not made aware by SSE of any negative impact to the ANM. This provides further evidence that smart switching and demand side management can work within the constraints of the Orkney ANM, pre-existing load profiles and not affect the grid for national demand side management systems for off peak heating.

5.4 Financial benefits realised through the project

Avoiding curtailment creates value for the local community by increasing generation and thus PPA and ROC payments, at ~ 15 p/kWh. Dispatching load via the HSO system involves a cost to the Rousay turbine. Until April 2020, average rebates of 5 p/kWh were paid to participating households to compensate for the cost of energy used at peak periods (see section 4.13).

Figure 5.7 summarises the revenue creation from curtailment mitigation over 2018-2019. Naturally, greater curtailment mitigation generated higher revenues for the community turbine (Fig. 5.7) - creating £2,300 in 2018, and £510 in 2019.

Continued future commercial viability of the project will require a substantial increase in net revenues - to account for maintenance, operational, and device installation costs that to date have been covered by project funding. As will be outlined in section 6, we propose that this can be achieved through scaling up the scheme, introducing additional turbines and new devices into the system.

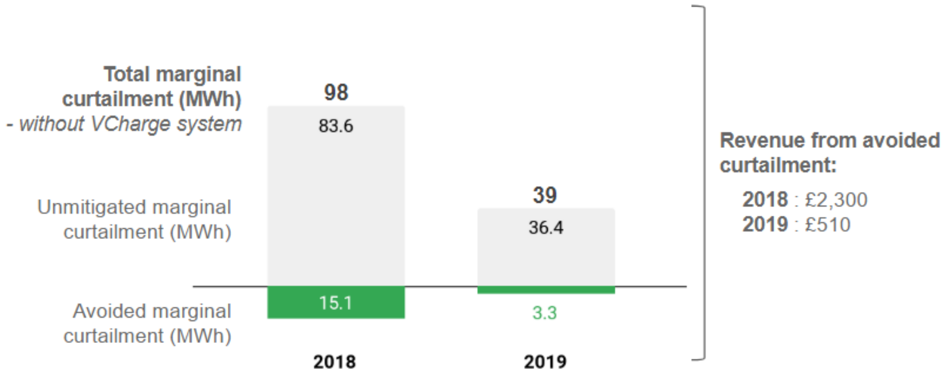

Fig. 5.7 *Summary of net avoided curtailment of the Rousay turbine through DSM loads, and associated revenue generation (at ~15 p/kWh) in 2018 and 2019. Curtailment data based on VCharge system data.*

5.5 Impact to the local communities

The final core objective of this project (objective D - section 3.2) was to: share knowledge and work with the existing collaborative consortium of grassroots organisations to address fuel poverty; to develop the well-being, resilience and self-sufficiency of the local communities; and tackle carbon reduction through reduced fossil fuel usage. This section outlines how the scheme has worked to meet these criteria.

5.5.1 Building a resilient self-sufficient community

The HSO Project has shared information, resources and built relationships with local grassroots organisations that work to address fuel poverty in the local community. These organisations include: Tackling Household Affordable Warmth (THAW) Orkney, Orkney Renewable Energy Forum (OREF) and Firefly Energi Orkney Ltd, all of whom work closely with the HSO project partner, CES.

These organisations are involved in customer education, tackling fuel poverty, carbon reduction, and promoting and developing innovative technologies that focus on an efficient, renewable energy system. Specifically:

- *THAW* - a charity that assists fuel-poor households in Orkney, to reduce levels of fuel poverty and achieve affordable warmth;
- *OREF* - forum aiming to address the strategic issues affecting Orkney's renewable energy sector, collaborating with local communities, businesses, and Orkney's world-leading academic and research organisations;
- Firefly Energi - provides free energy efficiency advices and installation of energy efficiency measures by qualified installers

5.5.2 Carbon savings

As outlined in section 4.1.2, of the total 72 properties recruited, only 19 households (26%) solely used electricity for their hot water and heating needs, with 53 households (74%) relying on fossil fuels. Heating oil generates ~3.0 kg CO_2 / litre of oil, coal generates ~3.3 kg CO_2 / kg of coal, calor LPG generates ~0.8 kg CO_2 / kg LPG.

Over the course of the HSO scheme, the use of electricity amongst participants increased by 46% to 27 households (38% of properties). Throughout the trial period, fossil fuel usage fell, and electricity consumption grew - with oil consumption dropping by 13,000 litres, solid fuel by 220 kgs, calor LPG gas by 428 kgs, and electricity rising by 68 MWh.

These carbon savings from reduced fossil fuel emissions are in addition to the increased renewable generation delivered by the scheme through reduced marginal curtailment of the Rousay turbine (~18 MWh over 2018 and 2019).

Whilst the scheme only directly supplied ~18 MWh of load through mitigated turbine curtailment, electricity consumption grew by a further ~40 MWh. This dramatic shift in energy consumption trends suggests that the trial has encouraged behavioural changes amongst participating customers. Without considering the increase in renewable energy generation, over the 2-year trial period ~40 tonnes of CO_2 were saved through a reduction in fossil fuel consumption alone.

5.5.3 Financial incentives

Between April 2018 – May 2019, HSO paid out £11,942.59 in total financial incentives to participants of the scheme. This included:

- £4,150 in initial sign-up payments to participating households
- £7,100 in additional payments to participating households that remained for the full duration of the scheme
- £692.59 in electricity rebates

5.6 Customer experience

Successful continuation and development of the HSO project into the legacy phases and beyond, will not only require well-designed technology solutions, but also backing from participant households and a strong reputation for delivering a quality service.

This section reports the customer retention figures throughout phase II and the start of the legacy phase of the trial, together with the insights received from customer surveys.

Please see Appendix 9, 9.1 for more information on Customer experience, end of project questionnaires and survey results

5.6.1 Customer recruitment and retention

Customer recruitment and retention have remained consistently high throughout the duration of the trial. Of 189 initially targeted households, 78 were invited to participate (41%), of which 72 were enrolled (38%). A 100% customer retention rate was achieved during Phase II, with no dropouts from the 72 households.

Once phase II had ended and the project entered the Legacy phase, only one household dropped out - bringing the total customer count to 71 households, and a 98% retention rate.

Although a 38% acquisition of targeted customers was deemed successful, some challenges were encountered in the recruitment of households, notably:

- householders did not want disruption to their homes by contractors;
- competition from an alternative heating supplier with a funded project, who offered some households installation of a complete home-heating system - rather than standalone, secondary heating units (this accounted for 3 declines to the project);
- unmet client expectations;
- prospective householders thought the offering was “too good to be true”;

- some households engaged with HSO as a learning opportunity, rather than actively seeking admission to the scheme; and,
- recruiting solely from the islands of Rousay, Egilsay and Wyre was not possible, and participants were sought from some of the northern islands.

5.6.2 Customer survey results

At the end of the trial, all participating households were invited to complete a survey of their experiences on the trial - ranging from their experiences with HSO and contractor staff, the perceived impact of the project to their finances and comfort, and their overall opinion of the trial mission. Out of the total 72 households participating in the trial, a high turnout of 43 households (~60% of customers) took part in the survey.

Overall, the customer results were incredibly positive - highlights being:

- over 90% of responses awarded HSO and RS Merriman staff the highest score possible for customer service across 3 in 4 areas surveyed;
- 23% of customers reported a reduction in fuel bills, and 13% a reduction in fuel use;
- roughly 1 in 4 customers felt their home temperatures increase, and 1 in 3 reported boosting their heaters less frequently;
- 93% felt that participating in the trial was valuable, with 78% believing HSO has potential to tackle fuel poverty in the future.

Whilst customer response was very positive, the wish for a greater volume of curtailment was expressed by several households. This would have boosted their rebate payments, and increased the size of the benefit passed on to participants.

The results of the customer survey are presented in Figures 5.8, 5.9 and 5.10. Figure 5.8 summarises customers' experiences with staff from HSO and the installation contractors from RS Merriman's. Figure 5.9 summarises customer perceptions on the impact of the project to their household energy bills, their comfort; Figure 5.10 summarises customer opinions on the overall project mission. The following sections will cover the key results obtained from the customer surveys. Full details on the surveys and customer feedback are provided in the Appendix.

Customers were surveyed on their experiences with HSO and RS Merriman across several categories:

- quality of service provided;
- problem resolution;
- staff knowledge;
- communication;
- whether staff were professional; and,
- whether installations were successful on the first attempt.

Overall, customer experiences of both HSO and RS Merriman staff were incredibly positive - with over 90% of responses awarding the highest score possible to 6 in 8 questions, with over 75% of responses awarding the highest score for the remaining 2 questions.

These lowest scoring areas related to HSO's processes for addressing issues, and whether installations were successful at the first attempt. Written feedback on these lower-scoring topics highlighted: challenges in identifying water cylinders that fit into existing cupboards;

slow responses due to delays from project partners; delays in setting up the hot water; water leaks following installation; and communications issues with a heater.

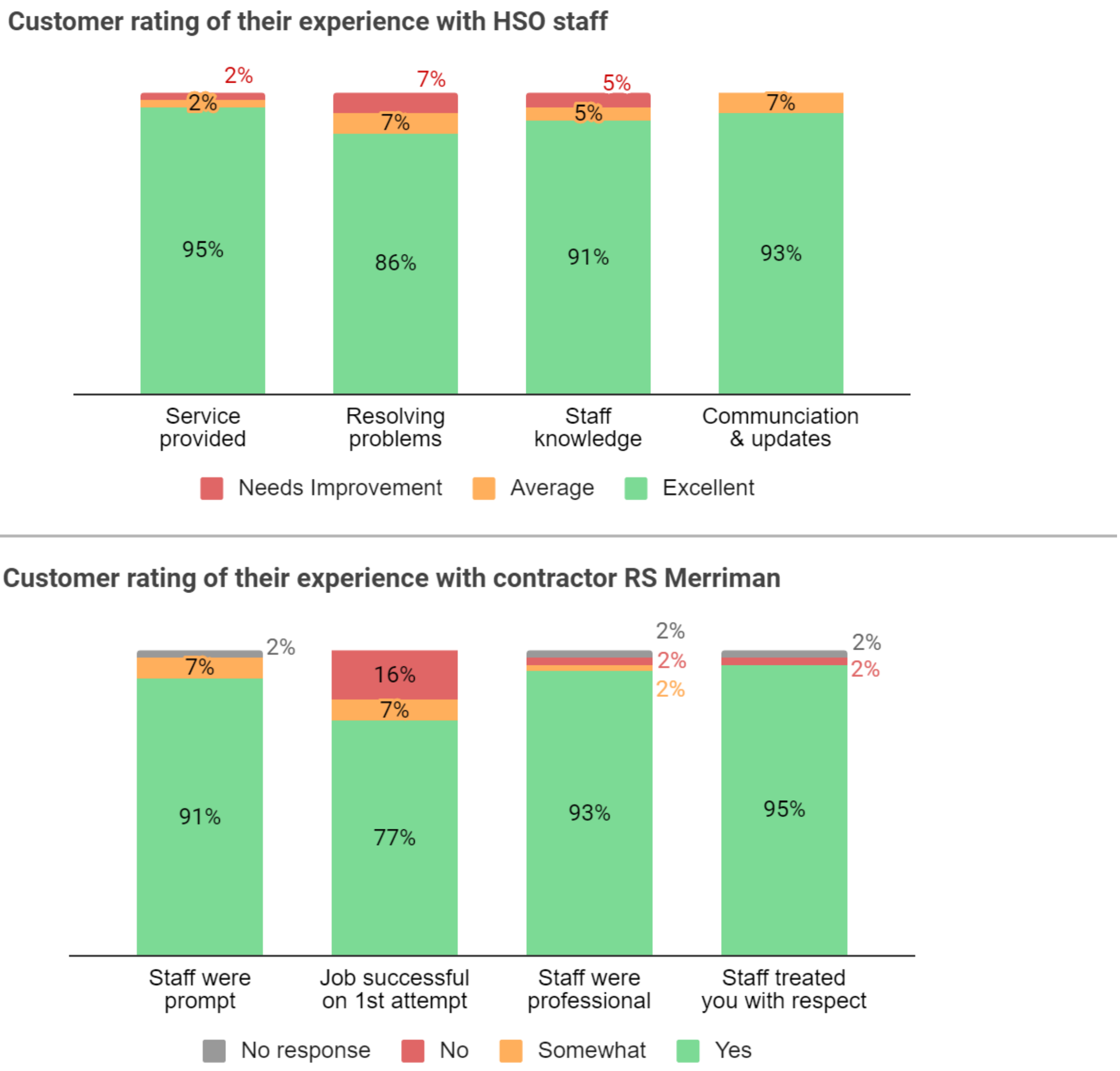

Fig. 5.8 *End of trial customer survey results - customer experiences of HSO staff and the installations contractor RS Merriman.*

Customers were surveyed on the perceived impact of the HSO scheme on their finances and levels of comfort within the house, including:

- how household heating expenses changed;
- how fuel consumption changed;
- whether HSO rebates and £150 bonus payments covered all expenses incurred;
- how comfort levels in the home changed;
- whether customer patterns around boosting their hot water have changed; and,
- whether customers understand how to use their heater.

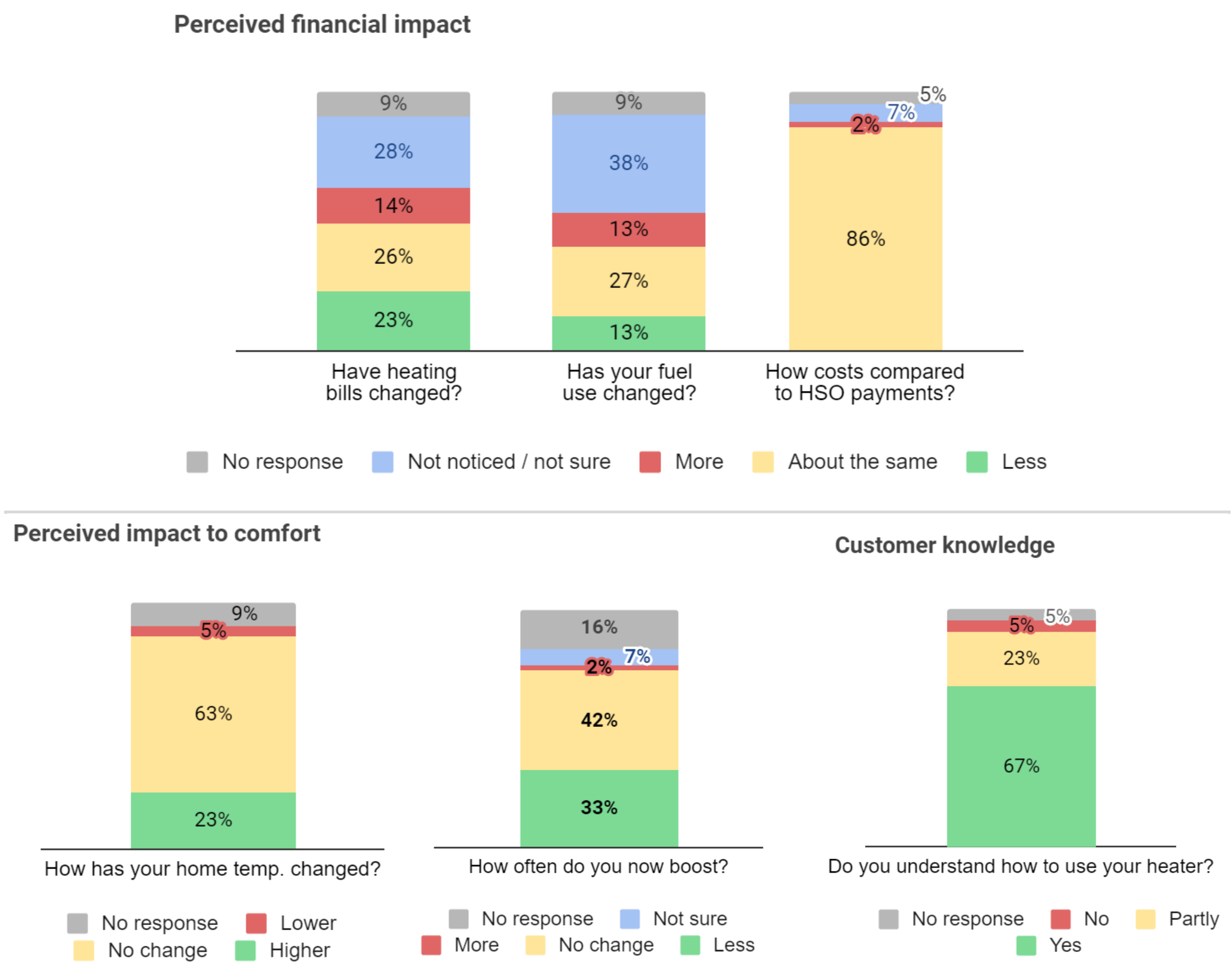

Fig. 5.9 *End of trial customer survey results - perceived financial impact of the trial, perceived impact to comfort, understanding of how to operate the heaters, and opinions on the HSO project mission.*

Considering first the project's financial impact, customers primarily reported either not noticing, not being sure of, or observing no impact to their finances. This result was seen across 54% of customers' heating bills, 65% of customers' fuel use, and 93% of customers' views on how costs compared to HSO payments. An impressive 23% of customers reported their heating bills declined, and 13% stated their fuel consumption declined - an illustration of how such technology can work to combat fuel poverty.

A small proportion of customers instead reported increases in fuel expenditure - 14% reported increases in fuel bills and 13% reported increases in fuel consumption, with 2% reporting that HSO payments did not cover costs incurred. For one customer (of six) who stated their fuel bills increased, they commented that this was "*because*... [they]... *didn't have a heater/boiler before*".

It is not fully clear what caused the remaining increase in bills and fuel consumption. The project's heating units were advertised as secondary heating sources. It is expected that in some cases, customers were either boosting their devices, or using these as primary sources. As highlighted in section 5.2.2, boosting could not be detected in this iteration of the data capture process. It is recommended that future projects should design data capture processes which include visibility of any user boosting.

Next considering the project's impact to customer comfort in the home, most customers reported feeling no change in room temperature or boosting habits. Impressively almost a quarter of customers reported an improvement in home temperature, with a third decreasing boosting frequency. This is surprisingly high, considering the low curtailment volume experienced by Rousay in recent months. Only 5% and 2% of respondents reported a decline in home temperature and boosting behaviour.

As for customer knowledge, Fig. 5.9 highlights how only 67% of customers fully understood how to use their heating systems. This is an area for improvement suggesting a greater emphasis could have been placed on customer education during installations.

Negative written feedback on the areas covered in Fig 5.9, commented on:

- rebate payments were modest due to limited curtailment;
- challenges due to an electric heater not working;
- a desire for greater heating from curtailment;
- surprise at requiring to modify existing heating systems, and equipment being larger than expected;
- water temperature being too hot.

Lastly, customers were surveyed on the project mission (Fig. 5.10), covering whether the project has potential to, and already has, addressed fuel poverty; the value of community-focused start-ups; and the value of participating in trials like HSO.

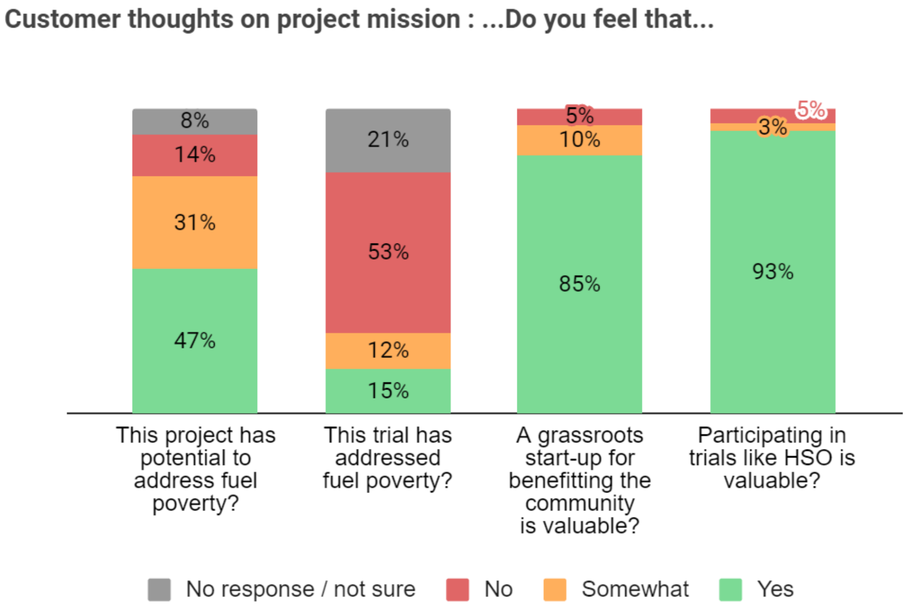

Fig. 5.10 *End of trial customer survey results - opinions on the HSO project mission.*

Again, customers gave overwhelmingly positive responses - particularly in the topics covering the value of a community start-up, and participating in such trials.

When asked about HSO's ability to tackle fuel poverty, 27% of customers felt that to date the trial had either addressed or somewhat addressed fuel poverty, while 53% of customers felt that fuel poverty was not yet addressed. Where provided, customer reasons among this 53% centred around insufficient evidence over the short trial period and the uncertainty around the volume of curtailment a turbine could experience. Although 53% of customers felt the trial had not yet addressed fuel poverty, some respondents commented that they felt there was scope for this to improve in future. Where customers provided a reason for answering "No", these are provided below:

- *"It needs longer to prove fuel poverty [...has been addressed...] this way"*
- *"Not in this first period"*
- *"Not yet, but I think it will come"*
- *"No, but making progress"*
- *"No, curtailment is uncertain"*
- *"Not sufficient curtailment"*
- *"Not by what we received from the turbine"*

Looking forwards, 78% felt that the project showed potential to tackle fuel poverty, given HSO's future plans.

5.7 Learnings from project implementation

In implementing this type and scale of project for the first time in Orkney, numerous operational learnings were made - ranging topics from customer engagement, logistical, and commercial pricing decisions. The most pertinent points are documented herein, with further detailed items provided in the Appendix.

Implementing a novel technology on a remote island

Developing and implementing innovative technologies at a pilot scale led to hurdles in the early stages:

- the specialised skills required to deliver the required technical surveys proved challenging - particularly in a remote island community with a small workforce;
- connecting to the ACP with a novel technology product (that was new to the UK market, and that still required to meet UK certification standards), introduced some initially unexpected delays

Rebate system

The manual process of determining household rebates (see section 4.1.3) proved inefficient and time consuming. This is an area the HSO Ltd team are looking into streamlining before the project is brought to further scale.

Media engagement

Various media outlets were used to engage participants and the community, including:

- Orkney Radio – CES gave a brief project outline on the local radio;
- Facebook – the HSO account was invaluable in reaching customers in the outer northern islands, who gave regular updates and information on any issues arising;
- Community Councils and other Development Trusts – relevant organisations in the catchment area were contacted and sent information packs to with an offer to visit and present. This received little interest, proving ineffective for engagement;
- REW Review – local monthly newsletter, with advertising space for events in Rousay, Egilsay and Wyre.

Customer education
One of the main points of clarification that arose from PO visits were the lack of understanding prospective householders had about their electricity tariffs and how much they were spending on electricity bills.

In turn, an unexpected role of the PO visits was in educating customers about the information provided on their bills - their tariffs, explaining dual tariffs and off-peak times, and highlighting any discrepancies in their bills with referrals to Ofgem and THAW (The Heat and Warmth Fund, an Orkney-based charitable foundation).

Wi-Fi challenges
If further, new installations were to be completed, we would recommend that Wi-Fi signals are tested throughout all areas of the property, during the Technical Assessments. This is to ensure that the Wi-Fi signal and broadband speed are not distorted by the thickness of walls, and distance between the broadband hub and the Dynamo.

Additionally, some households noted that the amount of data they were consuming increased upon connection of the Dynamo. This issue was rectified by VCharge.

Installation challenges
Installing, for the first time, a portfolio of new devices across the REW Islands presented the HSO team with challenges. These are detailed in the Appendix.

6 Future of the HSO trials

Throughout phases I and II of the scheme, the HSO project has demonstrated on numerous occasions that it can mitigate marginal curtailment through demand side management - without having a negative effect on the grid infrastructure, and alongside pre-existing grid loads and off-peak heating demands.

The legacy and future phases of the project must go beyond this - becoming a commercially-viable and scalable solution, that can be translated across numerous generators in the Orkney Islands.

This section outlines the HSO project's plans in the coming Legacy year and the scheme's projected earnings if it were to be built at scale. An introduction to an independent project - Project TraDER - is also provided. As of 2020, TRADER has built on HSO and incorporated its DSM assets to prove the technical capability for household devices to respond to network signals and manage grid congestion.

6.1 The Legacy phase

The legacy phase of the scheme seeks to demonstrate that the concept can both generate sufficient income to cover operational costs, and begin to integrate other generators within Zone 1 of the Orkney grid.

By targeting the generator behind and in front of Rousay in the priority stack, the volumes of marginal curtailment the scheme can access will increase. This will: allow devices to charge for longer, reduce customer bills and demands on fossil fuels heating, increase renewable generation - and ultimately, increase PPA and ROC payments to the community-owned turbine. Works to integrate the Eday turbine are already underway (section 5.2.3).

To meet the objective of the Scottish Government's LECF award, HSO aims to increase their portfolio size to 500 households over the next five years. The aim is to eventually provide over 50% of participating households' heating and hot water needs through HSO devices.

The legacy phase of the project will continue to build on the scheme's existing successes and partnerships:

- 71 of the original 72 households recruited have decided to remain involved in the scheme during its Legacy year;
- REWDT have allowed HSO Ltd to continue using its assets in the legacy phase - allowing the technology to be further developed, build further evidence of the technology in action, and promote the solution to other generators in Zone 1;
- REWIRED will demonstrate how the smart-switching of installed DSM load has increased generation during marginal curtailment events, providing data on the additional energy generated and income produced. REWIRED will also cover the remuneration of rebates;
- CES will play an active role in ensuring the technology developed is operated effectively and efficiently, providing the necessary data to recruit other generators in Zone 1.

A long-term goal is to extend the business model to other zones within the Orkney grid. The business plan and projected costs and earnings for this scenario are detailed in section 6.2.
Looking beyond the standalone goals of the HSO project, this scheme has had an impact that has been far wider reaching - it has created the foundations on which the Smart Islands Energy Systems (SMILE) and Responsive Flexibility (ReFLEX) projects have been built.

SMILE makes use of marginal curtailment from the RE&W community turbine, and uses the switching and DSM systems developed for HSO to power local primary heating systems. ReFLEX similarly has built on HSO's foundations. It aims to increase renewable generation, flexibility and diversity of the Orkney grid by mitigating curtailment through smart charging of domestic energy storage devices - such as electric vehicles, electric bikes, and Tesla home batteries. The HSO Ltd team are working closely with the SMILE team - supporting customer engagement efforts, and sharing learnings from HSO's own implementation.

6.2 The Legacy business plan

To date, the HSO project has operated as a small-scale pilot trial, dependent on external funding. Analysis of the earnings opportunity of this project at-scale expects break-even to be achieved with roughly five turbines and 800 heating devices (equivalent to ~500 households, based on an existing ratio of 1.7 devices per participant household).

It is expected that with inclusion of additional turbines and devices, both the ability to mitigate marginal curtailment increases (as system efficiencies increase), and unit costs associated with integrating turbines and devices will fall, due to their economies of scale.

The following sections explore: the underlying assumptions in the business modelling (6.2.1), the scale of the opportunity available in Orkney (6.2.2), the expected revenue stream (6.2.3), the costs breakdown (6.2.4), and details on the projected earnings at different scales (6.2.5).

6.2.1 Assumptions

The business model assumptions for the HSO scheme at-scale are documented herein. Further details on the assumptions in the projected costs are provided in section 6.2.4.

Time value of money

The time value of money is not considered in this analysis. Earnings have been calculated on a per annum basis, with the expected costs and revenues at present value. Accordingly, inflation, costs of depreciation of assets, and amortisation of intangible assets have not been included.

The cost of an asset over its lifetime has been crudely estimated by linearly spreading any capital expenditure over the expected asset lifetime, expressing the investment as a fixed cost per annum (i.e., total CAPEX / asset lifetime years).

Customer segment, and heating device types

It is assumed that heating devices that are integrated as DSM loads are existing, primary heating sources within Orkney households. An upper bound of ~10,000 households across Orkney is considered (in line with the 2018 National Records of Scotland).

As pre-existing devices purchased by homeowners, their initial capital, installation and maintenance costs are assumed to not be covered by the HSO scheme. Only the capital, installation and maintenance costs associated with retrofitting a Home Hub device are considered (Home Hubs are required for connecting devices to the Kaluza ACP - similar to the original VCharge Dynamo, but newer and cheaper).

Further, these household DSM heating devices are expected to have similar specifications to the immersion and Dimplex heaters used in the HSO trial to date - that is, with an average load of 2.3 kW, and an average of 1.7 devices per household.

Revenue opportunity

All revenues are assumed to originate from mitigated curtailment. The size of the revenue opportunity is based on the volume of curtailment (MWh) that can be mitigated by dispatching to integrated DSM devices, as per the existing HSO system.

The opportunity size is considered based on the total system curtailment across Orkney's 23 wind turbines, over the past six years. From this, an average annual curtailment volume per turbine of 1.0 GWh has been identified (equivalent to an average 0.11 MW curtailed output per turbine, spread evenly across the 8,760 hours per year). For each additional turbine added to the HSO scheme, a further 1.0 GWh of annual curtailment volume is added to the opportunity (as per the average turbine).

This value of 0.1 MW average curtailment per turbine is used as a boundary point to assess what portion of curtailed power can realistically be diverted to DSM load at different device counts. Specifically, this is used for identifying the limiting device count for varying turbine counts (the minimum number of devices required to accept all mitigated curtailment based on their device power).

The system efficiency in detecting and dispatching DSM load during curtailment events is assumed to be imperfect, but which improves with the inclusion of additional turbines. Namely, this system efficiency is assumed to lie at 50% for up to 5 turbines, 75% for 6-15 turbines, 85% for 16-20 turbines, and 90% for 21-23 turbines. This haircut to the revenue opportunity is included to reflect both: (i) the improved awareness of the turbine ANM status across the full priority stack, and (ii) the access to greater curtailment volumes, that will both arise as more turbines in the stack are integrated in the HSO system.

The maximum volume of mitigated curtailment that a single device can accept is assumed to be 2.9 MWh p.a., based on an average 2.3 kW device, operating for up to 7 hours per day (based on a typical E7 tariff window for storage heaters), and 365 days a year (5.9 MWh). A further 50% haircut is applied (resulting in 2.9 MWh p.a.), to reflect that the distribution of curtailment throughout the year is non-uniform and could at times far exceed the 0.11 MW and 1.0 GWh average per turbine figures, and thus may not be captured.

Turbines
All costs associated with turbine ownership (land rental, original capital investment, operational costs, maintenance costs etc.) are not included in the business model. It is assumed that these costs are covered by the original turbine owners, and their existing revenues from PPA and ROC payments.

6.2.2 The scale of the opportunity in Orkney

The Orkney system consists of 23 turbines with a total capacity of 24.3 MW, equivalent to an average capacity of 1.1 MW per turbine. Over the 2014-2019 period, total annual system curtailment averaged 2.6 MW, and thus 0.11 MW per average turbine. With 8,760 hours per year, this is equivalent to an average 1.0 GWh curtailed energy per turbine.

For reference, these average per turbine figures of 1.1 MW capacity turbines, with 1.0 GWh curtailed energy per year, are not dissimilar to those observed for Rousay (0.9 MW capacity, 0.4 GWh p.a. curtailed energy, over 2016-2019) and Eday (0.9 MW capacity, 0.6 GWh p.a. curtailed energy, over 2016-2018). This slight discrepancy arises from the averaging across the full Orkney system, and over different time periods. The underlying Orkney curtailment and generation data is provided in Table 6.1.

Table 6.1 *Orkney Islands total wind generation output and curtailment, 2014-2019*

	2014	2015	2016	2017	2018	2019	Average
Total Orkney output & curtailment							
Total system output, MW	6.6	8.2	9.0	10.2	9.9	7.8	**8.6**
Total system curtailment, MW	3.7	2.6	2.7	1.7	2.5	2.2	**2.6**
Per average turbine output & curtailment							
Energy output per turbine, GWh	2.5	3.1	3.4	3.9	3.8	3.0	**3.3**
Curtailed energy per turbine, GWh	1.4	1.0	1.0	0.6	0.9	0.9	**1.0**

6.2.3 Revenue

The revenue generated is assumed to originate solely from:

$$Revenue = Mitigated\ curtailment\ (MWh) \times Value\ of\ avoided\ curtailment\ (15\ p/kWh)$$

where the volume of mitigated curtailment is based on both the curtailment opportunity which varies with the number of turbines, and the DSM load dispatched to mitigate curtailment (i.e., the annual device consumption, varying with device and turbine count):

$$Mitigated\ curtailment\ (MWh) = Annual\ consumption\ per\ device\ (MWh) \times Device\ count$$

The curtailment opportunity per year is assumed as:

$$Curtailment\ opportunity\ (MWh) = Curtailment\ per\ turbine\ (1\ GWh) \times Turbine\ count \times System\ efficiency\ (50\text{-}90\%)$$

As outlined in the Assumptions (6.2.1), the system efficiency reflects the efficiency in detecting and dispatching load during curtailment events, ranging between 50-90%, depending on the number of integrated turbines.

The DSM load that can be dispatched is assumed to be equal for each device, and is calculated as follows:

The limiting device count (minimum number of devices required to accept all mitigated curtailment) is obtained from:

$$\textit{Limiting device count} = (\textit{Average turbine curtailment } (0.1\ MW) \times \textit{Turbine count}) / \textit{Device power } (2.3\ kW)$$

If the number of devices is below this limiting device count, not all curtailment can be mitigated and dispatched as DSM load. Similarly, if the device count is above the limiting device count, and the curtailment opportunity (MWh) over the device count is greater than the maximum annual consumption per device, not all curtailment can be mitigated. In both cases:

$$\textit{Annual consumption per device } (MWh) = \textit{Maximum annual consumption per device } (2.9\ MWh)$$

Instead, if the number of devices is above the limiting device count, and the curtailment opportunity (MWh) over the device count is less than the maximum annual consumption per device,

$$\textit{Annual consumption per device } (MWh) = \textit{Curtailment opportunity } (MWh) / \textit{Device count}$$

The maximum volume of mitigated curtailment that a single device can accept is assumed to be 2.9 MWh based on a 2.3 kW device, operating 7 hours per day, 365 days per day, with a 50% haircut applied - see section 6.2.1.

6.2.4 Costs

The following section outlines the fixed and variable costs associated with differing turbine and device counts, and the rebate costs to households.

Turbine-related costs

Fixed costs, which vary with turbine count include, on a per turbine basis:

- VScon capital investment - £300, over a 2-year lifetime
- VScon installation in Orkney - 2 days' x 1 contractor at £30/h, over a 2-year lifetime
- VScon installation (software developer support) - 2 days' x 1 FTE, at £60,000 p.a. x 1.4, over a 2-year lifetime (based on UK average software engineer cost, with scaling to account for true cost of hire)

Fixed costs, which do not vary with turbine count include:

- Software development costs - 2 months' x 1 FTE, at £60,000 p.a. x 1.4, over a 5-year lifetime
- HSO overheads - £90,000 p.a.

Variable costs, which vary with turbine count include:

- Software engineering support - 10% x 1 FTE, at £60,000 p.a. x 1.4 for one turbine, increasing by 20% for every additional turbine integrated in the system

Device-related costs

Fixed costs, which vary with device count include, on a per device basis:

- Home hub capital investment - £100, over a 5-year lifetime
- Home hub installation - 3 hours' x 1 contractor at £30/h, over a 5-year lifetime

Variable costs, which vary with device count include:

- Home hub maintenance - assuming 5% device failure rate, requiring 2 hours' x 1 contractor at £30/h, p.a.
- Kaluza ACP cloud platform operational costs - £22k p.a. for 100 devices, £45k p.a. for 1,000 devices, £112k p.a. for 5,000 devices, £224k for 10,000 devices
  (includes costs of Kubernetes orchestration system, Datastore database, BigQuery data warehouse, Azure cloud computing, Azure IoT hub, Kafka platform, Elasticsearch analytics)
- Software engineering support - 10% x 1 FTE, at £60,000 p.a. x 1.4 for 100 devices, increasing by 20% for every additional 100 devices

Rebate costs

The cost of rebates to households (for electricity supplied through avoided curtailment) has been factored in at 6 p/kWh.

Whilst to date, HSO has employed an average rebate of 5 p/kWh, this has been increased to 6 p/kWh by the HSO team from April 2020 onwards.

Costs associated with rebates were built into the business model based on the annual consumption per device, which varies with both turbine and device count (outlined in section 6.2.3).

6.2.5 Projected earnings and business readiness

Building on the revenue potential, costs, and assumptions outlined in sections 6.2.1 - 6.2.4, projected earnings before tax (revenue minus costs) have been modelled for the HSO system, for varying numbers of turbines and devices. We expect breakeven of the HSO scheme to occur with 5 turbines and roughly 800 integrated devices. Table 6.2 provides a more detailed breakdown of projected earnings at different scales.

Table 6.2 *Projected annual earnings (before tax) of the HSO scheme at scale - expressed in £'000s, for 1-23 turbines, and 100-10,000 heating devices.*

	Turbines					
Devices	**1**	**2**	**5**	**10**	**15**	**23**
100	£ (110)	£ (113)	£ (120)	£ (132)	£ (145)	£ (164)
250	£ (104)	£ (85)	£ (92)	£ (104)	£ (116)	£ (136)
500	£ (127)	£ (86)	£ (49)	£ (61)	£ (73)	£ (93)
800	£ (150)	£ (109)	£ 7	£ (5)	£ (17)	£ (37)
1,600	£ (212)	£ (170)	£ (46)	£ 144	£ 132	£ 112
2,400	£ (272)	£ (230)	£ (105)	£ 295	£ 283	£ 264
5,000	£ (466)	£ (424)	£ (299)	£ 128	£ 446	£ 755
10,000	£ (866)	£ (825)	£ (700)	£ (272)	£ 45	£ 857

As demonstrated in these projected earnings, as more turbines from the Orkney system are integrated (10-23 turbines), the HSO scheme not only breaks even, but begins to generate net earnings (ranging circa £10-850k p.a., depending on turbine and device count). With this revenue uplift, HSO could distribute earnings in various ways - increased rebate payments to participating households, providing financial support to the community-owned turbines, subsidising heating unit purchases costs for disadvantaged households, and investing in local community energy education programs or charities.

Note - Table 6.2 demonstrates how the earnings generated do not simply increase with device and turbine count. Whilst the curtailment (and thus revenue) opportunity is proportional to turbine count, devices can only capture the curtailment available. Continuing to add devices to the same turbine count, ultimately will not generate any new revenues, instead adding further costs, and thus no longer being profitable.

Achieving scale in device and turbine count through the HSO scheme will not escape its challenges. Expected challenges, risks, and strengths in HSO's business readiness to achieve scale are outlined below.

Challenges:

- ***Attracting new turbines to join the HSO scheme:***
  Challenges associated with generating interest from other turbines, including setting up new collaborations, and agreement to existing rebate structures.
  In particular, the third and fourth turbines to join after Eday are expected to not operate at profit - creating additional barriers to entry.

- ***Attracting new households to join the HSO scheme:***
  Challenges include recruiting households beyond the islands of Rousay, Egilsay and Wyre, for which HSO Ltd. has less experience through the trial to-date, and has fewer existing community networks.
  The business model at-scale assumes participant households have pre-existing electric heating. Per the 2011 census, ~30% of Orkney homes use electricity for their heating needs - limiting the expected pool of potential customers to 3,000 households (or ~5,100 devices, based on an average 1.7 heaters per house).

- ***Securing investment to scale:***
  Challenges associated with securing the investment required to scale the HSO scheme - particularly, in the initial scale-up stages before the scheme is profitable.

Risks:

- ***Assumed annual curtailment:***
  The business model is built upon Orkney's total system curtailment from 2014-2019. This is an estimate and not necessarily reflective of the true curtailment that will be experienced in future years. This introduces risk in either over- or under-estimating the revenue opportunity of the scheme at various scales.

- ***Competitive threats from similar projects:***
  The HSO project was a demonstrator, and predecessor of other similar projects aimed at mitigating curtailment - such as SMILE, and TraDER. If HSO were to scale, as is, it could face competitive pressures from these alternative projects.

- ***Operating in new Orkney network zones:***
  HSO has to date only operated in Zone 1 of the Orkney network. Expanding into new zones could introduce new complexities, such as due to different logistics

Strengths:

- ***Intangibles - HSO know-how***
  Over the past three years, HSO Ltd. has developed know-how in implementing a programme for curtailment mitigation through intelligently-controlled domestic heating. This know-how spans numerous areas including: processes for customer recruitment and engagement, device installation and logistics, the learnings from hindsight in project deployment, and building partnerships with the collaborators responsible for the technology development.

- ***Intangibles - HSO community trust***
  HSO has engaged with and built trust with its local community, relationships with local charities, and ultimately a trusted brand and reputation in the local area.

6.3 Project TraDER

At the time of submission of this report, all heating devices that were part of the HSO project continue to offer curtailment mitigation for the Rousay turbine under the aegis of Project TraDER.

Project TraDER brings together Community Energy Scotland (CES), CGI, EDF, Electron, Elexon, Energy Systems Catapult, Kaluza and Scottish and Southern Electricity Networks, alongside other key players in the emerging flexibility arena. The project aims to deliver a single access point to multiple energy services such as balancing, stability and network capacity, making it quicker and simpler for assets to provide these services.

The work of BEIS-funded project TraDER expands the success of Heat Smart Orkney and SMILE in proving the technical capabilities of consumer devices and responding to network signals to help manage grid congestion.
Kaluza has adopted the learnings from the original VCharge ACP control system and continues to make improvements for the curtailment mitigation system effectiveness (as outlined in Section 5.2). Furthermore, as part of project TraDER, Kaluza has worked with Electron to demonstrate a framework for a market driven approach for curtailment mitigation which allows for:

- Quantifying the value to a generator from a specific curtailment mitigation action via a bid price
- Quantifying the value that an end customer/smart heating device gets from providing a specific curtailment mitigation action via an offer price
- Creating direct matches or “trades” between individual device actions and generator need
- Tracking proof of delivery from individual trades, which can in the future used for purposes of settlement and payments

This framework makes it easier for new generators and demand assets to join such a curtailment mitigation market. The ability to vary the bid and offer prices at an individual generator and device level can ultimately lead to better quantification of the overall system value from curtailment mitigation actions, improved benefits to the device owners and consequently better overall outcomes from the system. It could form the basis by which a business plan as detailed in section 6.2 could be implemented.

Next steps of the TraDER project will continue to expand through integration with the active network management system to bring more parties online, with the ultimate aim to aggregate local and national markets. Figure 6.1 illustrates an early User Interface for the TraDER marketplace, built by Electron. The Interface surfaces the curtailment actions and corresponding DSM consumption used to mitigate curtailment, as facilitated by trades through the TraDER marketplace.

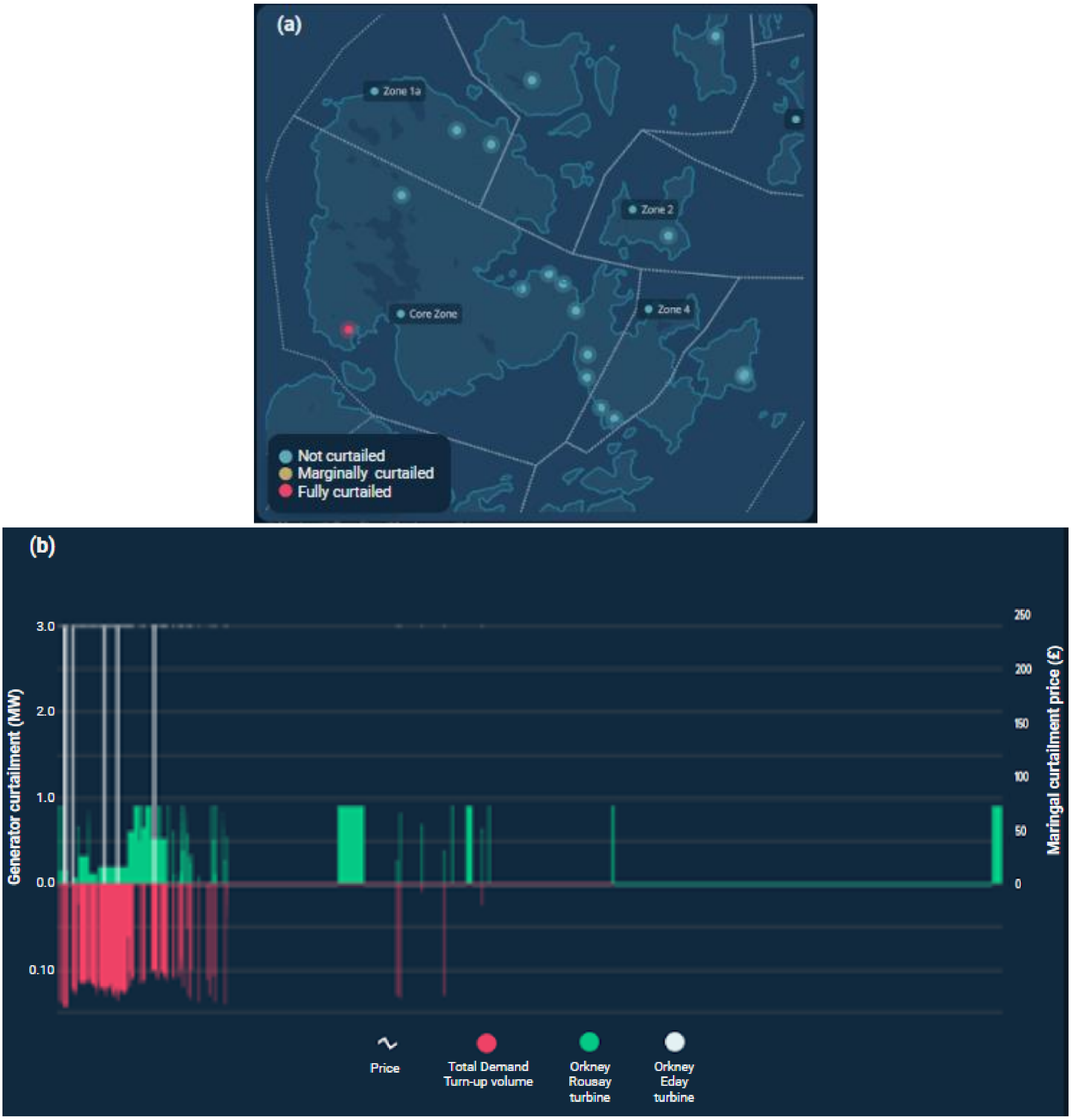

Fig. 6.1 *Project TraDER's Marketplace User Interface built by Electron, illustrating:* ***(a)*** *The curtailment of turbines across the Orkney network;* ***(b)*** *curtailment actions across the turbine stack, and corresponding consumption from DSM assets, facilitated via trades through the TraDER marketplace.*

7 Summary

The Heat Smart Orkney project (operational from 2017-2019) was funded by the Scottish Government, Local Energy Scotland Challenge Fund. Led by REWDT, the project was delivered by its subsidiary HSO Ltd., together with its project partners REWIRED, CES, VCharge and Catalyst.

The HSO project was developed following a growing need by the REWDT and REWIRED to address the issue of curtailment experienced by their community-owned wind turbine (the Rousay turbine). In the FY 2016-17, curtailment of the Rousay turbine resulted in 30% loss of production (~700 MWh) and a loss of ~£110k to its local economy. Curtailment in Orkney occurs when turbine generation exceeds the network capacity limits. Curtailment is the "switching off" of generation through a non-firm connection to the grid; in Orkney, this is controlled by SHEPD's Active Network Management (ANM) system.

The HSO project developed a small-scale community pilot, in which the Rousay turbine was linked through smart grid technologies to domestic DSM-enabled secondary heating devices. During marginal curtailment events, these heating devices would be switched on - thus reducing curtailment, and increasing generation payments to the community-owned turbine. As part of the project, 109 electric heaters and immersion heaters were installed in 72 households within the local islands. Participating customers received a £150 incentive, and rebate payments for all energy consumption through avoided curtailment.

The HSO project is estimated to have avoided 15 MWh and 3.3 MWh of marginal curtailment of the Rousay turbine in 2018 and 2019, respectively. This will have created ~£2,300 and £510 in additional generation payments each year.

Customer retention and satisfaction throughout the project were incredibly high - reaching over 98% retention, with only one of 72 households dropping out during the trial's Legacy phase. Customer surveys showed that ~1 in 4 customers reported a reduction in fuel bills and felt their home temperature increase, with 93% of customers having felt that participating in the trial was valuable.

Considering the system's effectiveness; of a maximum theoretical reduction in marginal curtailment of 67%, a 15% reduction in marginal curtailment was achieved in 2018 and an 8% reduction in 2019. The fall in 2019 resulted from communication issues throughout September - which unfortunately coincided with the month of greatest curtailment (>50%). Considering dispatch load efficiency (how much DSM-dispatched load coincided with marginal curtailment events), this was 74% in 2018, and 50% in 2019. This decline is primarily attributed to customers manually overriding their devices, together with some communications issues. As a result of system performance monitoring, improvements in the system are being implemented - including incorporating additional turbines such as the Eday turbine into the system, and investigating non-communicating households.

The HSO project has demonstrated, for the first time, that technologies can be brought together to intelligently control electrical demand in response to the onset of turbine curtailment. The project is unique in that it uses real-time data from a fully commissioned wind turbine connected to an ANM system and quantifies the level of intervention required to reduce constraint, whilst simultaneously benefitting a fuel-poor community.

The project has now completed its pilot stages (phases I and II of the project), and is in its Legacy phase. The Legacy phase seeks to demonstrate that the concept can both generate sufficient income to cover operational costs, and begin to integrate other generators within Zone 1 of the Orkney grid. An analysis of projected earnings for the HSO model at-scale, expects break-even to be achieved with roughly five turbines and 800 heating devices installed.

The HSO project has had an impact far wider-reaching than its original objectives. It has developed resources and built relationships with local grassroots organisations working to address fuel poverty in the local community, and has created the foundations on which the Smart Islands Energy Systems (SMILE) and Responsive Flexibility (ReFLEX) projects have been built on. Continued improvements to the HSO project legacy via Project TraDER could ultimately lead to the commercialization of the business model that HSO was conceptualised upon.

8 List of Appendices

The following appendices provide supplementary information on various project stages and activities, and are referenced where relevant throughout the report.

1. Minute of Agreement
2. Explanation of Grid Leaflet
    2.1. FAQ Leaflet
    2.2. Project Info Leaflet
3. Customer First Contact Form
    3.1. Project Officer First Visit Form
    3.2. Flow Chart 2018
4. Solid & Other Fuel Questionnaire
    4.1. Oil Questionnaire
    4.2. Property Electricity Questionnaire
5. Technical Advisor's Property Info Sheet
6. Client Process Flowchart
7. Incident Report Template
8. Client Agreement to Remain in Project Form
9. Client End-of-Project Questionnaire
    9.1. Survey Results