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IDSR Stream 4 Lot 2 Published Report

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IDSR Lot 2 Consortium

University of Strathclyde PNDC — A Decade of Innovation

ScottishPower

QualityLogic®

Distribution	
Name	**Organisation**
Iain Robertson	Department for Energy Security and Net Zero
Jane Winn	Department for Energy Security and Net Zero
Jonathan MACKENZIE	Resillion
Bill Chard	Resillion

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1 Glossary and Abbreviations

API	Application Programming Interface
BSI	British Standards Institute
CEM	Customer Energy Manager
CLI	Command Line Interface
DOxx	DSR Objective use case xx, defined in *03-P-009-D3.2-IDSR Lot 2 Test Scenarios Specification*
DSG	Demonstration Steering Group
DSR	Demand Side Response
DSRSP	Demand Side Response Service Provider
ESA	Energy Smart Appliance
EMxx	ESA Management use case xx, defined in *03-P-009-D3.2-IDSR Lot 2 Test Scenarios Specification*
EUI	Extended Unique Identifier
EV	Electric Vehicle
EVSE	Electrical Vehicle Supply Equipment
FIP	Flexibility Innovation Programme
GUI	Graphical User Interface
HP	Heat Pump
HTTP(S)	Hypertext Transfer Protocol (Secure)
IO	Intended Operation (a profile sent from ESA/CEM to DSRSP)
kW	Kilowatt
PAS	Publicly Available Specification
ToU	Time of Use (of tariffs)
UCP	User Customer Preference
SoC	State of Charge
SSH	Secure Shell
SSL	Secure Sockets Layer
TUC	Technical Use Case
UI	User Interface
VEN	Virtual End Node, as defined in BS IEC 62746-10-1
VENID	Virtual End Node Identifier, as defined in BS IEC 62746-10-1 e.g. identifying a CEM
VTN	Virtual Top Node, as defined in BS IEC 62746-10-1
VTNID	Virtual Top Node Identifier, as defined in BS IEC 62746-10-1 e.g. identifying a DSRSP
XML	EXtensible Markup Language

2 References

[1] PAS 1878:2021
https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/about-standards/Innovation/energy-smart-appliances-programme/pas-1878/

[2] PAS 1879:2021
https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/about-standards/Innovation/energy-smart-appliances-programme/pas-1879/

[3] BS IEC 62746-10-1:2018 (also known as the IEC International Standard published version of "OpenADR 2.0b")

[4] Flexibility Innovation Programme: Laboratory testing and demonstration of interoperable DSR applications in settings indicative of the real world – ITT Reference number 5532/12/2021

[5] Queries PAS 1878 (version 1) (spreadsheet)

[6] Updated FIP IDSR Programme Use Cases_Annex 6.ppt

[7] PAS 1878 OpenADR Message Requirements Rev 2 v1.0.pdf

3 Executive Summary

This report is an anonymised version of the final deliverable of the Interoperable Demand Side Response (IDSR) Stream 4 Lot 2 demonstrations of interoperable DSR applications in settings indicative of the real world. The IDSR programme is part of the Department for Energy Security and Net Zero's Net Zero Innovation Portfolio (NZIP). The IDSR programme sits within the Flexibility Innovation Programme (FIP) which aims to support innovative solutions to enable large-scale widespread electrical system flexibility.

The IDSR Stream 4 Lot 2 project was awarded to a consortium led by Resillion with partners PNDC, ScottishPower and QualityLogic. The project commenced in January 2023 and demonstrations concluded in January 2025. Phase 3 follows on from the IDSR Phase 2 Lot 1 ‘laboratory testing and demonstration’ activities delivered by a consortium led by Engage Limited.

In this executive summary the key findings and conclusions detailed in the remainder of the document have been summarised.

3.1 DSR and ESA Policy Principles summary of findings and conclusions

This DSR and ESA Policy Principles, as outlined in PAS1878:2021 [1], formed a key focus of the IDSR Lot 2 project. Of the 4 principles, 2 were central to the aims and objectives of the Lot 2 demonstrations. This section, at a high level, summarises the aims, objectives and results for each of them:

- ***Interoperability***
    - To meet the high-level goal of a user being able to register with and switch between DSR Service Providers seamlessly, it was fundamental that interoperability between the IDSR developed solutions could be proven. The Lot 2 aim was to demonstrate all interoperability pairings between ESA/CEM and DSRSP – building upon the work completed in Lot 1 – to validate that the system was interoperable. During Phase 1 planning it was expected some interoperability failings would be observed, but that this would not be the majority of ESA/CEM and DSRSP. At the handover between Phase 2 to Phase 3 some interoperability issues were known, but most interoperability pairings were yet to be attempted. During Phase 3, not all registration results from Phase 2 could be successfully replicated.
    - The best DSRSP results demonstrated an ability for a DSRSP to register four of the twelve ESA/CEM implementations (N.B. includes multiple distinct ESA implemented by the same project). The best ESA/CEM results demonstrated an ability for an ESA/CEM to register with four of the six DSRSPs. Significant effort was spent on this stage of the demonstrations and despite repeated efforts to fix and then redemonstrate the interoperability, the results indicate that changes are required to PAS1878 [1] to enable the high-level goal of a seamless user experience. It was also noted that the maturity of the user interfaces was typically low, and indicated the systems presented were not ready for a production environment (5.1.1.2).
    - As a programme, it was observed by Lot 2 that an earlier opportunity to test functional interoperability in an independent lab setting during Phase 1, initially focusing on the user steps of registration and de-registration, would have greatly improved the maturity of the systems before Phase 2 conformance testing was attempted. Demonstrations in Phase 3 could then have been completed as planned. The outcome of the ESA Management (EM) interoperability demonstrations was that 3 of the 6 IDSR

Stream 1 projects progressed to the DSR Operation (DO) stage, with the majority of the demonstrations performed between only two of the projects. It should be noted that 1 project, though interoperable with ESA/CEM and DSRSP for registration and de-registration, did not pass final checks regarding DSR operational running. For more details, please see 5.1.1.1.

- ***Grid Stability***
  - At the core of Demand Side Response is the ability for an aggregator (DSRSP) to predictably shift energy usage and/or production in time (defer/expedite) for a specific geography based on input parameters as defined in PAS1879 [2]. The Lot 2 aims were to demonstrate and prove for all of the IDSR programme use cases [6], for all combinations of the delivered systems, that they could successfully; respond to a DSR request, manage the power usage of the system as intended, and report predictably and accurately on the actual power used. In simple terms, to prove for the IDSR developed systems that PAS1878 [1] defined DSR mechanisms can work predictably and consistently.
  - The most successful demonstrations observed routine mode operation being influenced by time of use tariffs to move energy usage away from high price time periods. This was consistently shown to alter energy usage compared to equivalent demonstrations with the same user preferences but using a flat rate tariff. Demonstrations of response mode operation, seeking to expedite or defer energy usage, including equivalent energy production use cases, were however impacted by inconsistent device behaviour and were not observed to be as successful.
  - Equally, cases of cancelling DSR events had inconsistent ESA behaviour results. Capability for automatic reselection of ESA/CEM upon devices becoming unavailable during a DSR event was not present in the DSRSP and could not be demonstrated. Manual selection could be demonstrated with one DSRSP, but this raised questions around flex offer validity as energy consumption during routine mode had commenced, and the start time of some flex offers has passed.
  - It must be noted that the small number of ESA/CEM and DSRSP available during DO demonstrations poses a risk to results being outliers, and it is recommended that further demonstrations with a larger number of devices and more comprehensive DSRSP business logic be performed to state any conclusive results. However, from these demonstrations initial indications are that PAS1878 [1] mechanisms, as stated today, may limit the amount of available flexibility in the system - most notably during active routine and response mode periods (5.2.1.4). It should also be noted that data volumes for interface A OpenADR messaging [1] are large and may pose scaling issues in the real world for PAS defined DSR (5.2.1.3) if not controlled/constrained appropriately in future revisions of [1]. For more details on grid stability findings in general please see 5.1.3.

3.2 PAS 1878:2021 summary of findings and conclusions

The high-level aim for the Lot 2 project relating to PAS1878 [1] was to exercise, DSRSP by DSRSP, a system containing 20 ESAs (implemented by six projects and comprising 12 distinct ESA types) which had been proven conformant to PAS1878 [1] during Phase 2 testing, with the plan for outcomes to be evidence as to the effectiveness of the PAS DSR mechanisms. Though some evidence and insights have been gained on the PAS DSR mechanisms, a significant number of PAS1878 [1] findings during Phase 3 were found during OpenADR log message processing and interoperability activities. A concise summary of these findings is included below.

Interoperability

Based on the ESA and DSRSP issues that were encountered and resolved during demonstrations, we found broadly that interoperability issues had arisen because of the relevant text of the specification either being overlooked or misinterpreted by implementers. Once these issues were brought to the implementers attention and the specification consulted, agreement could be reached about what was the expected required behaviour to achieve interoperability. We clarify here that by interoperability, we refer to successful registration and DSR message exchanges; however, we do not refer to the effectiveness of the DSR system to offer high levels of flexibility to meet a grid side objective, nor do we refer to the scalability of the system across large numbers of devices. We conclude from this that, although the PAS specification could potentially be improved to clarify and help avoid all such individual cases, we did not yet notice clear trends in specific key sections of the specification which were overlooked or misinterpreted (those which we did are described in section 5.2.1.3).

We note, however, that the number of ESA implementations achieving interoperability were limited to three, so this would have likely limited the number of repeat issues encountered during demonstrations. Based on this information our opinion is that a dedicated exercise to clarify the specification every time the specification is misinterpreted by an implementer could be a never-ending exercise (unless patterns emerge in future). Instead, our key finding is that interoperability testing should be done as early as possible across multiple manufacturer implementations (ideally reference ones), as this should expose all such issues much more quickly, and hence they can be worked on much earlier in the manufacturer development cycle, as described in section 5.2.1.3. Should there be issues not necessarily caught during such interoperability testing, then this may provide further justification to clarify the specification instead or to periodically issue some separate guidelines to avoid the recurrence of such issues. Further to these measures, we think that the provisions of multiple reference interface A logs (XML messages) to implementers (e.g. an extension of Annex G in [1]) could be a useful informative resource to help more quickly understand the PAS/OpenADR protocols, as described in section 5.2.1.3.

ESA Forecasting Effectiveness

Interoperability of registration and DSR message exchanges was in the end achieved between three ESA implementations (a heat pump, an EV charger, a battery) and three DSRSP implementations within the timescales of this project, as described further in section 3.1. These cases served as an effective basis to evaluate the effectiveness of each ESA implementation in forecasting power profiles and accurately using/generating power in accordance with the relevant forecast(s) followed during demonstrations. We found on all demonstration days, that overall (aggregated across all ESAs) the participating ESA implementations most of the time did not closely follow the forecasted data. This can be seen in the aggregated real / forecast power plots in section Appendix A (one graph per demonstration day). Further feedback seems necessary minimally from the three constituent ESA implementations in these graphs, regarding the reasons why each set of ESA's forecasts could not be accurately met at all times (with respect to the ESA specific "followed/selected" graphs provided

Appendix A Aggregated Graphs (All Demonstration Days)), and whether it would be feasible to resolve those discrepancies.

Looking more closely at the ESA specific graphs, one can see that the forecasts and measurements do follow similar trends in various portions of the graphs. However, it only takes one ESA to deviate at any one time to create a discrepancy in the aggregated view across all ESAs. We clarify that the discrepancies (most of the time) in the aggregated plots therefore do not mean that all ESAs were not behaving as expected at that time.

Our overall findings were that, although some projects demonstrated a level of interoperability of the PAS messages relating to registration/de-registration and DSR operation, technically they were all compliant with the specification [1] as the specification does not define any power profile accuracy requirements. We feel, therefore, that the specification would benefit from defining some objective accuracy requirements or guidelines to ensure a flexible and stable DSR system can be reliably achieved using objective criteria.

Unfortunately, we cannot speculate on the amount of effort or feasibility for these ESA implementations to make forecasts more accurately (and always) aligned with their actual power usage/generation. We therefore cannot comment on whether alternative approaches (e.g. using something other than power profiles) in [1] are necessary. Certainly, there is room for future work to understand whether ESA implementation improvements can feasibly be made and to explore how much closer the accuracy of the aggregated graphs could be refined with said improvements.

System Flexibility and Scalability

During demonstrations and the corresponding analysis of the demonstration data, we did notice some notable specification gaps which may prohibit a DSR system that is consistently flexible for a large number of connected ESAs. We comment on this not because we consistently reproduced these limitations with the small number of ESAs demonstrated, but as we would anticipate this to be a more significant limitation of system flexibility as the system scales in size. We highlight that the specification operational model (section 0.3 of [1]) outlines that the DSRSP is expected to maintain a “portfolio” of every ESA in the system at any given moment in time, and, when required, for it to optimally calculate an outcome which is communicated at a given moment to many connected ESAs. We think, however, that the current specification [1] in its entirety does not yet fully support this operational model with high levels of flexibility.

Specifically, we identified that the defined [1] ESA flex offer update triggers (referred to in 6.1.5) do not incorporate the necessary triggers to ensure an ESA reliably and controllably updates (e.g. active mode minimum update period) all of its flex offers during periods of active (non-zero) routine or response mode power usage/generation (as per 6.1.6). Similarly, that ESA flex offer update triggers are not defined to reliably and controllably “refresh” any expired offers (e.g. expiry minimum update period), such as an imminent starting LD offer not selected (as per 6.1.7).

Also, consideration seems necessary to constrain the system message traffic; most obviously in order to avoid the high levels of inefficiency introduced by pull mode operation in [3] or “polling” (as per 6.1.9). Further to the pull mode inefficiencies being addressed, consideration seems also necessary to ensure that any of the resolutions, for example to resolve 6.1.5, 6.1.6, 6.1.7, do not result in a non-scalable or unstable system e.g. DSRSP controlled update periods.

We have explored in detail, in the graphs plotted from the demonstration days, the ‘IO’ intended operation and the relevant DSRSP selected profiles (e.g. LD/MD). We consider that a more in-depth investigation of all flex profiles offered by ESA implementations (but not selected by the DSRSP) could help inform future optimisations of [1] for ESAs to more efficiently update power profiles, whether that be periodically or otherwise e.g. power profiles with a sliding availability window. This could be relevant as part of any message traffic considerations too (e.g. in 6.1.9). A high-level suggestion, instead of continuous reporting, could be to implement reporting that only triggers on specific events or thresholds, further reducing unnecessary data transmission. Or even implementing an adaptive reporting mechanism where the frequency of updates adjusts based on system conditions, such as demand spikes, rather than a fixed schedule. For instance, during peak demand, more frequent updates could be useful, while during normal operation, less frequent updates could suffice.

In line with the above, we recommend investigating if this could be achieved via a hybrid top-down and bottom-up approach or, potentially, a move to a fully top-down approach. These were not investigated as part of the Lot 2 activities, however, as a bottom-up only approach could not be conclusively found to be scalable in its current form. It is advised to explore these options to understand if a more effective and scalable DSR mechanism could be defined.

4 Introduction

The Department for Energy Security and Net Zero 'Flexibility Innovation Programme' (FIP) was launched, as part of the Net Zero Innovation Portfolio (NZIP), to support the transition to a smart and decarbonised energy system based on the 2021 'Smart Systems Flexibility Plan' and 'Energy Digitalisation Strategy'. As part of this, the 'Interoperable Demand Side Response' (IDSR) programme was launched to support the development and demonstrations of 'energy smart appliances' (ESA) for the delivery of interoperable demand side response. The IDSR programme was in turn subdivided into 4 streams:

1. Stream 1: the development of ESA delivering interoperable demand side response according to PAS1878 [1].
2. Stream 2: the development of ESA delivering interoperable demand side response via the GB smart metering system.
3. Stream 3: a feasibility assessment to understand the different functional and technical options available to create interoperable domestic energy management system.
4. Stream 4: laboratory testing and demonstration of interoperable DSR applications in settings indicative of the real world.

This final stream, stream 4, was itself subdivided into two lots:

1. Lot 1: laboratory testing.
2. Lot 2: demonstrations in (*settings indicative of*) the real world.

This document encapsulates the outputs from the Lot 2 activities which were performed by the Lot 2 Consortium, the authors of this final report. The Lot 2 demonstration activities were performed after the IDSR systems had been built and tested during phases 1 and 2. The Phase 3 demonstrations were the final phase of the IDSR programme. No systems developed as part of Stream 2 formally progressed from Phase 2 to Phase 3; therefore, the scope of these demonstrations focused on ESA delivering demand side response according to PAS1878 [1] only.

The reported Stream 2 issues relating to unacceptable interface A message latency via the DCC communications path were in line with Lot 2 expectations. Data volumes and sizes required for the successful implementation of DSR utilising the smart metering network were not expected to be compatible with existing DCC communications infrastructure; particularly the need to split OADR payloads into a sequence of small fragments, that were subsequently carried in existing message structures, not explicitly designed for that purpose. It had been anticipated that using DCC boxed may create an idealised environment; however, the Stream 2 reported results confirmed, even with improved performance by project 7, that an at scale system would have significant issues operating. Unless data sizes and volume could be reduced and appropriate message structures defined to transfer messages over the DCC communications infrastructure, this will continue to challenge any desired usage of the smart metering network for secure DSR communications.

4.1 Scope of Document

This document, 02-R-149-IDSR_Published_Report, is intended to provide the reader with a single reference for the Lot 2 project outputs and findings during Phase 3 of the IDSR programme. The report covers the activities performed from the point of receiving DSR equipment to the end of the Lot 2 demonstrations – which also marks the conclusion of the IDSR programme.

This document is structured as follows:

- Section 5: Findings and conclusions
    - This section brings together all of the relevant outputs from the ESA Management and DSR Operation stages and groups them by 'DSR and ESA policy Principles' and 'PAS1878:2021', which were the overarching inputs to and focus of the demonstrations.
- Section 6: Logs and graph generation
    - The capture and processing of power and log data was vital to the production of outputs for the Lot 2 demonstrations. Many learnings came from this activity and section 6 provides an insight to the process and the key findings.
- Section 7: Table of findings
    - A table of findings has been provided in section 7 which references back to the relevant document sections.

4.2 Approach

The Lot 2 activity has been delivered in line with IDSR programme planning outlined in Figure 1. During Phase 1 the Lot 2 consortium developed:

- The demonstration scenarios and schemes to be used during the demonstration period,
- The implementation plans for each Stream 1 and Stream 2 project,
- The Phase 3 schedule,
- The detailed lab design.

Once reviewed and approved all required laboratory items were procured, and the fit out of the DSR laboratory was completed. The key focus during phase 1 was that the demonstrations would cover the in scope DSR and ESA Policy Principles (interoperability and grid stability) and the IDSR programme use cases.

Prior to Phase 3 commencing, two key exclusions were noted and agreed regarding the scope of Phase 3 demonstrations:

- Stream 2: due to issues reported and demonstrated regarding delays to DCC communications relating to the signing of data packets containing OpenADR 2.0b [3] payloads, it was deemed Stream 2 projects would not progress into the Lot 2 Phase 3 activities.
- Frequency Response: a lack of support for PAS 1878 defined Frequency Response in the Stream 1 and Stream 2 ESA led to the Lot 2 proposed DO07 demonstration case to be out of scope.

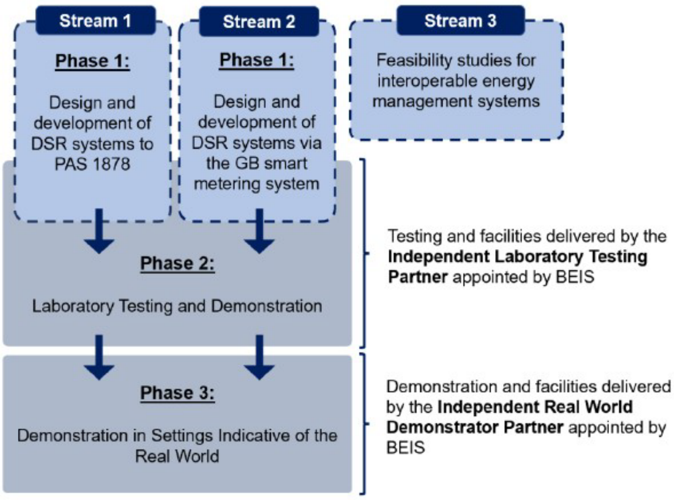


Figure 1: IDSR Programme

Due to significant interoperability issues during the initial delivery of Phase 3 it was agreed to be necessary to replan the activity. Demonstrating the Stream 1 ESA in two distinct groups, one after another, posed a risk to the end deliverables. Therefore, Phase 3 was changed to have a single Stream 1 ESA group representing all distinct ESA types, but with a two-stage approach for the demonstrations.

1) The first stage installed one instance of all ESA into the lab to demonstrate the ESA Management (EM) use cases. This was required to prove interoperability before DSR demonstrations could be performed.
2) The second stage utilised all DSRSP and ESA/CEM with proven interoperability to run through the defined DSR Operation (DO) use cases. EM activities could, where necessary, continue in parallel with DO activities to ensure as many data points as possible for analysis in the final deliverables.

This was a significant change from the planned Phase 3 scheduling but was necessary to ensure the planned outputs from Lot 2 could be delivered.

As a high-level overview to help with understanding the approach taken, the primary inputs to the Stream 4 Lot 2 demonstration scenarios are:

1) Two of the four DSR and ESA policy principles, 'Interoperability' and 'Grid Stability', which can be seen in PAS 1878 section 0.4 [1].
2) The Stream 4 'Annex 6 Programme Use Cases' which formed part of the Stream 4 Invitation To Tender (ITT) documentation [6].

When used together these form the set of ESA Management and DSR Operation scenarios which in turn provides the basis for the demonstrations and the findings within this report.

5 Findings and Conclusions

This section summarises the findings and conclusions for the Stream 4 Lot 2 demonstrations. These have been grouped within two main categories, the 'DSR and ESA Policy Principles' and 'PAS 1878'.

5.1 DSR and ESA Policy Principles

The DSR and ESA Policy Principles, as documented in PAS 1878 [1], cover four key areas – of which two were within the agreed scope of the Stream 4 Lot 2 demonstrations:

- Interoperability
- Grid Stability

User Privacy and Cyber Security were agreed to not be in scope of the Lot 2 demonstrations.

5.1.1 Interoperability

Fundamental to the rollout of any technical system which relies upon multiple dissimilar implementations of end devices and communication hubs, is the need to be interoperable. Conformance testing is very important, as is the need for common internationally recognised standards, but increasingly as systems require smart communications technology the need to plan for and demonstrate interoperability becomes vital to the effectiveness and success of any system. If this cannot be assured and delivered, there is a risk that consumers will not adopt or use the technology. In the case of UK DSR this would be to the detriment of consumers and all key stakeholders for the UK electricity grid operation and infrastructure.

During Phase 3 the following were focused upon during the ESA Management stage:

- Do the delivered systems provide sufficient interoperability?
  - Can each ESA/CEM successfully:
    - Register with each of the 6 provided DSRSP?
    - De-register from each DSRSP and be re-registered with each different DSRSP?
- Are the systems consumer ready?
  - What level of knowledge and skill is required to register the ESA to the CEM?
  - What level of knowledge and skill is required to perform registration, de-registration and re-registration activities with each DSRSP?
  - How long does it take to perform these steps?
    - If engineers are required to perform these tasks what impact might that have?
    - Could communications delays reasonably lead to consumers stopping the process and not registering / re-registering with a DSRSP service?
  - Are failure states and use-cases well managed by the system?
    - If not, is this due to gaps in PAS 1878?
- Are the systems ready for DSR Operation running?
  - Are flex offers received by the DSRSP, and can it successfully select them?
  - Do ESA/CEM respond as expected to DSR event requests?

5.1.1.1 ESA Management (EM) Final Snapshot

		DSRSP 1	DSRSP 2	DSRSP 3	DSRSP 4	DSRSP 5	DSRSP 6
Registration	*ESA 1 - Battery*	Pass	Issue-DSRSP	Issue-DSRSP	Pass	Pass	Pass
	ESA 2 - EV Charger	Pass	Issue-DSRSP	Issue-DSRSP	Pass	Pass	Pass
	ESA 3 - EV Charger	Issue-DSRSP	Issue-DSRSP	Pass	Pass	Issue-CEM/ESA	Issue-DSRSP
	ESA 4 - EV Charger	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 5 - Elec Heater	Issue-DSRSP		Issue-CEM/ESA	Issue-CEM/ESA	Pass	Issue-CEM/ESA
	ESA 6 - Elec Heater	Issue-CEM/ESA	Pass	Fail	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 7 - Heat Pump	Pass	Issue-DSRSP	Fail	Pass	Pass	Pass
	ESA 8 - Heat Pump	Issue-DSRSP	Issue-DSRSP	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-DSRSP
	ESA 9 - Heat Pump	Issue-CEM/ESA		Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 10 - HW Cylinder	Issue-CEM/ESA		Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 11 - HW Cylinder	Issue-CEM/ESA	Issue-DSRSP	Fail	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 12 - Boiler	Issue-CEM/ESA		Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA

Table 1: ESA Management Registration final snapshot

		DSRSP 1	DSRSP 2	DSRSP 3	DSRSP 4	DSRSP 5	DSRSP 6
De-Registration	*ESA 1 - Battery*	Pass	Issue-DSRSP	Issue-DSRSP	Pass	Pass	Pass
	ESA 2 - EV Charger	Pass	Issue-DSRSP	Issue-DSRSP	Pass	Pass	Pass
	ESA 3 - EV Charger	Issue-DSRSP	Issue-DSRSP	Pass	Pass	Issue-CEM/ESA	Issue-DSRSP
	ESA 4 - EV Charger	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 5 - Elec Heater					Pass	
	ESA 6 - Elec Heater	Issue-CEM/ESA	Pass	Fail	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 7 - Heat Pump	Pass	Issue-DSRSP	Fail	Pass	Pass	Pass
	ESA 8 - Heat Pump	Issue-DSRSP	Issue-DSRSP	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA	Issue-DSRSP
	ESA 9 - Heat Pump						
	ESA 10 - HW Cylinder						
	ESA 11 - HW Cylinder	Issue-CEM/ESA	Issue-DSRSP	Fail	Issue-CEM/ESA	Issue-CEM/ESA	Issue-CEM/ESA
	ESA 12 - Boiler						

Table 2: ESA Management De-registration final snapshot

The following bullet points are to reinforce what the aim of the EM phase was to achieve including our position after handover from Lot 1. We then summarised in the table to show the %'s of completion for each project during this stage to give a clear visual overview.

- The ESA Management stage initially planned to focus on the maturity / performance of the solutions, specifically the times taken to register, de-register and re-register consumer ESA/CEM to be able to then participate in DSR activities. It was important to establish if there may be any blockers to large scale rollout of the technology due to unacceptable delays for any consumer or skilled engineer commissioning steps.

- It was also planned to extend upon the interoperability testing in Lot 1 to provide comprehensive coverage of those results to confirm if the vision of seamless switching for customers could be achieved and what level of failures may be observed.

- Though these both remained important considerations, the lack of maturity of the systems during the Lot 1 activities and into the Lot 2 activities meant most of the effort during this stage and focus was on working through functional interoperability issues. These related to specification ambiguity, specification gaps, and several implementation issues.

EM: ESA/CEM Interoperability Summary	Project 1		Project 2		Project 3		Project 4		Project 5		Project 6		Pass (%)
ESA/CEM registered / deregistered with 1 DSRSP	2/2	100%	1/2	50%	1/2	50%	1/1	100%	1/4	25%	0/1	0%	50%
ESA/CEM registered / deregistered with 2 DSRSP	2/2	100%	0/2	0%	1/2	50%	1/1	100%	0/4	0%	0/1	0%	33%
ESA/CEM registered / deregistered with 3+ DSRSP	2/2	100%	0/2	0%	0/2	0%	1/1	100%	0/4	0%	0/1	0%	25%
EM: DSRSP Interoperability Summary	DSRSP 1		DSRSP 2		DSRSP 3		DSRSP 4		DSRSP 5		DSRSP 6		Pass (%)
DSRSP registered / deregistered with ESA/CEM	3/12	25%	1/12	8%	1/12	8%	4/12	33%	4/12	33%	3/12	25%	22%

Table 3: EM Interoperability Summary

High-level ESA/CEM results:

- In the EM interoperability summary above only 50% of the ESA/CEM were able to successfully pass registration and de-registration with 1 DSRSP. This drops to 33% when passing with 2 DSRSP and 25% with 3 or more DSRSP.
- Only 2 of the Stream 1 projects were successful in delivering all their ESA/CEM capable of interoperating with 2 or more DSRSP, and only 1 other project demonstrated at least 1 ESA/CEM with the same level of interoperability.

High-level DSRSP results:

- When reviewing the DSRSP interoperability the best EM results were from DSRSPs 4 and 5 which passed with 33% (4/12) of the ESA/CEM.
- The overall result of a 22% success rate was much lower than anticipated and the true success drops further as only the DSRSPs 1, 4 and 6 were able to be utilised during the DSR Operation stage. This was despite some success with the DSRSP 5 during EM phase registration/de-registration demonstrations.

Summary:

- The EM results above indicate a lack of maturity in the delivered solutions. They are not functionally interoperable to the required level for scaled up demonstrations or consumer usage and were found to be at a much lower interoperability level than expected for the Phase 3 demonstrations. It should be noted that issues raised typically differed between interoperability pairings. The same issues were not consistently observed, and these primarily related to misunderstanding of the specification or gaps in the specification. Interoperability issues were not due to the specification being found to be wrong.
- However, this lack of interoperability did limit the ability to provide additional data points for findings and constrained the time available for DSR Operation demonstrations due to much longer than expected Phase 3 EM activities.

- At the end of Lot 2 work on the project we saw a third of the distinct ESA types being used for the DO phase. This does not mean interoperability is impossible. We believe with more time, better dedicated resources and shared knowledge between the Lots we could see the projects being able to produce a product which would be viable and achieve interoperability (i.e. registration and de-registration). An example of this would be ESA 5, 9, 10 and 12 where we feel that they just ran out of time due to losing resources early in the project.
- If the project was to be run again with new sets of manufacturers, we believe lessons learnt would be useful to put in place. This would allow us to work with the new entrants to set realistic timescales, prepare them for the resources they would be expected to bring in and finely tune our process with communications. If this was all in place, new entrants would certainly have a more streamlined journey into the project and achieve interoperability with minimum problems.

5.1.1.2 Consumer experience

Following is a summary of the Lot 2 findings for consumer experience:

- The setup and usage of the systems was performed in the Lot2 lab by testing resources who have industry and technical experience. Initial commissioning was supported by engineers from each project.
- The quantity and complexity of data was deemed to be unreasonable for a typical consumer to be able to process and input into a system. There were also typically many steps to go through to confirm an ESA to be registered with a CEM, and the CEM to be registered with a DSRSP. This also was deemed to be unreasonable for a typical consumer to be able to successfully complete.
- Issues with commissioning were commonplace and required significant work in almost all instances to result in a successful outcome.
- Timescales for registration requests to be successful ranged from tens of seconds to several minutes, making it hard to understand when the request had failed or if it may yet be successful.
- The Lot 2 conclusion is that an onsite engineer would be required to commission these systems, and that de-registering and re-registering the CEM with a different DSRSP would also require engineering support due to the data requested to be entered into the systems as they are currently designed. When also considering the delays to message communication these could be significant limiting factors to the wide roll-out of this technology.
- We believe that the systems we have seen are not currently ready for the consumer market; in some cases, the experience is complicated or difficult to understand. However, in time, and through speaking to the projects, we can see that the products would be streamlined. This would involve resources being allocated and maybe the setting up of consumer groups to gain feedback on useability. Improvements to required user inputs may also be possible through the adoption of a more recent OpenADR version.

5.1.2 Data Privacy

Data Privacy (*the secure transmission and storing of data on the device or with any controlling party*) was not in scope of the agreed Stream 4 Lot 2 demonstrations.

To note when instructing projects to make changes to help interoperability, it is important to consider any data privacy implications. We had an incident between ESA 7 where a change was made on DSRSP 6 which they mentioned could cause a GDPR issue.

"Allowing a system to transmit data to us without the completion of User Asset registration milestones is highly unusual. It also breaches common security principles by accepting data from a potentially unknown source, bearing in mind that GDPR compliance was a requirement."

5.1.3 Grid Stability

The focus of the planned DSR Operation demonstrations was to exercise, observe and comment on the effectiveness of the delivered systems relating to grid stability (*the prevention of outages on the grid caused by inappropriate operation of ESAs*) as documented in PAS 1878 section 0.1 [1]:

- Match short-term availability of intermittent renewable energy
- Decrease peak load
- Offset of short-term market imbalances
- Control of electricity network characteristics

With it noted in PAS 1878 [1] that: "These aims are achieved by shifting (in time) and/or modulating (increasing or decreasing) the collective electricity consumption or production of domestic appliances, in line with consumer preferences and agreement, in response to signals from grid-side actors."

All demonstrations were planned by Lot 2:

- To be run at a system level, maximising interoperability by utilising a range of ESA/CEM in each demonstration in as many lab bays as is feasible and running demonstrations with one DSRSP at a time.
- Each demonstration scenario was designed to combine one or more IDSR Stream 4 programme use cases [6] with one or more of the grid objectives above.
- As a minimum, the goal was to ensure:
    - Each DSRSP suitable for the DO phase can successfully complete at least 1 DO case.
    - Each DO case can be successfully completed with at least 1 DSRSP.
    - Each interoperable ESA/CEM can be shown to operate in routine mode as expected.
    - Each interoperable ESA/CEM can be shown to participate in a DSR event as expected.

Due to the issues noted during the EM stage, interoperability groups were limited during the DO stage. It should be noted that this significantly increases the risk of outlier results and findings which may not accurately reflect typical behaviour across a larger group of disparate ESA/CEM and DSRSP.

5.1.3.1 DSR Operation (DO) Final Snapshot

DO to DSRSP overview	DSRSP 1	DSRSP 2	DSRSP 3	DSRSP 4	DSRSP 5	DSRSP 6
DO1: Routine Mode (1)	Pass	Failed DO Stage	Failed DO Stage	Pass	Failed DO Stage	Pass
DO2: Reduce/defer demand, Response Mode (2)	Pass			Pass		Pass
DO3: Increase/expedite demand, Response Mode (2)	Pass			Pass		Pass
DO4: Decrease generation, Response Mode (2)	Pass			Pass		Pass
DO5: Increase generation, Response Mode (2)	Pass			Pass		Pass
DO6: Decrease peak load, Response Mode (2)	N/A			N/A		N/A
DO7: Control of electricity network characteristics	N/A			N/A		N/A
DO8: DSRSP cancels active DSR	Pass			Pass		Fail
DO9: Availability changes	Fail			Pass		Fail
DO10: Change incentive information	Pass			Pass		N/A

Table 4: DSR Operation to DSRSP final snapshot

DO to ESA Type Overview												
	ESA Type 1 Battery	ESA Type 2 EV Charger	ESA Type 3 EV Charger	ESA Type 4 EV Charger	ESA Type 5 Elec Heater	ESA Type 6 Elec Heater	ESA Type 7 Heat Pump	ESA Type 8 Heat Pump	ESA Type 9 Heat Pump	ESA Type 10 HW Cylinder	ESA Type 11 HW Cylinder	ESA Type 12 Boiler
DO1: Routine Mode (1)	Pass	Pass	Failed DO Stage	Failed EM Stage	Blocked at DO Stage (DSRSP 5)	Blocked at DO Stage (DSRSP 2)	Pass	Failed EM Stage	Failed EM Stage	Failed EM Stage	Failed EM Stage	Failed EM Stage
DO2: Reduce/defer demand, Response Mode (2)	Pass	Pass					Pass					
DO3: Increase/expedite demand, Response Mode (2)	Pass	Pass					Pass					
DO4: Decrease generation, Response Mode (2)	Pass	N/A					N/A					
DO5: Increase generation, Response Mode (2)	Pass	N/A					N/A					
DO6: Decrease peak load, Response Mode (2)	N/A	N/A					N/A					
DO7: Control of electricity network characteristics	N/A	N/A					N/A					
DO8: DSRSP cancels active DSR	Pass	Pass					Fail					
DO9: Availability changes	Pass	Pass					Fail					
DO10: Change incentive information	Pass	Pass					Pass					

Table 5: DSR Operation to ESA Type final snapshot

High-level Results:

- Of the 6 DSRSP, only 3 were able to be successfully used for DSR Operation Demonstrations.
- DSRSP goals
  - DO scenarios 1-5 and 8-10 were successfully completed with at least 1 DSRSP.
  - DO06 capability, 'decreasing peak load', could not be demonstrated by the DSRSPs as a peak threshold could not be set. However, as permitted input parameters were in line with PAS 1879 [2] this was not deemed a non-conformity or a failure.
  - DO07, frequency response, had been descoped prior to Phase 3 due to the capability not being implemented in the delivered systems.

- DO08 was demonstrated by DSRSP 1. For DSRSP 4 there were issues when executing DSRSP Cancel Request - ESA 7 CEM which failed to respond; the reason being that, in the logs, the DSRSP responds to an oadrPoll with an oadrRegisterReport message including the FLEX_DSRSP_CANCEL message. However, there is no corresponding oadrCreateReport message from the CEM. The FLEX_DSRSP_CANCEL report is therefore not created successfully (doesn't have a report_request_id) and so cannot be used when sending a DSRSP Cancel Request. For ESA 1 & 2 CEMs —ESA 7 suspected that the DSRSP 4 might be losing track of the oadrCreateReports from the CEM overnight. Therefore, for it to work, it was suggested by DSRSP 4 to re-register the ESA 1 & 2 CEMs each morning to safeguard against this. ESA 1 & 2 successfully responded to the DSR cancel request after reregistration.
- Automated management during DO09, ESA/CEM availability changes, was not demonstrated by any DSRSP. DSRSP 4 did allow for manual selection of additional ESA during the DSR event period.

- ESA/CEM goals
  - Of the 12 unique ESA/CEM instances, 3 were able to be used for the DSR Operation Demonstrations due to interoperability issues.
  - 2 of the 3 ESA/CEM had at least 1 instance of successfully participating in all applicable DO cases.
  - 1 of the 3 ESA/CEM failed 2 of the applicable DO cases, which both related to changes to DSR events.
- Though all applicable DO cases could be successfully completed at least once with a DSRSP, indicating the minimum standard for checking PAS 1878 DSR mechanisms could operate, failures were observed regarding cancelling a DSR event and in reselection during a period of ESA unavailability which indicated potential issues during the management of ESA relating to DSR event periods. Please see below for more details.

DO Cases Summary:

- Routine mode operation (DO01) and Change incentive information (DO10):
  - During routine mode operation, there were 2 key inputs which were used to assess Intended Operation (IO) performance; a flat rate tariff, and a time of use (ToU) tariff.
    - Flat rate tariff:
      - During routine mode / IO operation ESA were observed to broadly follow the IO profile which had been set by the ESA according to the consumer preferences. Power usage in this mode was broadly predictable, other than some power usage deviations from the IO profile by some of the home batteries. This unpredictable behaviour is understood to be a characteristic of the specific battery implementations provided and not to be considered as an issue which would typically be observed.
    - Time of use tariff:

        - When a time of use tariff was input to the ESA before a demonstration period, it was noted that the IO profile – when based on the same user preferences during flat rate tariff operation – altered the planned IO power usage to reduce it during periods with high pricing and increase it during periods of low pricing. Devices, as per the measured lab power data, broadly followed these IO profiles which indicates an ability to influence smart appliances to alter energy usage patterns through incentivising and disincentivising power usage at certain times of day through ToU tariffs.
    - The PAS 1878 defined randomised offset for IO profiles was also investigated as part of the demonstrations; a key feature mirroring capability in smart metering to help protect widespread energy usage changes at single points in time.
        - 2 of the 3 distinct implementations of ESA during the DO demonstrations implemented the randomised offset as defined in PAS 1878.
        - The IO profile was demonstrated by the ESA to be offset by a value between 0 and 1799 seconds as expected where this functionality had been implemented.
        - Consideration as to how any tariff pricing and the randomised offset can be synchronised needs to be clarified for any real-world implementation. This is needed to avoid any misalignment which could lead to consumers being negatively impacted by shifting the IO profile in time but tariff pricing boundaries remaining unchanged.
- Response mode operation (DO02 Reduce/Defer, DO03 Increase/Expedite, DO04 Decrease Generation, DO05 Increase Generation):
    - Capability to defer (DO02) and expedite (DO03) power usage was demonstrated by at least one instance of each ESA type and each DSRSP used during the DO stage.
    - Capability to decrease (DO04) and increase (DO05) power generation was demonstrated by at least one instance of the ESA type capability of energy production.
    - Actual power usage vs forecast power usage of selected flex offers accuracy reporting was impacted by inconsistent and unexpected ESA behaviour by the home batteries, both during routine and response mode operation. With the reporting of actual power only covering response mode operation, this raises a concern regarding visibility and predictability of power usage for aggregators, both when assessing commitment to a contracted period of power shifting and during an event where power usage may not be known until the event period has concluded. Further and scaled up demonstrations with a greater variety of ESA would be required to establish if there is any statistical merit in these findings.
- DSRSP Cancels active DSR event (DO08):
    - 2 out of 3 DSRSP used in the DO stage demonstrated successfully cancelling an active DSR event. In these instances, the ESA go into override mode and then can be returned to IO operation as expected.
    - Where there has been a failure to cancel an active DSR event the chain of messages required has not been completed successfully.

- Availability changes (DO09):
  - The ability for the system to be robust to availability changes is critical if the shifting of defined amounts of power usage within a region over a defined period of time needs to be performed accurately and consistently.
  - None of the DSRSP utilised during the DO stage demonstrated any form of business logic to automatically recruit additional ESA during an active DSR event. This capability was clarified as not specifically requested as part of the tender process; therefore, is permissible to be absent at this stage.
  - 1 DSRSP demonstrated the capability to allow manual selection of additional ESA during an active DSR event. This was performed after a consumer override was performed on ESA which had initially selected for the DSR event and were in routine mode. This, however, led to some observations regarding the validity of the flex offers if they are not periodically updated but an active period of power usage has already commenced (i.e. IO routine mode running), and what is the specific definition of flex offer expiration. Please see 6.1.6 and 6.1.7 for more details.
- In conclusion, though routine mode operation using a Time of Use tariff indicated a successful mechanism to achieve changes to energy demand through high and low pricing periods, difficulties were observed during response mode operation. This was in part due to inconsistent ESA behaviour but ultimately means that Lot 2 could not conclusively demonstrate predictable and reliable changes to energy demand during routine mode operation.

5.1.4 Cyber Security

Cyber security (*the appropriate protection of ESAs from unauthorized access and the correct use of ESAs by authorized parties only in order to achieve valid DSR events*) was not in scope of the agreed Stream 4 Lot 2 project demonstrations.

We did note one finding in the section 7 F18 - Cybersecurity requirements such as secure boot, tamper detection etc need to be defined early while the DSR products are being developed to avoid expensive hardware redesigns – for e.g., when EV smart charge point regulations were introduced, this forced several EV charge point manufacturers to completely redesign their hardware, costing time and money.

5.2 PAS 1878:2021

During the ESA Management and DSR Operation stages of the Lot 2 Phase 3 activities, observations were made regarding the Stream 1 implementations relating to PAS 1787:2021 [1]. These have been summarised below in section 5.2.1, and a list of findings can be found in tabular form in section 7.

5.2.1 Summary of Findings

During Phase 3 there were several key areas relating to PAS 1878 against which Lot 2 logged issues and observations. These can broadly be grouped into management of requirements, registration, interface A communication and available flexibility. For more details, please refer to the table of findings in section 7 of this document which references into the relevant sections of this document.

5.2.1.1 Management of Requirements

The recording and sharing of issues and agreed final decisions relating to the PAS Query Log was found to be incomplete and posed issues for Lot 2 during Phase 3.

- Some clarifications and conclusions, agreed via communications channels such as email, were neither shared nor recorded in the PAS1878 Query Log [5] leading to missing information when assessing potential non-conformances during Phase 3. As a minimum the emails (and any other communication) should have been saved and shared with all relevant parties. Ideally, a marked up draft version of PAS1878 should have been maintained with clear references back to the query log so a single master PAS1878 reference existed.
- Agreed stream 1 project change requests relating to PAS Query Log, but not recorded in the query log, were cited to the Lot 2 project as reasons for permissible non-conformances to PAS 1878. This information was only referred to Lot 2 after analysis had been performed and no permissible case for the implementation being found in the available documentation. Ideally the agreed permissible non-conformances should have been known to Lot 2 in advance.

The outcome of the above is that time and effort which could have been spent by Lot 2 on other EM and DO activities was lost, potentially constraining further the possible outputs of Lot2.

5.2.1.2 Registration

Gaps in the definition of the user registration process in PAS 1878 [1] were noted. These related to the management of failure use-cases which, with no defined process, led to interoperability issues and in some cases a need to clear out DSRSP databases of registration entries which did not complete and then blocked a second registration attempt. The mandated input data to register was also not defined in the specification [1] and was more complicated for some systems than others. More clarity and examples in this area are required if the aim is to provide a universally seamless process for registering with and switching from a DSRSP provider.

5.2.1.3 Interface A Communication

In the lead up to demonstrations large quantities of non-compliance issues were encountered when exercising Interface A [1] communications between DSRSP and ESA combinations not previously validated before. Many of these issues were blocking in nature e.g. blocking registration and/or DSR protocol interactions. Significant effort was required to drive out these non-compliance issues to be able to reach a point of demonstrating DSR behaviour across implementations. In various DSRSP / ESA pairings, stable registration and DSR interaction could not be achieved due to further issues that could not be resolved in time. The result of this was that the extent of DSR demonstrations across a breadth of several manufacturer implementations was more restricted than anticipated. We note also that many blocking issues were resolved to achieve interoperability between a subset of DSRSP / ESA pairings. However, we do not yet consider any implementation to be fully compliant nor ready for deployment, due to the various remaining observed issues and scope for further interoperability testing and/or demonstrations.

We consider overall that many of the issues driven out in this process have arisen from an extended period prior to Lot 2 demonstrations which did not involve any early interoperability testing between a breadth of different DSRSP and ESA manufacturers. We encountered a repeating pattern where a given DSRSP and ESA implementation pairing known to interoperate, would not interoperate with another implementation. Typically, in such cases, further investigation would reveal that the specification was not being adhered to resulting in blocked or unexpected communications. It should be noted however that only in some isolated cases were repeating issues observed such as relating to the rID, reportName and reportSpecifierID.

We seldom found new cases where the specification wording or requirements were categorically "incorrect" in a way that prevented interoperability between implementations. We found in general that the issues arising were a result of portions of the specification text being missed or misinterpreted by different implementers of [1]. Typically, any differences in interpretation would not be disputed once the relevant interoperability issue / specification text were brought to the implementer's attention. Sometimes it was necessary to clarify with DESNZ whether a particular interpretation of the specification [1] and existing clarifications [5] were valid or not; however, this was rare. Details of specification gaps / conflicts / ambiguities identified in the context of graph generation scripts are described in section 6.1. A summary of all findings is given in section 7.

We also consider that (for example) Annex F of the PAS specification [1] does not fully or clearly describe many of the mappings between PAS messages / parameters and the corresponding underlying OpenADR [3] mechanisms. We therefore found it particularly challenging to implement the graph generation scripts against the specification descriptions alone. We assume that new ESA and DSRSP implementers of this specification would also face the same challenges for the same reasons. In the end we found that the specification, as well as sample interface A logs of real ESA / DSRSP implementations, were the most helpful tools in combination to much more quickly understand and implement the PAS defined protocols. There are singular XML message examples (ESA oadrRegisterReport, DSRSP oadrRegisterReport, ESA oadrUpdateReport) included in Annex G of the PAS specification; however, we found these to be too limited to account for the breadth of possible implementations that we subsequently encountered. We think that the availability of full sets of (interface A) XML logs including all defined message types captured from a variety of reference ESA types / implementations and DSRSP implementations would be a highly useful resource to new implementers to speed up their development. We think that this would also help promote more informed implementation decisions and better interoperability at an earlier stage of development.

We conclude that any future demonstrations should necessitate a prior phase of interoperability testing against other reference implementation(s) as early as possible as part of the ESA/DSRSP implementation process. This would complement the scope of any certification testing performed. For example, minimally performing interoperability testing for a given ESA with two or three DSRSP implementations from independent manufacturers; exercising both registration and DSR communications. We would expect this approach to catch a great majority of non-compliance issues in advance of entering a system level flexibility demonstration phase. Also, we think that the availability of example reference (interface A) XML logs from such reference implementation(s) for various scenarios would be a highly useful preliminary resource for new implementers as an extension of Annex G in [1].

5.2.1.4 Available System Flexibility

During the demonstrations that were performed, we were able to demonstrate DSR operation to some degree by successfully selecting flex offer profiles other than the 'IO' (intended operation) profile. This in most cases resulted in a clear outcome of the ESA power consumption/generation following an alternative power forecast by this DSR action. Our general observation was that such alternative forecasts were adhered to with varying levels of power inaccuracy / timing misalignment between implementations. Various instances of unexpected behaviours, instability and incomplete functionality were still observed by the end of this demonstration phase. This could therefore be the basis of further work to fully drive out all such issues to achieve one or more reference implementations matching all expected behaviour, as well as an "appropriate" level of stability and accuracy. We note, however, that the specification does not define any forecast accuracy requirements, and so this could become a rather open-ended exercise unless accuracy requirements are defined.

While performing these demonstrations and interpreting the flexibility offers of the different implementations, we became aware of some potential limitations of the specification which were not specifically revealed by the demonstration use cases exercised as part of this report and have therefore drawn attention to it here. We identified that the specification [1] sets out the operational model as below, with the key DSRSP objectives redacted from section 0.3, and attention drawn below in **bold**:

> *a) The ESA determines its flexibility offers ... and provides them to the DSRSP...*
>
> *b) This information is updated whenever the flexibility status of the ESA changes...*
>
> *c)* ***The DSRSP maintains an up-to-date list of the possible flexibility offers*** *provided by the CEM on behalf of the ESAs that it manages.*
>
> *d)* ***Whenever the DSRSP is requested to perform a DSR operation, the DSRSP is able to select its chosen flexibility*** *and time parameters from its portfolio of flexibility offers…*
>
> *e) The DSRSP then sends a message to a selected number of ESAs, via their CEMs, requesting that they implement one of their provided flexibility offers. The ESA implements this flexibility offer and enters response mode.*

We have however found that interface A in [1] is defined such that the set of flex offers available to a DSRSP (at any moment in time) will only be available and valid for the connected ESAs which are inactive at that time (not using/generating power) – a full explanation is offered in section 6.1.6. We reason that this could significantly impact the available flexibility of a system aligning with [1] if the expectation of the system is that the DSRSP performs its flexibility optimisation at a specific point in time. This is especially pertinent considering that some devices can be in an active mode for very long periods of time, and that could be when the DSR system may want the most flexibility from those devices. Some potential approaches to solving this are outlined in section 6.1.6.

Although the demonstrations performed as part of this report were successful in achieving meaningful DSR operation, we highlight that the DSRSP implementations were typically constrained in how they could meet a hypothetical grid objective set out by the DO use cases in this report. Specifically, the DSRSP 4 implementation required the lab operator to perform a fully manual process of selecting a flex profile for each ESA. The DSRSPs 1 and 6 were less manual but broadly limited to allowing the operator to expedite or delay power over a particular period. We consider that the restricted number of ESA implementations demonstrated and their remnant issues / inaccuracies, have resulted in data and graphs which were more meaningful to analyse on an ESA-by-ESA basis rather offering a clear picture of system behaviour at the aggregated level. The availability of aggregated graphs also was not available until late in report writing. The analysis and findings from the data have therefore been more focussed on specific ESA behaviours as captured elsewhere in this report.

We conclude that the specification does yet not fully define all ESA requirements that would enable a DSRSP to modify the power usage of any ESA in the system at any moment in time. Our findings and observations show that DSRSPs are confined in performing and achieving a higher system flexibility than they are currently able to attain. We have highlighted several factors that impact this outcome; the observed instability and inaccuracy of response mode ESAs, the limitations of the manual flex selection process whilst using the DSRSP 4 (which was observed the most in the DO demonstration phase, due to its interoperability status), and most significantly, the flex offer and selection operational model as specified in [1]. Such is the way interface A is currently defined [1], which relies on the DSRSP waiting for ESAs to update with a valid flex offer until end of active mode. Further consideration into the validity of flex offer updates during active periods, would provide the DSRSP with a wider scope of available ESAs that can help meet its grid objective.

5.3 Recommendations

The creation of this report overlaps with known activities to review and update the specification [1] and separately review approaches to ensure ESA interoperability ahead of changes to legislation for the provision of DSR in the UK electricity network. As such it is expected that this report, the findings and recommendations, can feed into those activities and help to support further discussion and design of the systems as well as contributing to the design of any follow-on DSR programmes (one reference of note is 6.1.10).

5.3.1 Updated revision of PAS 1878:2021

The table of findings in section 7 contains many points for consideration as part of the review and update of PAS 1878:2021 – which Lot 2 believe are necessary to address to improve the levels of interoperability, cover use case gaps in the user experience and make the DSR mechanisms more effective. Specifically, issues with registration, data sizes and data volumes need to be addressed along with the validity of flex offers and access to available flexibility in the system.

5.3.2 Reference OpenADR implementation

In line with the OpenADR 2.0d table of findings entries in section 7, a common sample stack for a VEN and VTN would increase the level of interoperability and, if provided by the Department for Energy Security and Net Zero, could avoid proprietary lock-ins and lower the bar to entry. A reliance on common standards and differing OpenADR code sources led to interoperability issues within the IDSR programme which could have been avoided with a reference implementation to work from. As a minimum, defined reference OpenADR profiles are needed to provide gold standard examples to implementors.

5.3.3 Alignment with the smart metering system

For the operation of DSR, particularly when time of use tariffs may be used, there is a need for more clarification as to how metering requirements would be aligned with PAS 1878 defined capability. This relates to both the management of pricing boundaries relative to ESA applied offsets and the ability to validate actual power usage to ensure reported data over interface A is from real devices and relates to actual power consumption.

5.3.4 Earlier interoperability testing

Throughout the Stream 4 activities, both for Lot 1 and Lot 2, there has been evidence that earlier interoperability testing would have driven out key issues relating to specification and design ambiguity, and use-case gaps. A number of Stream 1 projects, very late in their development process, were impacted by interoperability issues which were difficult or costly to change. Early access to a facility and/or reference implementations prior to Phase 2 where ESA Management interoperability testing could have been performed would have allowed for earlier feedback and greater clarity around intended designs and implementations based on PAS 1878 [1]. These activities, performed as part of Phase 1 during the ESA/CEM development cycle, would complement and not replace any certification testing, ensuring implementations were more mature prior to conformance checking and be less likely to be non-conformant. In turn this would ensure a high level of basic interoperability during Phase 3 demonstrations, allowing the focus to be of the effectiveness of DSR capability.

5.3.5 Management of requirements

For any future activities we would recommend noting agreed changes and clarifications to PAS 1878 in a marked up draft copy which is controlled and can be available to all programme participants. The draft could be documented as containing agreed programme deviations from, or clarification to, the specification [1] which will then be submitted to appropriate standards group for consideration as formal changes. This would greatly help preserve the outcomes of any PAS Query Log process, simplify the task for all of requirement traceability through separate documents and aid the passing of these proposed changes and clarifications to the relevant standards committee.

5.3.6 Scalability demonstrations

Though Lot 2 planned to take a first step towards scaling up to a system level, the lack of ESA/CEM able to participate in DSR Operation runs and the concerns around data sizes and volumes means there is still a need to establish at scale what the impacts are of using the PAS 1878 defined mechanisms. This aligns with considerations as to what the definition of an expired offer is as well as any limits on the frequency of CEM to DSRSP messaging. Calculations on potential data volumes have been included in this report (6.1.9) but more would need to be done in this area. Scaled-up demonstrations would also allow for more statistically meaningful sets of data regarding the effectiveness of DSR.

5.3.7 DSRSP capability

The demonstration of DSR capability of a system of ESA is heavily constrained by the capability present in the DSRSP. It is recommended to include within any future work the need for DSR logic to automatically manage, at scale, the selection of ESA prior to and throughout the duration of any DSR event. The demonstrations as part of Lot 2 indicate that changes in availability may present challenges and accurate power shifting via DSR events will be reliant on an ability to actively manage situations when ESA become unavailable. More must also be done to demonstrate the impacts of inaccurate power usage by ESA during an event compared to their selected flex offer, and due to this the impact, that may have on a DSRSP providers ability to commit to contracted agreements to defer or expedite power.

6 Logs and Graph Generation Scripts

6.1 Specification Interoperability Risks

Throughout the course of the script development, numerous script issues and DSRSP/ESA issues were encountered. Often, the apparent reason for these issues occurring were due to differences of interpretation of the specification. In this section we seek to identify the explicitly described or implied functionalities in [1] that resulted in interesting behaviour that was difficult to distinguish as compliant or non-compliant. We consider that these topics would likely warrant further consideration to amend or clarify the wording in [1] and avoid equivalent interoperability issues occurring in the future.[1]

We have, where possible, avoided raising topics that have already been raised in [5]. Where topics raised here do have some commonality with items in [5], we have considered that the responses provided in [5] (and any subsequent revision(s) to [1]) may require further consideration and clearer action or clarification to avoid interoperability issues in the future.

6.1.1 Flex offer selection multiple definitions

There are two separate definitions for flex offer selection in [1] and [5], referred to here as "indexed selection" and "identifier selection" respectively. By implementing what is stated in [1], interoperability will not be possible with another device if that is implementing what is defined in [5]. Also, there is currently nothing to forbid an ESA and/or DSRSP implementation from implementing both definitions. However, such tolerant implementations would be expected to give rise to interoperability issues between only some pairings of implementations.

For example, if a DSRSP supported both definitions (flex request includes index and identifier), then an ESA could be implemented with indexed selection, and would appear to be interoperable. However, if that ESA was to be migrated to another DSRSP provider, supporting just identifier selection, the ESA and the other DSRSP would not interoperate.

Proposal:

Remove the flex selection by indexed selection definition from [1] and replace with the identifier selection definition from [5].

6.1.2 Actual and instantaneous power reporting interoperability

Section 5.4.4.1.3 of [1] describes that the ESA may support one or both power reporting types:

- Instantaneous power reporting (periodic reports during a DSR event) and/or
- "Actual" power reporting (single report at the end of a DSR event)

Section 5.4.4.3 describes that a DSRSP can choose a preferred reporting type if the ESA advertises that it supports multiple reporting types.

However, there is no requirement in [1] for the DSRSP to support both reporting types, which creates an interoperability issue between DSRSP and ESA i.e. if the ESA supports a single reporting type, but the DSRSP supports a different (single) reporting type.

Proposal:

Amend any relevant sections of [1] to state clearly that an ESA may support one or both of the power reporting types, and that a DSRSP shall have the capability to process both reporting types but may negotiate its own preferred reporting type if an ESA supports both.

6.1.3 Flex offer and flex offer update differences

Sections 5.3.5.1 / 5.4.5.1.2 / 5.5.2 / 5.5.4.6 of [1] require that the ESA shall submit its "flexibility offer" or a "flexibility offer update". However, it is not clearly defined how these mechanisms are distinguished, nor how their contents shall differ. The description of these two processes is separated across multiple sections, but with no clear definition of either.

Our original interpretation of the above was that both the initial flexibility offers, and subsequent flexibility offer updates issued by the ESAs, would always include all available profiles e.g. if one profile has changed, then all profiles are re-submitted by the ESA. This interpretation leads to the understanding that the ESA will manage its profile changes rather than the DSRSP managing the ESA profiles and all incremental changes.

Another interpretation of [1] (as clarified in [5]) is where the ESA issues flexibility offer updates which include only the profile(s) that have changed. This interpretation imposes a mandatory requirement on all DSRSPs to precisely manage all ESA profiles through every incremental change notified by the ESA in the updates. However, this DSRSP requirement is not explicitly or clearly defined as a necessary DSRSP implementation to support such ESA implementations.

Further to the above, it is clarified in [5] that ESAs are required to only include the profile(s) that have changed in each flexibility offer update.

We observed during demonstrations that the ESA/CEM 4 implementation will inform the DSRSP of its initial set of mandatory profiles in separate flexibility offer / flexibility offer update messages, rather than in a single flexibility offer message after initialization. It is not clearly defined in [1] whether this is compliant or non-compliant, although our interpretation is it is not compliant.

Proposal:

Amend any relevant sections of [1] to explicitly define what a "flexibility offer" and a "flexibility offer update" are (how to distinguish them), when they shall or shall not be triggered, and what they shall or shall not include. Also to define when the DSRSP shall expire or is permitted to purge an ESAs offers.

6.1.4 Flex offer mandatory profiles

It is assumed in section 5.5.4.1 of [1] that an ESA will support either just power consumption, or support power consumption and generation. It is therefore defined that the latter shall report all profile types: IO, LD, MD, LD_P, MD_P. However, a fully charged battery for example would reasonably be expected to only issue: IO, LD_P and MD_P profiles.

This specification definition could lead to some DSRSP implementations which wait for IO, LD, MD profiles before performing flex selection, and hence there is the potential for blocking interoperability issue(s) arising from this.

Proposal:

Clarify in [1] that an ESA may issue just LD_P, MD_P profiles but not LD, MD profiles as part of its mandatory set e.g. fully charged battery during initialisation.

6.1.5 Flex offer update triggers

Section 5.5.2 of [1] defines that flex offer updates shall be triggered when the status of a flexibility offer profile changes for any of the below reasons.

- *consumer intervention*
- *optional external data update*

- ➢ *other change in parameters to ESA forecast calculation, resulting in a change of flexibility offer status*
- ➢ *start of any active period in any profile (IO, MD, LD)*
- ➢ *end of any active period in any profile (IO, MD, LD)*

The expectation cited for this in the same section is to avoid "*an approach of providing updates continuously at regular intervals*". However, we have observed that one heat pump implementation triggers periodic updates (for example) for the 'IO' power profile around every 15 minutes or less. These are triggered periodically both during routine mode and response mode. We understand from feedback from the manufacturer that this is the intended implementation, due to this heat pump's forecasts being both time and condition dependent and not simply forecasted based on a fixed amount of energy i.e. the forecast is constantly changing by small amounts incrementally. We conclude that such an ESA implementation appears to be compliant with the requirements of [1]; however, it does not align in expectation. This highlights that an ESA implementation triggering updates (for example) multiple times per second would be compliant with [1]. However, this would likely result in an unscalable DSR system for large numbers of ESAs implemented in this way. Consideration has also not been given in [1] to define requirements for flex offer updates during active periods (see section 6.1.6 for a full explanation), nor for updates in response to flex offer expiration (as described in section 6.1.7). N.B. Flex offer expiration is listed as a flex update trigger in the operational model 0.3 of [1] but not in the explicit requirements in section 5.5.2.

Proposal:

Further requirements or guidelines appear necessary in [1] to account for ESA implementations whose power profiles are constantly changing e.g. to restrict the frequency of profile updates for such an implementation. Similarly, requirement(s) should be added to [1] to address how an ESA shall trigger flex offer updates while it is actively consuming/generating power, and whenever any offers have expired.

6.1.6 All Flex Offers Invalidated During Active ESA Power Usage/Generation

During script development, we noticed that [1] does not explicitly identify that whenever the ESA actively uses/generates power in routine or response mode (i.e. any active period), any other available flex offer power profiles should very quickly become invalidated due to inaccuracy. This is based on the principle that any ongoing energy usage or generation by an ESA should (typically) continuously impact and hence invalidate all other forecasts. For example, any power being actively consumed by an ESA in routine mode (e.g. active 'IO' forecast) should incrementally mean less energy will be required in all other (inactive / not yet selected) flex offers e.g. an inactive 'MD' profile for the next day. The functionality offered in [1] does not define a mechanism for available flex offers (e.g. the inactive 'MD' profile) to be withdrawn / expired, nor a requirement for the ESA to renew them periodically to keep forecasts accurate and valid for this unavoidable condition during power usage/generation. Note, however, that in accordance with section 5.5.2 of [1], periodic updates are not expected / required in-between the start and end of any active period (see also the relevant section 6.1.5 in this report).

N.B. The above description assumes that active power consumption/generation does not qualify as a "*change in parameters to ESA forecast calculation*", as that would conflict with the expectation not to trigger periodic updates in [1]. The consequence of this is that [1] does not define a mechanism for the DSRSP to reliably or accurately change to a different flex offer while the ESA is actively using/generating power (in active mode) e.g. to transition from an active ‘IO’ routine mode to response mode. N.B. There is no mechanism that the DSRSP can trigger the ESA’s flex offers under such circumstances. We anticipate that this scenario will be notably problematic when an ESA (compliant with [1]) enters prolonged active periods in routine mode, leaving the DSRSP without any valid (i.e. accurate) flex offers to select as an alternative (response mode) power profile e.g. EV charger charging in routine mode. This could severely hinder the operational model set out in section 0.3 of [1] “Whenever the DSRSP is requested to perform a DSR operation, the DSRSP is able to select its chosen flexibility and time parameters from its portfolio of flexibility offers”.

We can see a suitable precondition for this scenario below in Figure 2, taken from the demonstration on 19-11-2024 [1] with a project 1 EV charger which demonstrated an active routine period between ~12:45 to 13:30. Although flex selection was not intended to be demonstrated during active routine mode here (nor for other demonstrations), we did find during exploratory testing with the project 1 CEM implementations that indeed it would not accept any attempts to select an alternative offer while already in active mode. This specific ESA behaviour is not explicitly defined by [1]; however, it does corroborate in practice the limitation of [1] raised in this section.

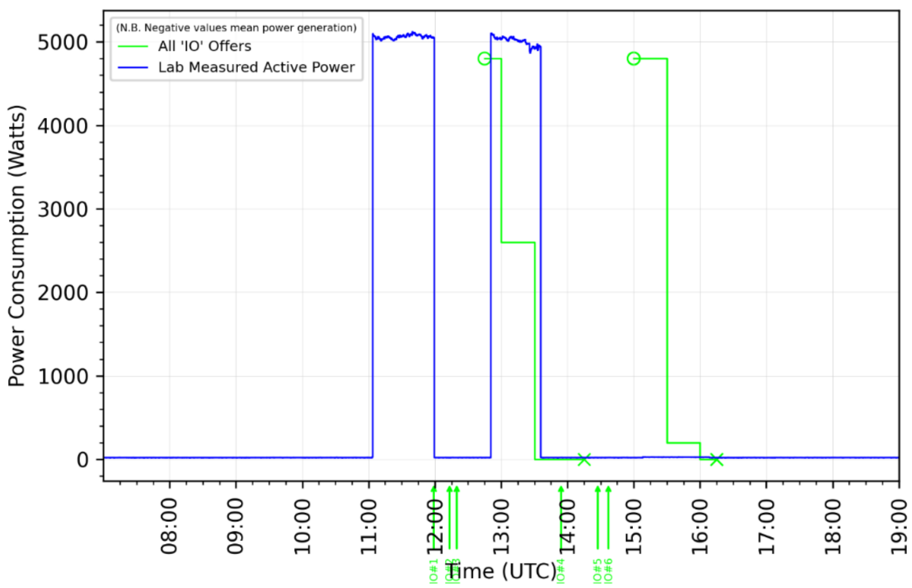


Figure 2: Example of all flex offers being invalided during active ‘IO’ routine mode between ~12:45 to 13:30

We see also a similar situation below in Figure 3, taken from the demonstration on 2024-12-04 with a project 4 heat pump ESA. In this demonstration, the ESA enters active routine mode and stays in this mode for the entirety of the log capture between around 10:30 to 15:15. This ESA implementation happens to trigger flex offer updates periodically due to a change in parameters affecting its forecast calculation (as described in section 6.1.5). This results in the ‘IO’ profile being updated periodically throughout the demonstration period and highlights the long durations that an ESA could remain in active routine mode.

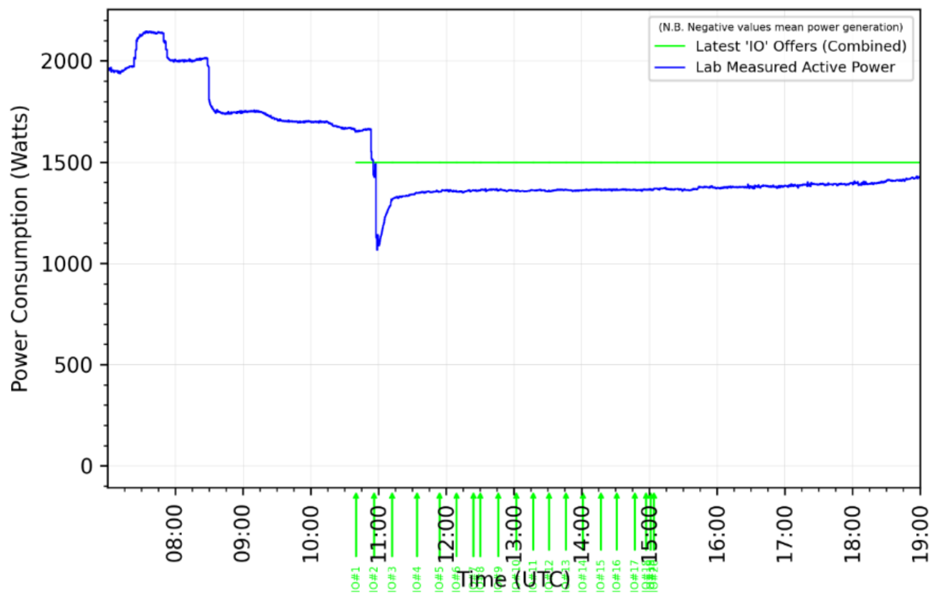


Figure 3: Second example of flex offers being invalided for a prolonged period of 'IO' profile updates

We note that the situation described in this section is possible for active response mode periods too; in that ESAs are not required to trigger flex offer updates (e.g. IO/LD/MD) until the end of response mode. The DSRSP can therefore not know the (valid) flexibility of that ESA at all times over these periods. However, conversely in response mode, the DSRSP could trigger a flex offer cancellation and thereby trigger the ESA to send a flex offer update. Such a cancellation would however interrupt the ESA power usage for the sake of seeing an up to date set of flex offers which also seems an undesirable limitation of [1].

Conclusion:

We conclude that [1] does not define an approach where the DSRSP has an accurate and valid (i.e. selectable) set of flex offers for all ESAs at all times. This prevents the DSRSP from being able to transition an ESA from one active profile (routine or response mode) to another active profile (routine or response mode). Instead, the approach described in [1] implicitly relies on the DSRSP waiting for example until the end of active mode for the ESA to trigger a valid flex offer update which the DSRSP can then apply its DSR algorithm to. This could severely limit the flexibility of a DSR system compliant with [1]. For some ESA implementations this could also result in the ESA becoming "stuck" in active routine mode for very long periods of time or even indefinitely if it is always or often using/generating a non-zero amount of power.

Proposal:

Further consideration to [1] seems necessary to ensure that a DSRSP can always perform demand side response for all connected ESAs, even during active periods. This may include consideration of (but not limited to):

- Flex offer updates during active periods e.g. periodic (section 5.5.2 of [1])
- DSRSP flex offer update request mechanism
- PAS defined or ESA defined flex offer validity duration during active periods

Alternatively, if the above approach is not desired, then the operational model may need to be amended to clarify that the DSRSP can only perform DSR operations at more limited opportunities on an ESA event driven basis e.g. when a given ESA starts or ends active mode.

Further demonstrations could help to inform this process by more closely investigating all ESA flex offer profile updates when transitioning from active routine mode to response mode, and when transitioning from active response mode to routine mode.

6.1.7 Flex offer expiration

There are multiple references in [1] to a required ESA behaviour to trigger a flex offer update in response to a flex offer expiring; however, flex offer expiration itself is not defined. In the absence of any definition, we assume that this may be referring to a flex offer profile which does not become active (e.g. selected) before the profile's start time is exceeded by the current time.

It can be implied from this that flex offers should always include a non-zero lead time before the defined start time of the profiles. Otherwise without any lead time, that profile could be considered as immediately expired after being offered.

We have observed varying lead times of this nature in the different ESA implementations. However, we have observed that this can cause an issue during active routine mode 'IO' profile updates, as can be seen in the below graph from 2025-01-21 [1] for ESA 7 heat pump. This ESA implementation triggers a flex offer update with an updated 'IO' profile around every 15 minutes. However, because there is typically a lead time of slightly less than 15 minutes (e.g. around 14 minutes), the lead in period of each updated flex offer overwrites the defined portion of the profile of the previous offer. The result is that the continuously updated 'IO' profile data is mostly undefined when interpreted as a combined profile as per the plot below. The small portions of defined data that were not overwritten can be seen in the below graph as small periodic green dots around 800W.

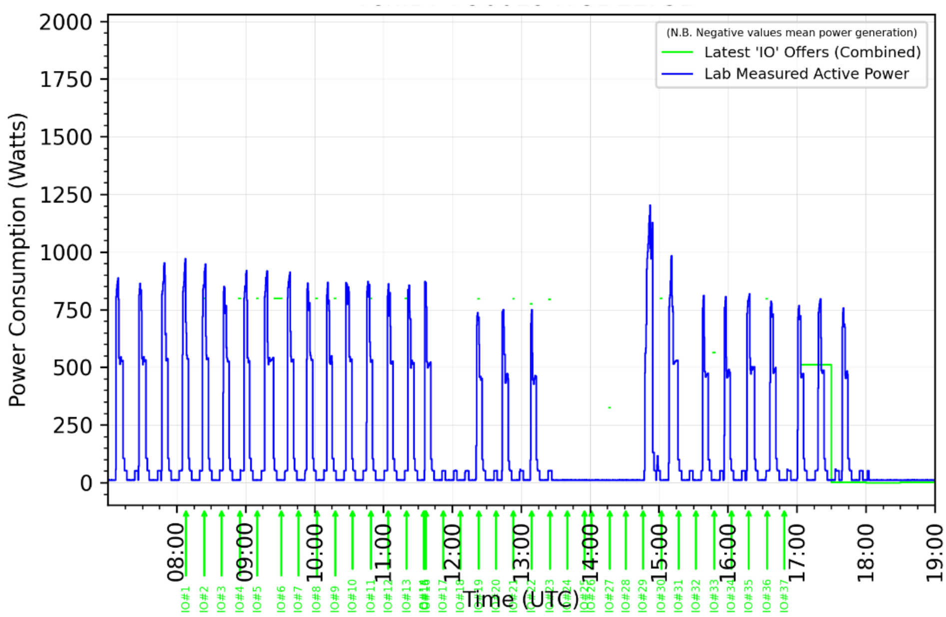


Figure 4: Flex offer 'IO' updates with lead in times (for expiry) resulting in gaps in the combined 'IO' profile data

Proposal:

The condition(s) under which flex offer profiles expire should be defined in [1]. Guidelines may also be necessary regarding profile lead times to avoid expiration e.g. for LD or IO profiles. These should consider any specific handling for 'IO' profile updates, if necessary, e.g. there should not be any lead time applied to 'IO' profiles during active routine mode updates.

6.1.8 Flex offer profile duplication with time cropping

During demonstrations, we have observed an ESA implementation which sends flex offer updates for the LD/MD profiles which are the same flex profile, except time cropped from the time of message onwards. Our interpretation is that such time cropped profiles should not be considered as a profile change and therefore should not be sent by the ESA.

Proposal:

It should be clarified in [1] that a flex offer update shall not be triggered for a profile which is the same as the same previously issued profile except cropped from the time of the flex offer update message onwards.

6.1.9 OpenADR 2.0b Pull Mode (Polling) Overheads and Typical XML Message Sizes

During demonstrations, we observed that log capture files for a given demonstration day resulted in some quite substantial file capture sizes with only several ESAs communicating. This poses some concerns for the scalability of a system based on real world implementations based on [1] (using the OpenADR 2.0b [3] protocol) which have been demonstrated so far.

We note that [1] does not restrict an ESA implementation to support either pull mode or push mode as defined in [3]. Our observation in the demonstrations done was that all implementations were using pull mode, as oadrPoll messages were observed in all communication exchanges. See also section 6.1.10 for related interoperability risks identified between different pull mode implementations.

We have in this section analysed a typical and representative set of logs from the demonstration on 2025-01-14 (N.B. no registrations were performed in this capture) using the DSRSP 4 with 7 connected ESAs.

We extracted the below metrics, some estimated for example based on typical DSRSP header or XML sizes. N.B. Units such as "MB" or "Megabyte" etc used in this section refer to a decimal Megabyte for simplicity and consistency (i.e. not a binary Megabyte / Mebibyte etc as reported in the Microsoft Windows OS). The below calculated estimates are summarised in Table 6.

- Log capture time range = about 08:10 to 16:10 (~8 hours)
- Total log capture (including non-XML DSRSP headers) = 152,438,280 bytes (~152.5MB)
- DSRSP VEN + VTN (non-XML) headers = (~454 Bytes x 18900=8,580,600) + (~388 Bytes x 18900 = 7,333,200) = 15,913,800 Bytes estimated (~16MB)
- Total log capture (XML only) i.e. above two values subtracted = 136,524,480 (~136.5MB) over interface A in [1]
- Equating on average to around 2.4 MB/hour per ESA
- With oadrPoll XML messages totalling ~3,301 Bytes x18817 = 62,114,917 Bytes (~62.1MB) or 45.5% over interface A in [1]
- And oadrResponse XML messages totalling ~3,670 Bytes x 18811 = 69,036,380 Bytes (~69MB) or 50.6% over interface A in [1]
- All other XML messages e.g. flex offers, flex select, flex cancel etc totalling 5,373,193 Bytes (~5.4MB) or 3.9% over interface A in [1]. N.B. This includes 91x oadrUpdateReport XML messages, containing 435x ESA flex profiles of various types.

Breaking down "All other XML messages" above in more detail for DSRSP update sequences:

[7x flex selection messages…]

- 7x ESA oadrPoll. ~ 3,301 Bytes x7 = 23,107 Bytes

- 7x DSRSP oadrUpdateReport. ~4,857 Bytes x7 = 33,999 Bytes
- 1x ESA (ESA 4) oadrUpdatedReport = 3,603 Bytes (ESA 1 doesn't send as per 6.1.10)
- 1x DSRSP oadrResponse = 3,675 Bytes

Breaking down "All other XML messages" above in more detail for ESA update sequences:

[7x actual profiles…]

- 7x ESA oadrUpdateReport = 6149 + 8038 + 5517 + 8038 + 8031 + 15817 = 59,619 Bytes
- 7x DSRSP oadrUpdatedReport = ~3730 Bytes x7 = 11,190 Bytes

[3x ESA cancellations…]

- 3x ESA oadrUpdateReport = 4875 + 4875 + 4859 = 14,609 Bytes
- 2x DSRSP oadrUpdatedReport = 3730 + 3735 = 7,465 Bytes (one missing in logs due to "OADR Schema Validation failed")

[74x oadrUpdateReport containing 435x flex profiles…]

- 74x ESA oadrUpdateReport ~ 5.4MB – 272.29KB – (23.1+34+3.6+3.7KB) ~ 5.1MB
- 74x DSRSP oadrUpdatedReport. 3,730 Bytes x74 = 272,290 Bytes

Total XML Captured Over Interface A [1] = 136.5MB (7x ESAs over 8 hours)			
Sequence Types:	**'Null' Poll Sequences**	**DSRSP Update Sequences (7x Flex selections)**	**ESA Update Sequences (7x Actual profiles, 3x ESA cancellations, 435x Flex profiles)**
oadrPoll	62.1 MB (ESAs sent)	23 KB (ESAs sent)	n/a
oadrUpdateReport	n/a	34 KB (DSRSP sent)	5.1 MB (ESAs sent)
oadrUpdatedReport	n/a	4 KB (ESAs sent)	272 KB (DSRSP sent)
oadrResponse	69 MB (DSRSP sent)	4 KB (DSRSP sent)	n/a
Total (7x ESAs over 8 hours)	**131.1 MB**	**65 KB**	**5.4 MB**
Average Data Exchanged Per ESA	**2.34 MB/hour**	**1.2 KB/hour**	**96 KB/hour**
Average Data Exchanged Per ESA (All Sequences)	**2.44 MB/hour**		
Percentage Of Total Communications	**~96%**	**<0.1%**	**~4%**

Table 6: Accumulated message traffic (estimated) over Interface A

If we extrapolate the 2.44 Megabytes/hour per ESA metric on average across one million ESAs, then that is 2.44 Terabytes/hour or around 680 Megabytes/second of XML data continuously communicated over interface A in [1]. N.B. These figures are combined download and upload, roughly split equally e.g. roughly 340 MB/s download and 340 MB/s upload.

Below we also review some typical individual message payload sizes from the same log capture:

- ➢ First ESA 4 flex offer, containing 4x profiles (LD / MD / IO / 1), each with number of intervals 5 / 5 / 49 / 21 respectively = 55,725 Bytes (~56 KB)
- ➢ First ESA 1 flex offer, containing 5x profiles (IO / LD_P / MD_P / 1 / 2), each with number of intervals 3 / 3 / 3 / 3 / 3 respectively = 16,407 Bytes (~16 KB)
- ➢ First (DSRSP 4) flex selection message = 4,857 Bytes (~5 KB)
- ➢ First ESA cancellation message (ESA 1) = 4,875 Bytes (~5 KB)
- ➢ First oadrPoll message size = 3,301 Bytes (~3 KB), around once (per ESA) every 10s
- ➢ First oadrResponse message size = 3,670 Bytes (~4KB), around once (per ESA) every 10s

Conclusion:

We conclude from the above metrics that the polling mechanism defined in OpenADR 2.0b [3], using "oadrPoll" and "oadrResponse" messages, would lead to a significant overhead (~96%) in the communications bandwidth used by this protocol. We anticipate that the resulting high volume of data continuously exchanged with the DSRSP(s) could pose excessive challenges and cost to implement the required infrastructure to ensure a reliable DSR system. For example, one million ESAs might need to exchange a continuous data rate of (on average) around 670 Megabytes/second with the DSRSP (combined upload and download).

Proposal:

Further consideration appears necessary in [1] to reduce the excessive communication overheads associated with OpenADR 2.0b [3] to ensure a DSR system that supports long term scalability with large numbers of connected ESAs. Consideration may also be necessary to constrain the volume of messages exchanges to be scalable even with the additional flex offer update considerations raised in section 6.1.5.

6.1.10 ESA/CEM Acknowledgements to DSRSP Messages

During demonstrations, we have observed some ESA/CEMs and DSRSPs providing unexpected implementations with respect to ESA/CEM acknowledgements to oadrPoll triggered DSRSP messages i.e. during pull mode operation [1]. Our investigations only analysed the flex offer select (oadrUpdateReport) DSRSP message type. However, we would expect the same behaviour to apply equivalently to any oadrPoll triggered DSRSP messages. Our understanding of [3] is that the following message exchanges are required for an oadrUpdateReport sent by the DSRSP:

(DSRSP message)

oadrPoll (ESA/CEM) -> oadrUpdateReport (DSRSP)

(Followed by an acknowledgement sequence)

oadrUpdatedReport (ESA/CEM) -> oadrResponse (DSRSP)

Observed ESA/CEM Non-compliance:

In the first instance we have concluded that the ESAs 1 & 2 have an issue as they proceed to transition to response mode without notifying the DSRSPs with an oadrUpdatedReport. Such an ESA/CEM implementation does not allow for communications integrity following any DSRSP actions. Project 1 have commented "We believe we should be sending oadrUpdatedReport response. If we are not then this would be a bug from our planned operation".

DSRSP Behaviours:

We observed that DSRSP 6 (for example) has in place validation for the CEM oadrUpdatedReport acknowledgement and will keep issuing the flex offer select up to 5 times after a timeout [1]. We understand that this DSRSP implementation does not consider the CEM to be in response mode until it has successfully received the CEM oadrUpdatedReport (with responseCode=200).

On the contrary, we found that the DSRSP 4 does not have in place any validation for the CEM oadrUpdatedReport acknowledgement. Interestingly, however, it does seem to respond with an oadrResponse. We therefore did not notice that ESA 1 CEM behaviour was incorrect when exercised with this DSRSP, as the DSRSP is effectively tolerant of such a non-compliant CEM implementation. DSRSP 4 has been made aware of this point and will be investigating this for future iterations of their DSRSP.

		DSRSP 4			DSRSP 6		
CEM	**Mode**	**After flex offer select, VEN sends oadrUpdatedReport**	**DSRSP validates for oadrUpdatedReport response from VEN**	**DSRSP sends oadrResponse to oadrUpdatedReport**	**After flex offer select, VEN sends oadrUpdatedReport**	**DSRSP validates for oadrUpdatedReport response from VEN**	**DSRSP sends oadrResponse to oadrUpdatedReport**
Project 1 CEM	Pull	x	x	x	x	✓	x
Project 4 CEM	Pull	✓	x	✓	✓	✓	✓
Project 3 CEM	Pull	✓	x	✓			

Table 7: Observed CEM and DSRSP behaviour relating to oadrUpdatedReport response for flex offer select

Conclusion:

The specifications [1][3] do not explicitly state that CEMs must respond (for example) with an oadrUpdatedReport in response to a DSRSP oadrUpdateReport. This has resulted in one CEM implementation (as observed so far) not implementing support for this acknowledgement. This extends also to any other DSRSP message type triggered by oadrPoll e.g. oadrRegisteredReport, oadrCreatedReport, oadrUpdatedReport. We consider that such an acknowledgement is imperative for communications integrity and interoperability following any DSRSP actions e.g. during registration or DSR activity such as flex offer selection etc. Further to this, the DSRSP 4 implementation has been observed to not meaningfully validate such ESA/CEM acknowledgements (although it did respond with an oadrResponse).

Proposal:

[1] should state explicitly that ESA/CEMs are required to acknowledge DSRSP messages following an oadrPoll (or "pushed" DSRSP messages), and that DSRSP implementations should not tolerate ESA/CEMs that do not implement such acknowledgements. It should be noted that oadrUpdateReport,

oadrCreateReport and oadrUpdateReport are explicitly listed, but there are zero mentions of the oadrRegisteredReported, oadrCreatedReport and oadrUpdatedReport message types in [1]. Further clarification in [1] therefore seems necessary for pull mode or push mode.

6.2 Graph Views

Multiple graphs are generated. These can be categorised as either ESA specific graphs or aggregation graphs (summed across all ESAs).

The ESA specific data is plotted in the following graph views:

- Full Data
  - Time axis of graphs is scaled so that all plotted profiles are plotted in the graph

- Working Day
  - Time axis is set to a fixed time window which centres around a working day. The time range is set to 7am to 7pm UTC (defined in process.py).

- Inaccuracy
  - The following data is plotted in this view
    - 'Selected Offer' - 'Lab Measured'
    - 'ESA Measured' - 'Lab Measured'
  - The time axis is cropped from 7am to 7pm UTC.

The aggregation data (across all ESAs) is plotted in the following graph view:

- Working Day Aggregated
  - The following data is plotted in this view
    - The summation of the Followed 'IO' / Selected Offer(s) (with DSR) curve (described above) across all ESAs
    - The summation of the Laboratory data across all ESAs.
  - The time axis is cropped from 7am to 7pm UTC.

Aggregated data examples can be viewed in Appendix A.

7 Table of Findings

ID	Area	Observation / Challenge	Key Finding / Recommendation
F1	Programme Lessons Learnt (Communication)	Limited visibility of change requests resulting from PAS query log process	Lot 2 technical team unaware of CR work that happened prior to Lot 2 (in particular CR 18 and CR 19).
F2	Programme Lessons Learnt (Communication)	Project CEMs issuing Query Registration as the first message; Project VTNs not supporting this, as was discussed in CR 18 to remove Query Registration	Clarification and communication to all projects, regarding Query Registration or CreatePartyRegistration
F3	Programme Lessons Learnt (Requirements Management)	Some projects understood ReportSpecifierID to be specific value, which were result of Lot 1 discussions. Lot 2 could not find evidence of this in Query Log.	Query log did not have evidence of ReportSpecifierID to be hard-coded. Lot 2 understood ReportSpecifierID to not be defined as specific value but issued from source party. Two project's understandings were that the ReportSpecifierID should be hard-coded, but were unable to provide email confirmation of such discussions, and so in the end made the changes not to hard-code. A more transparent process for the PAS Query Log could help to avoid such cases in future.
F4	Technical Recommendations (OpenADR 2.0b)	Projects using different OpenADR 2.0b implementation (i.e. GridFabric and OpenLEADR) are not fully interoperable	ESA/CEM and DSRSP pairings when based on different OpenADR 2.0b stacks (GridFabric and OpenLEADR) have interoperability issues. Using the same OpenADR 2.0b source implementations would remove these issues. Grid Fabric is a commercially available solution. Mandating this would create an anti-competitive environment which would force implementors to pay for a proprietary offering. An alternative could be for equivalent VEN and VTN implementations to be created from an existing open-source offering which can then be certified as OpenADR 2.0b conformant. These could then be freely available to companies implementing DSR in the UK, lowering the bar to entry and avoiding any commercial lock-in.

ID	Area	Observation / Challenge	Key Finding / Recommendation
F5	Technical Recommendations (OpenADR 2.0b)	OpenADR 2.0b protocol inefficiency with pull mode, and further message size analysis	Large log capture file sizes were observed during demonstrations e.g. around 150MB for an 8 hour capture with 7x ESAs. Further analysis was performed on this set of example logs revealing that this would extrapolate to around 680 Megabytes / second DSRSP traffic (combined upload and download) for example for one million ESAs. It was found that around 96% of the PAS interface A traffic was for oadrPoll / oadrResponse message exchanges. It is recommended that a more efficient protocol is employed to ensure that the DSR system is scalable without excessive cost implications. It is suggested that further assessment of communications bandwidth requirements are inspected again for example after any amendments to the PAS specification to ensure a scalable and reliable DSR system.
F6	Technical Recommendations (PAS 1878 Annex G)	Lot 2 referring to WiP document [7]for conformance naming of reportName, rID	Provide authorised documentation to all interested parties with values for all required hard-coded values.
F7	Technical Recommendations (PAS 1878 Annex G)	Projects referring to incorrect, and undefined XML example screenshots (Annex G) for defined payload/elements	Provide specific and defined elements for payloads.
F8	Technical Recommendations (PAS 1878)	Metering requirements are not defined in PAS 1878.	PAS 1878 doesn't mention about the metering requirements, and no guidelines are provided for the manufacturer regarding how to measure the power when the ESA is in response mode. Any electricity meter used for billing purposes must be approved by the GB national legislation or the European Measuring Instruments Directive (MID 2014/32/EU - previously 2004/22/EC). If the customers participating in DSR event are going to be financially rewarded to encourage adopting DSR capable appliance (at an added cost) and participate in DSR services, the metering requirements will have to be defined at this stage, while the products are under development. For example, smart meters could be mandated to ensure support for

ID	Area	Observation / Challenge	Key Finding / Recommendation
			half hourly power readings and twin element meters could be used to enable separate billing for DSR products.
F9	Technical Recommendations (PAS 1878)	The PAS 1878 defined mechanism for flex offer generation may limit the flexibility available to the DSRSP to select from.	The ESAs generate flex offers based on the ToU tariffs and the user preferences. For the ESAs 1 & 2, the user, in addition, has to provide the start and end time, and this is used for generating the offers, and any offer will have to be selected by the DSRSP before the start time of the offers. Such an approach will mean that the DSRSP will have only a limited number of ESAs available for participating in a DSR event, as some of the ESAs that could have participated in the event will not be able to do so since their start time has already passed. Instead, if the DSR requirements are shared with the ESAs prior to it generating the flex offers, then the ESA can adjust its flex offer start time, making itself available for a DSR event.
F10	Technical Recommendations (PAS 1878)	A common set of required user details for registration have not been defined.	The details that a customer needs to provide for registration with a DSRSP varies across each project. Some projects require only the CEM fingerprint, while other projects require more details including ESA serial number, VEN name. To ensure interoperability, guidelines on what details should a customer be expected to enter when registering with a DSRSP must be defined within the PAS specifications. This will ensure the registration process followed by each service provider will be uniform, and interoperable. Without this guideline, a DSRSP could end up asking information which certain customers do not have access to, preventing them from registering with this DSRSP.
F11	Technical Recommendations (PAS 1878)	SSL Certificates expire and need to be renewed.	Currently the projects use SSL certificates for mutual authentication. The maximum validity for these certificates is 397 days, after which they will have to be renewed. Renewing a certificate changes its fingerprint, which will then cause issues with the registration, as the fingerprint was used for authenticating a CEM.

ID	Area	Observation / Challenge	Key Finding / Recommendation
F12	Technical Recommendations (PAS 1878)	CEM to DSRSP communication from a static IP address.	Some of the projects required the IP address from which the CEM traffic originate from to be whitelisted within their firewall to enable the communication between the CEM and the DSRSP. This requires the CEM to have a static IP address, which would be difficult for systems with a hardware based CEM, as most household's internet will not have a static IP address. A cloud based CEM could be implemented with a static IP address, thus enabling the DSRSP to implement security features and allow access to only authorised devices. A DSRSP with firewall and IP whitelisting will be better protected against any cyber attacks
F13	Technical Recommendations (PAS 1878)	The failed registration use case is not defined.	The PAS standard currently doesn't clearly define how the system will handle a failed registration process. This has caused several interoperability issues for Lot2. When a CEM tries to register with a DSRSP, the DSRSP generates a VEN ID for the device, and if the registration has failed, it is not clearly defined how to handle this, creating issues when the CEM tries to register with the DSRSP again.
F14	Technical Recommendations (PAS 1878)	The frequency of CEM to DSRSP messages needs to be defined.	The DSRSP specifies the frequency at which the CEM can send the oadrPoll messages, and for the other messages, it is up to the CEM to decide how frequently it can be sent. Lot2 have seen several instances where the CEM goes into an error state and keeps sending the same messages to the DSRSP, ignoring any error messages in the response from the DSRSP. This can be handled by strictly implementing error handling within the CEM and defining how the CEM should respond to these error messages rather than sending the same messages again. Lot2 had seen instances where the CEM kept sending the same message repeatedly, causing huge traffic at the DSRSP side, overwhelming it and preventing its normal operation – this highlights the importance of properly testing any CEM, and any of its firmware updates in a lab environment before being deployed in the real world, especially if the DSRSP is considered a critical grid infrastructure.
F15	Technical Recommendations (PAS 1878)	Guidelines for permissible values are required.	Lot2 faced several interoperability issues as different projects used characters or words that certain DSRSP didn't accept. For e.g., the colon delimiter ':' within serial number of the ESA 1 & 2 devices were not accepted by DSRSP 6, a manufacturer name of 'None' within the ESA details of system 3 was rejected by the DSRSP 1. These issues resulted in the registration attempts to fail and can be avoided by

ID	Area	Observation / Challenge	Key Finding / Recommendation
			providing guidelines on what characters and values are allowed within each field. [Query No]
F16	Technical Recommendations (PAS 1878)	No central registry of CEM to DSRSP mappings exists.	A CEM can register with a DSRSP without properly de-registering from another DSRSP; therefore, DSRSP could select a CEM for a DSR operation, even though the CEM has tried to register with another DSRSP. A means to confirm CEM to DSRSP mappings is required.
F17	Wider implications (PAS 1878)	Emulated ESAs could potentially be used to game the system.	There is no method defined to verify if an asset is real or emulated – if customers are compensated for participating in DSR event, people could setup emulators to influence the compensation, particularly if the aggregator does not have access to household actual power data via the metering system.
F18	Wider implications (PAS 1878)	Cybersecurity requirements.	Cybersecurity requirements like secure boot, tamper detection etc need to be defined early while the DSR products are being developed to avoid expensive hardware redesigns – for e.g., when EV smart charge point regulations were introduced, this forced several EV charge point manufacturers to completely redesign their hardware, costing time and money.
F19	Recommendations for Future Interop Work (PAS 1878)	Unexpected ESA performance.	The presence of unexpected behaviours of the ESAs indicates potential inconsistencies in performance, which may require additional monitoring and troubleshooting. Further demonstrations and monitoring are required in this area.
F20	Wider implications (PAS 1878)	Effectiveness of DSR during an event when availability changes.	The transition of ESA to routine mode after a consumer override demonstrates that manual overrides are functioning as intended, but the lack of new DSR requests during this transition signifies a gap that could compromise demand response effectiveness. This relates to DSRSP logic and consumer preferences / start times.
F21	Wider implications (PAS 1878)	Effectiveness of DSR where actual power usage does not match forecast.	The failure of the ESAs to meet their SoC targets raises concerns about the effectiveness.

ID	Area	Observation / Challenge	Key Finding / Recommendation
F22	Wider implications (PAS 1878)	Effectiveness of DSR, tariffs not influencing LD and MD profiles.	The ability of devices to shift power consumption to lower-cost periods demonstrates some degree of flexibility, but the lack of change in flex offers (MD and LD) indicates a potential underutilization of tariff structures.
F23	Wider implications (PAS 1878)	Unexpected ESA performance.	There were instances where the ESA 1 started discharging without any previous schedule, leading their entry into Failsafe mode. This indicates a need for close monitoring of SOC levels to prevent such situations.
F24	Technical recommendations (PAS 1878)	Power report readings with granularity of "PT0S" which is a valid value in [1], thus causing divide by zero error within CEM system, and no power reports issued.	Define power report granularity to be non-zero.
F25	Programme Lessons Learnt (PAS 1878)	Two sources of information; PAS 1878 and PAS Query Log.	There are two separate definitions for flex offer selection defined in the PAS 1878 and PAS query log that do not interoperate. We recommend that the definition in the PAS1878 2021 is replaced with the definition in the PAS query log.
F26	Technical recommendations (PAS 1878)	Mismatch in requirements between ESA and DSRSP actual power reporting types.	ESA may support one or both power reporting types. However, the DSRSP shall have the capability to process both reporting types but may negotiate its own preferred reporting type if an ESA supports both.
F27	Technical recommendations (PAS 1878)	There is not a clear distinction between flexibility offer compared to flexibility offer 'update' in PAS 1878.	Amend any relevant sections of PAS 1878 to explicitly define what a "flexibility offer" and a "flexibility offer update" are (how to distinguish them), when they shall or shall not be triggered, and what they shall or shall not include. Also to define when the DSRSP shall expire or is permitted to purge an ESAs offers
F28	Technical recommendations (PAS 1878)	The minimum set of mandatory profiles does not align with all potential ESA implementations and/or states.	Clarify in PAS 1878 that an ESA may issue LD_P, MD_P profiles but not LD, MD profiles as part of its mandatory set e.g. fully charged battery during initialisation.

ID	Area	Observation / Challenge	Key Finding / Recommendation
F29	Technical Recommendations (PAS 1878)	ESA providing periodic updates for the IO power profile at intervals of 15 minutes or less.	The intended goal for updates as clarified in PAS 1878: "In order to minimize the number of updates required, this event triggered update approach is specified as opposed to an approach of providing updates continuously at regular intervals". Further clarifications or guidelines may be necessary in PAS 1878 to account for ESA implementations whose power profiles are always changing e.g. to restrict the frequency of profile updates for such an implementation.
F30	Wider implications (PAS 1878)	We conclude that PAS 1878 does not define a truly flexible approach that allows a DSRSP to transition an ESA from one active profile (routine or response mode) to another active profile (routine or response mode). Instead, the approach in PAS 1878 is reliant for example on waiting until the end of active mode for the ESA to trigger a valid flex offer update which the DSRSP can apply a DSR algorithm to at any moment in time. For some ESA implementations this could result in the ESA becoming "stuck" in active routine mode for very long periods of time or even indefinitely.	Further consideration to PAS 1878 seems necessary to ensure that a DSRSP can always perform demand side response for all connected ESAs, even during active periods. This may include consideration of: • Flex offer updates during active periods e.g. periodic (section 5.5.2 of PAS 1878) • DSRSP flex offer update request mechanism • PAS defined or ESA defined flex offer validity duration during active periods Further demonstrations could help to inform this process by more closely investigating all ESA flex offer profile updates when transitioning from active routine mode to response mode, and when transitioning from active response mode to routine mode

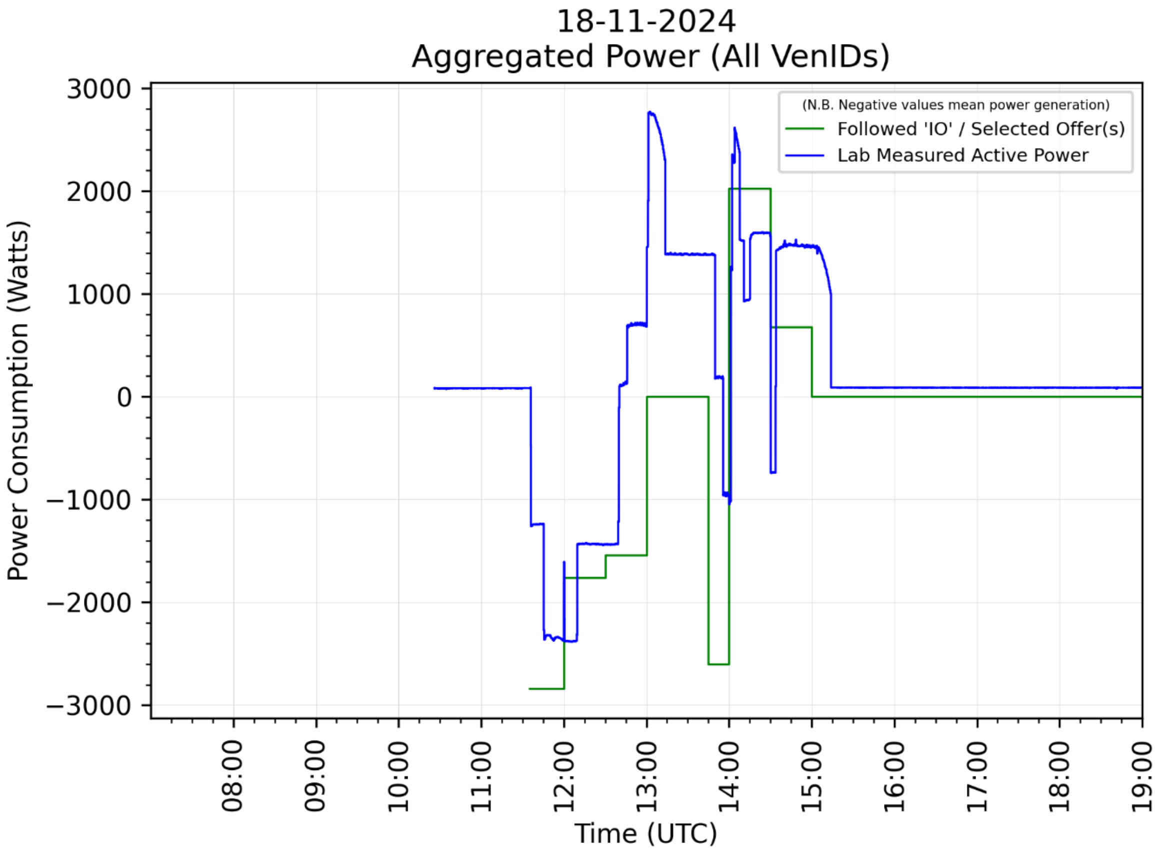
ID	Area	Observation / Challenge	Key Finding / Recommendation
F31	Technical Recommendations (PAS 1878)	There are multiple references to flex offer expiration. However, expiration itself is not defined	The condition(s) under which flex offer profiles expire should be defined in PAS 1878. Guidelines may also be necessary regarding profile lead times to avoid expiration e.g. for LD or IO profiles. These should consider any specific handling for 'IO' profile updates, if necessary, e.g. there should not be any lead time applied to 'IO' profiles during active routine mode updates.
F32	Technical Recommendations (PAS 1878)	During demonstrations, we have observed an ESA implementation which sends flex offer updates for the LD/MD profiles which are the same flex profile, except time cropped from the time of message onwards	It should be clarified in PAS 1878 that a flex offer update shall not be triggered for a profile which is the same as the previously issued profile except cropped from the time of the flex offer update message onwards.
F33	Wider implications (PAS1878)	Synchronisation of the randomised offset across the ESA and the smart meter	PAS 1878 specifies that the ESA shall be capable of applying a randomised offset to the IO profile. Within a household, it is the smart meter which applies an offset to the ToU tariff and to any of its load control devices like the SAPC. The offset that the ESA applies to the IO profile must be synchronised with the offset within the smart meter to ensure the IO profile follows the ToU tariff periods accurately.
F34	Technical Recommendations (PAS 1878)	During demonstrations, we have observed in pull mode operation an ESA/CEM not implementing acknowledgements to DSRSP initiated actions, and separately observed a DSRSP from a different manufacturer not validating these acknowledgements. This will compromise data integrity over interface A.	The specifications do not explicitly (clearly) require the ESA/CEM to send acknowledgements to DSRSP initiated actions e.g. flex selection, and this is particularly easy to overlook during pull mode operation. Equally the importance of the DSRSP validating these actions is not explicitly stated in the specifications. We conclude that further definition or clarification (or change) is required to the relevant specifications to avoid this potential data integrity and interoperability problem in future implementations. N.B. Clarification seems necessary regardless of whether pull mode or push mode operation is used.

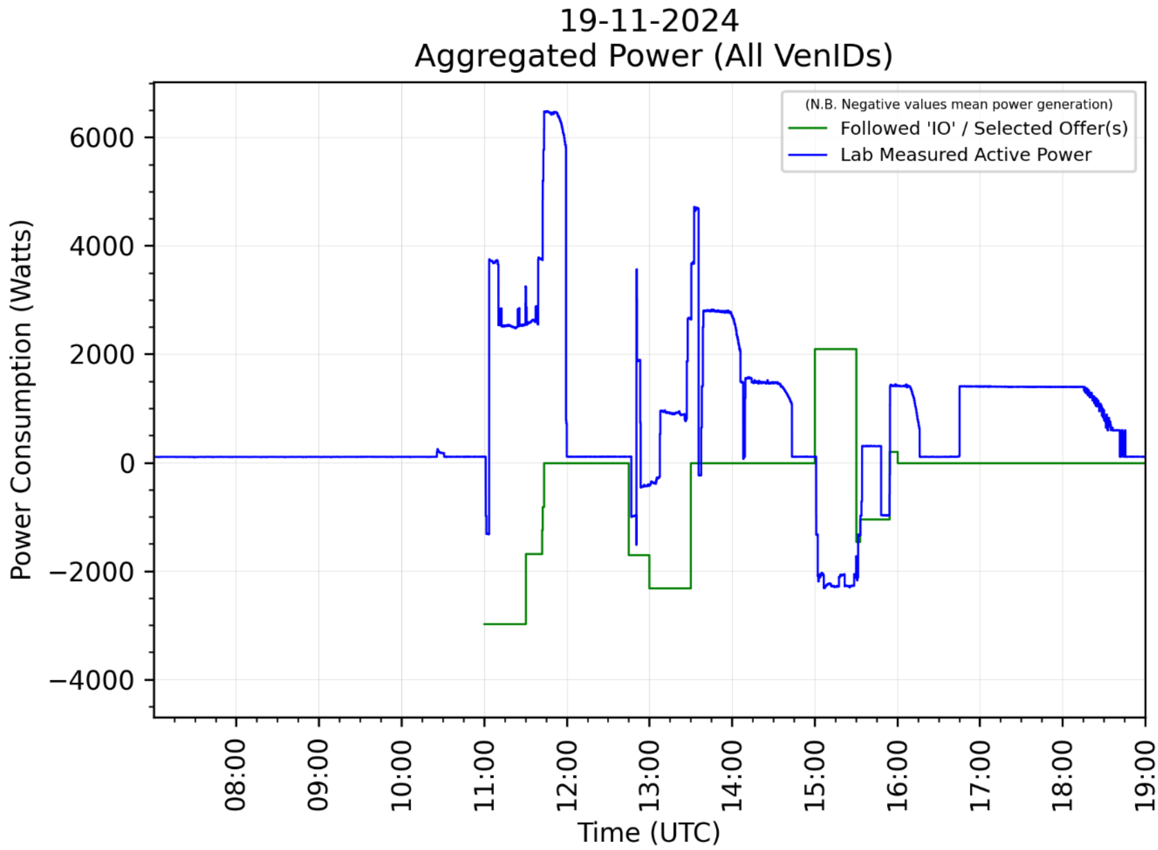
ID	Area	Observation / Challenge	Key Finding / Recommendation
F35	Recommendations for Future Interop Work (Performance)	Management of cancellation failures.	Addressing the identified cancellation processing failures, and the integrity of reporting mechanisms will be essential in optimizing performance and ensuring reliable operation during future demand response events.

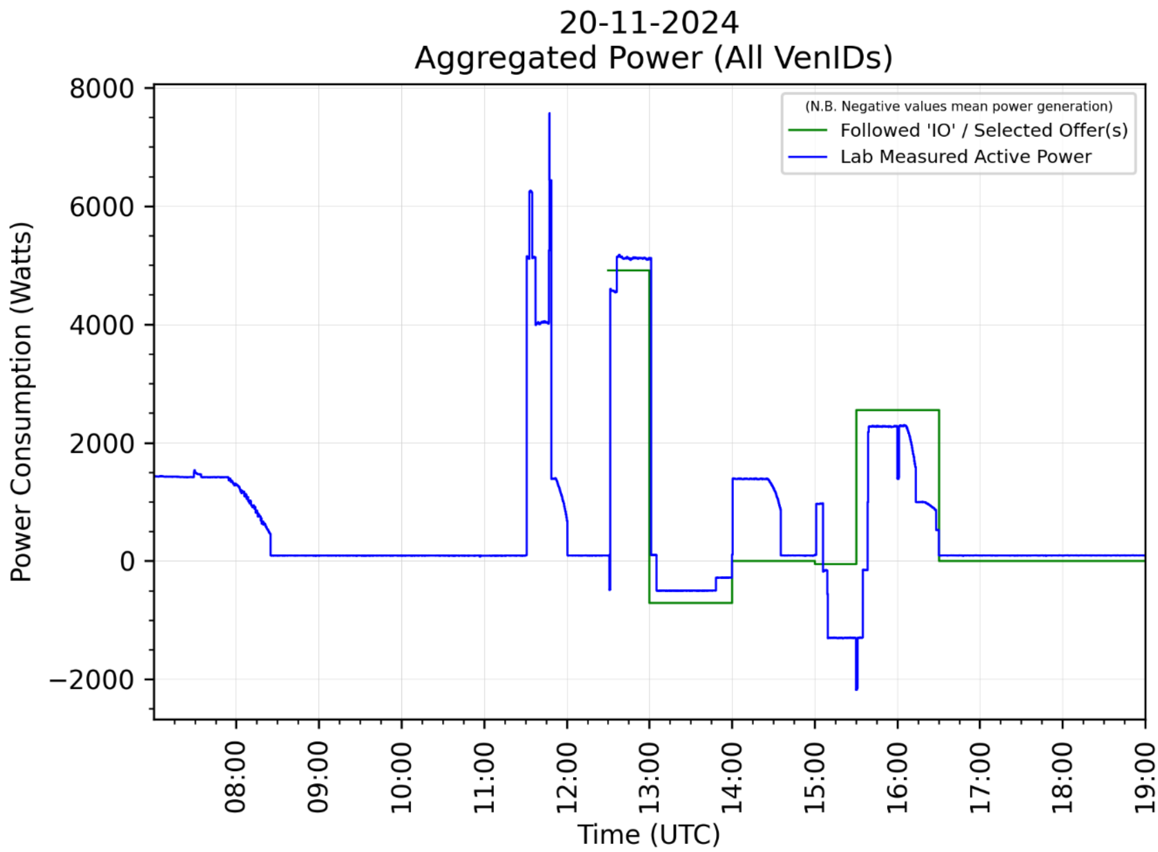
Table 8: Table of IDSR Stream 4 Lot 2 project key findings

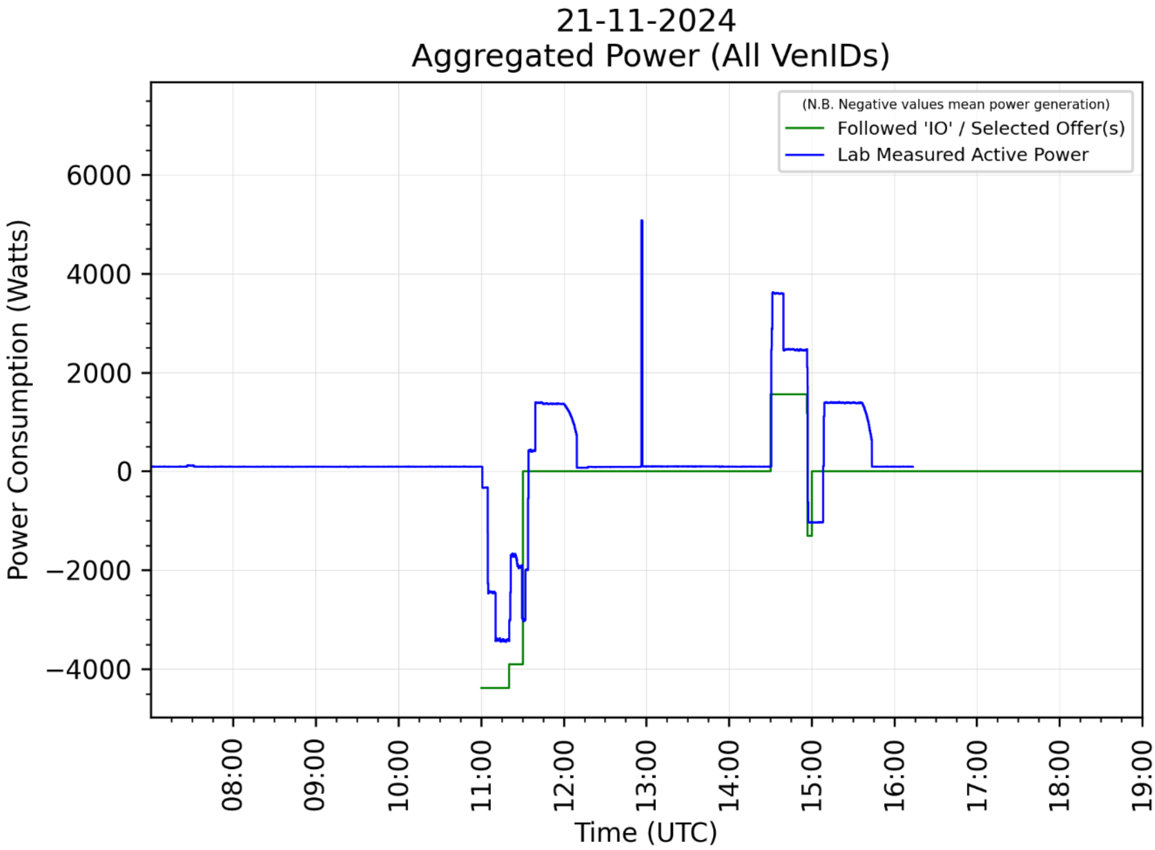
Appendix A Aggregated Graphs (All Demonstration Days)

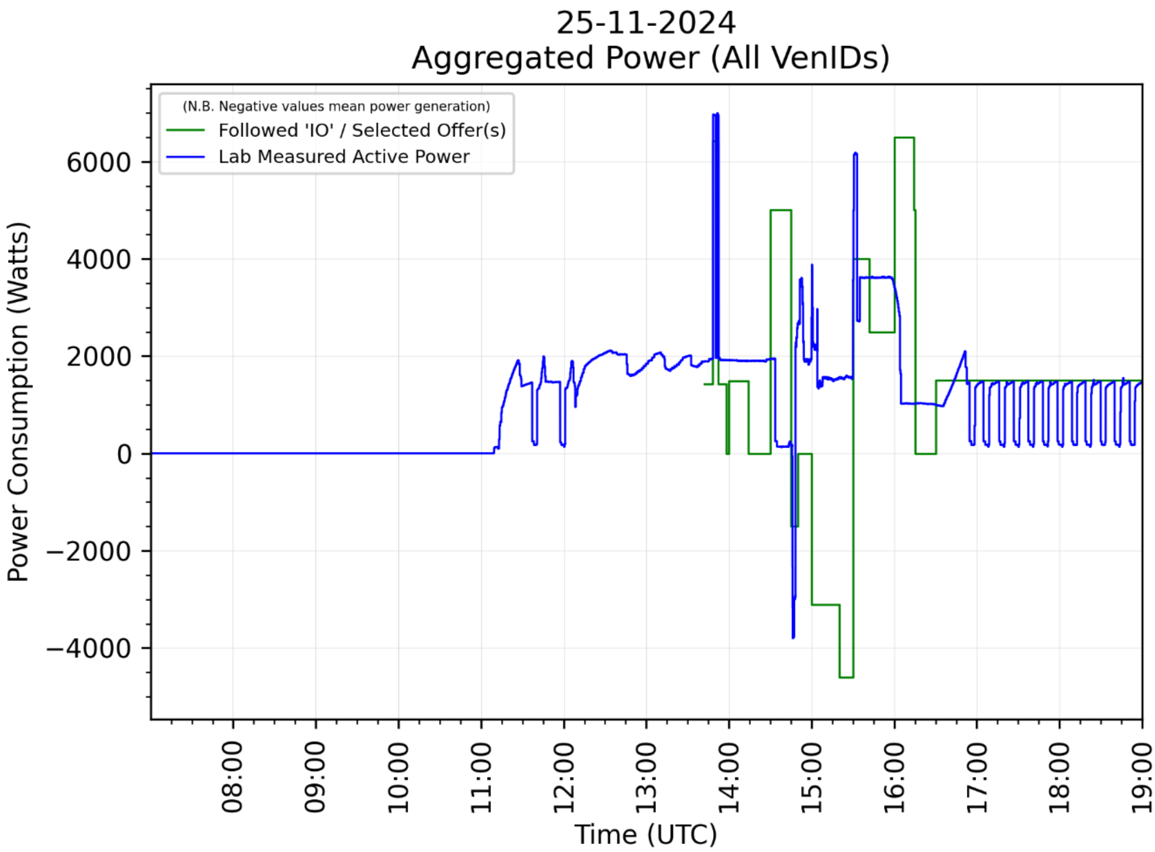
A full set of aggregated power profile graphs is included below from all demonstration days, comparing all followed / selected forecast data and the corresponding laboratory measurements (for all ESAs on each day).

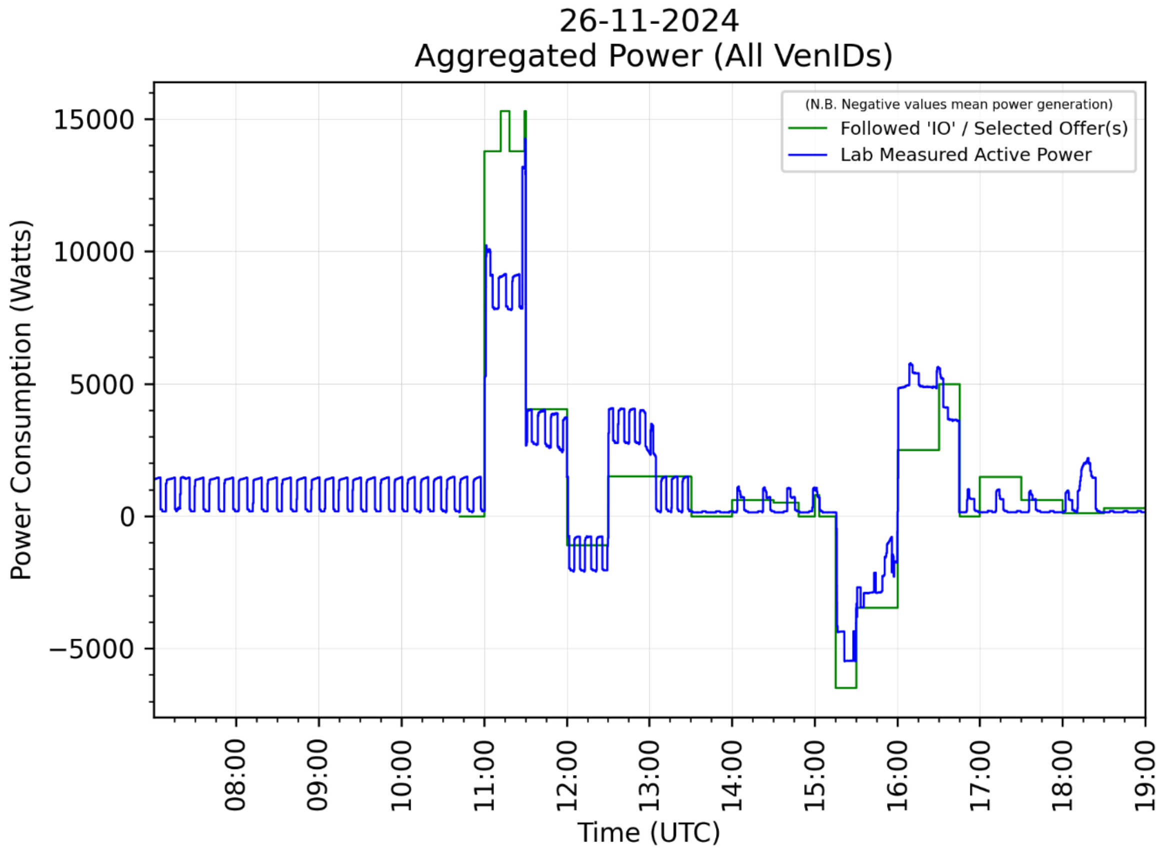


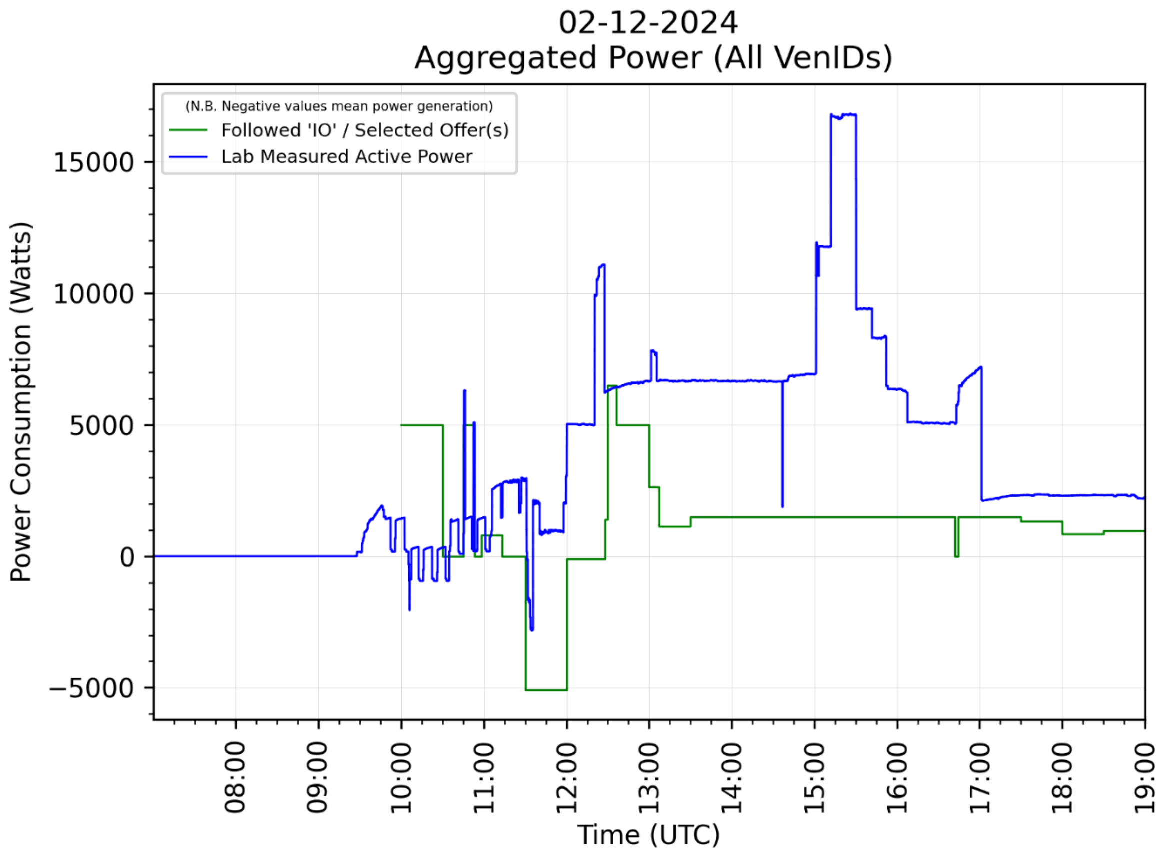

19-11-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
6000
4000
2000
0
−2000
−4000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)

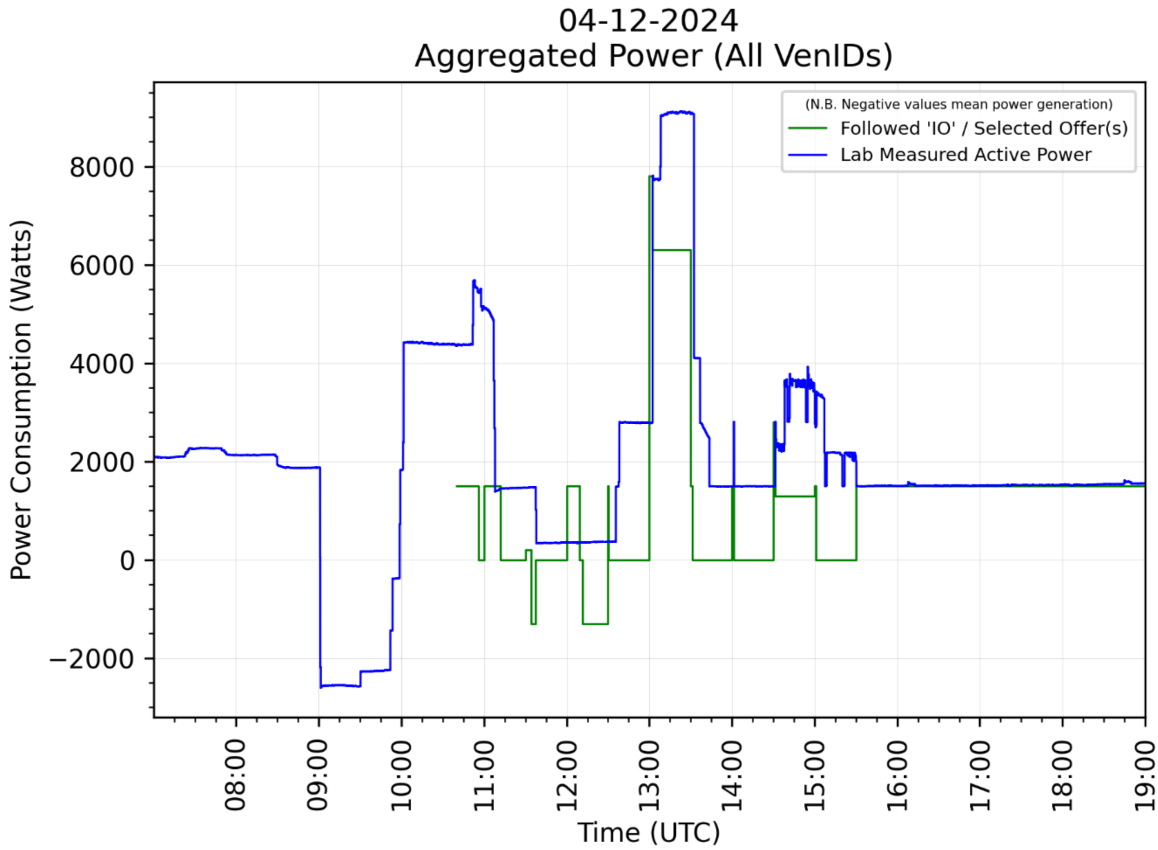

20-11-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
8000
6000
4000
2000
0
−2000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)

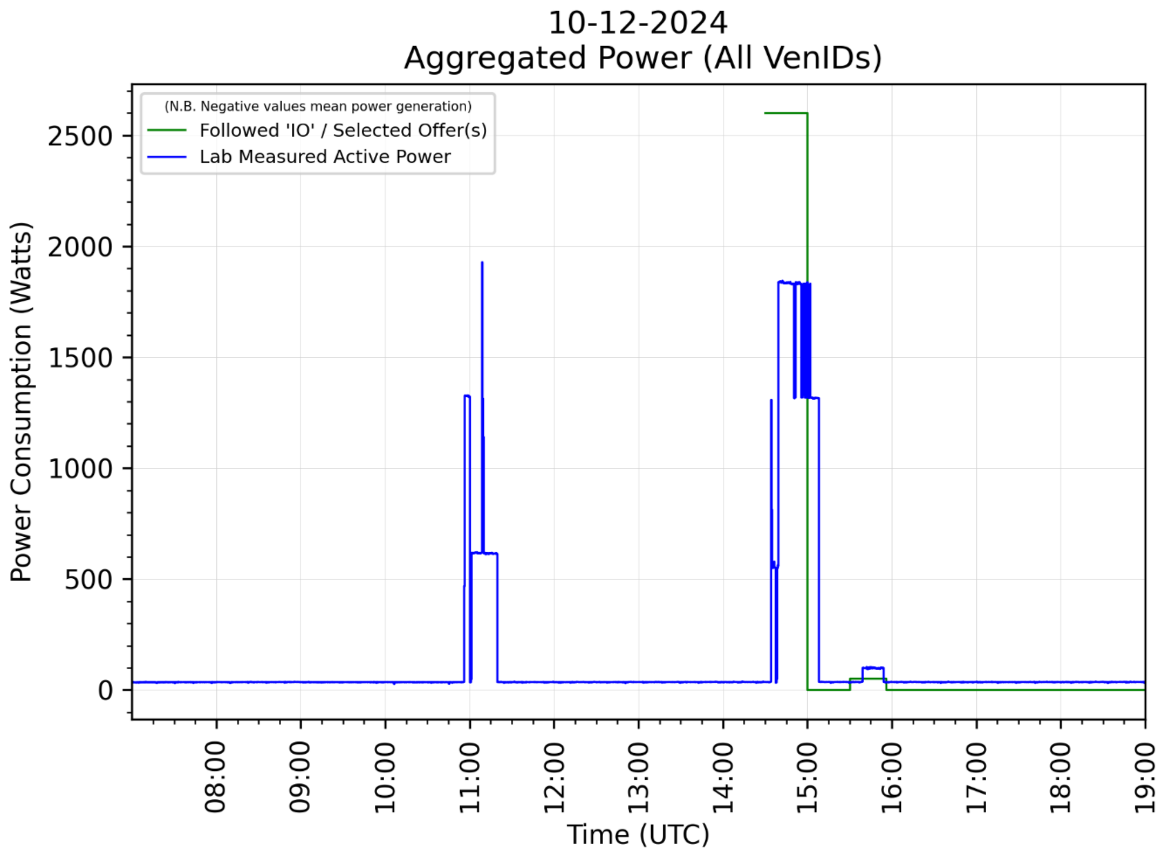

21-11-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
6000
4000
2000
0
−2000
−4000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


25-11-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
6000
4000
2000
0
−2000
−4000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


26-11-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
15000
10000
5000
0
−5000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


02-12-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
15000
10000
5000
0
−5000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


04-12-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
8000
6000
4000
2000
0
−2000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)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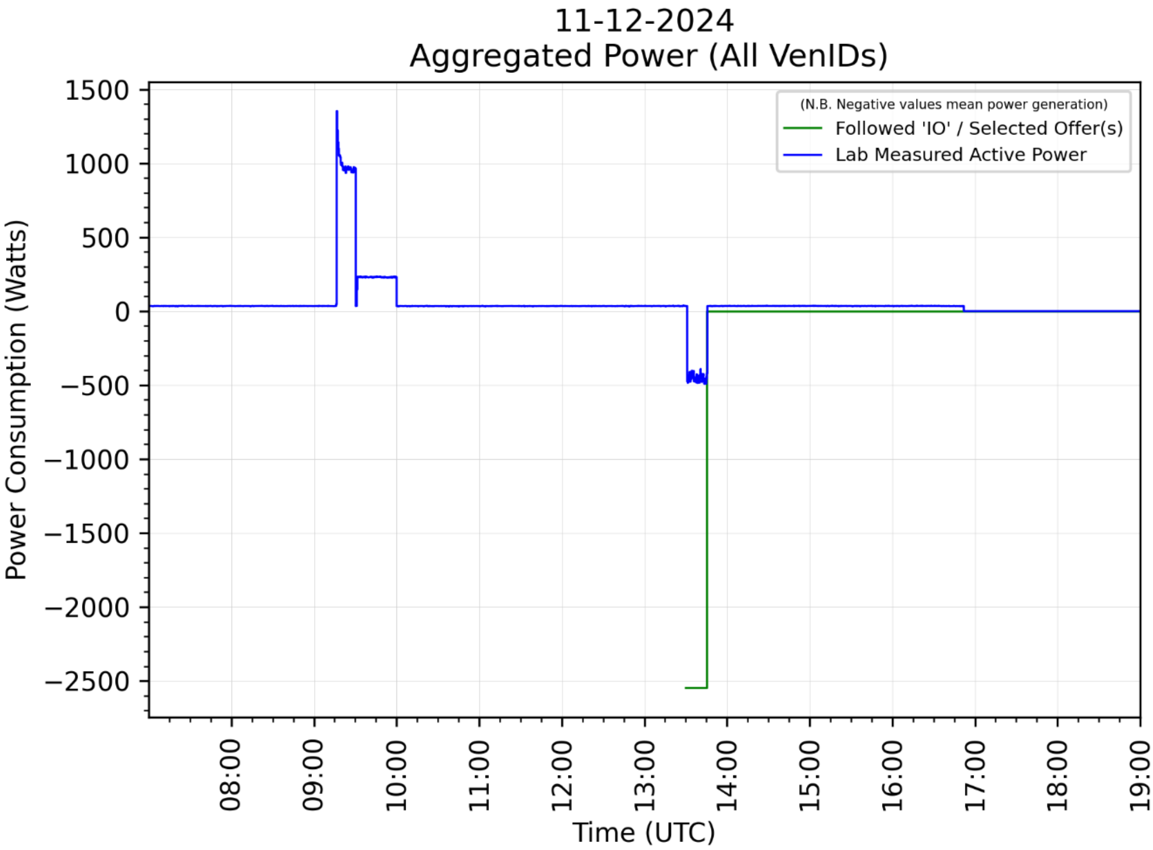
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
2500
2000
1500
1000
500
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


11-12-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
1500
1000
500
0
−500
−1000
−1500
−2000
−2500
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
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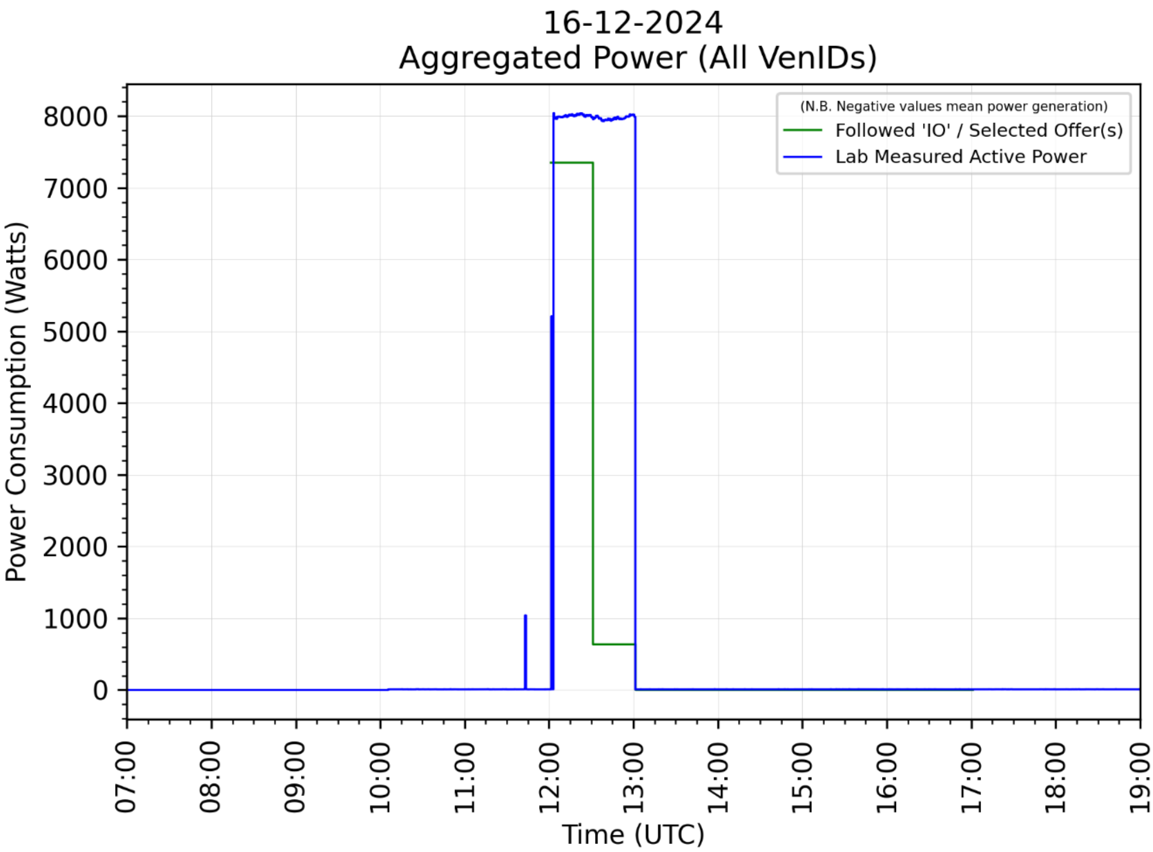
18:00
19:00
Time (UTC)


16-12-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
8000
7000
6000
5000
4000
3000
2000
1000
0
07:00
08:00
09:00
10:00
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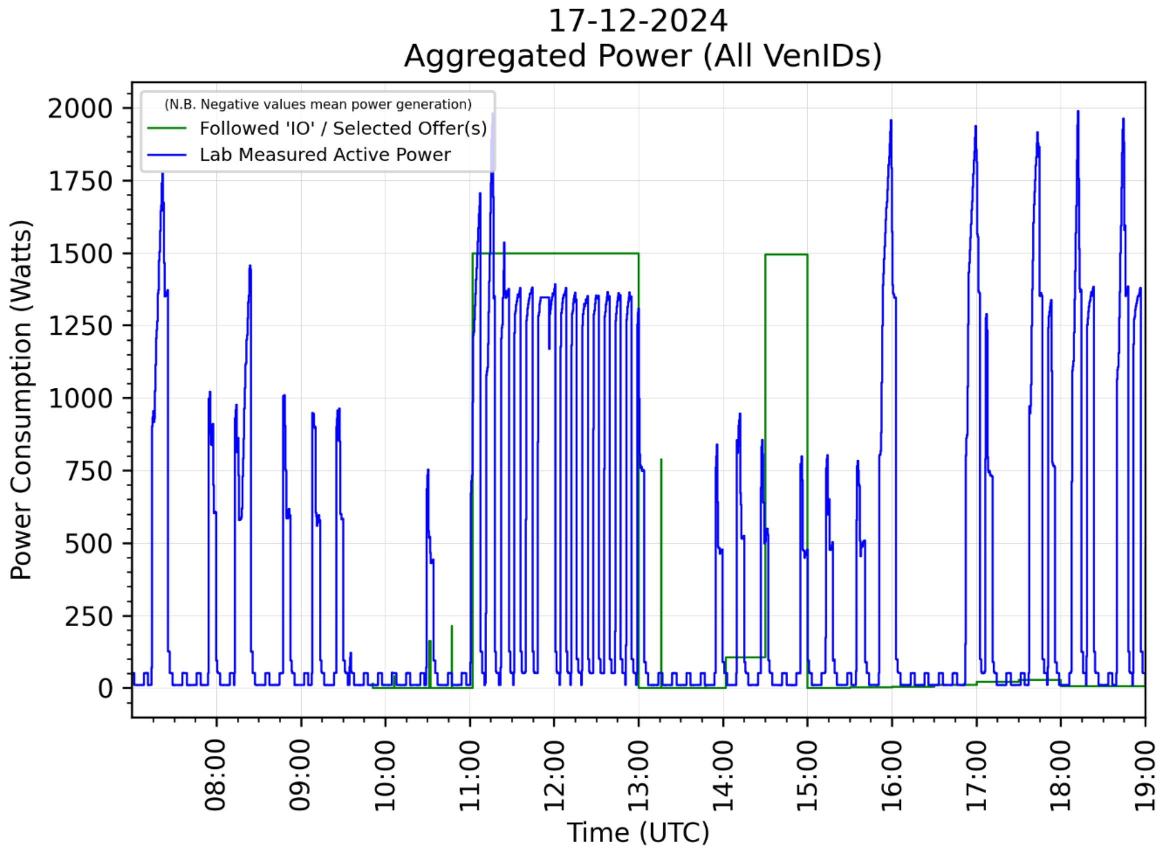
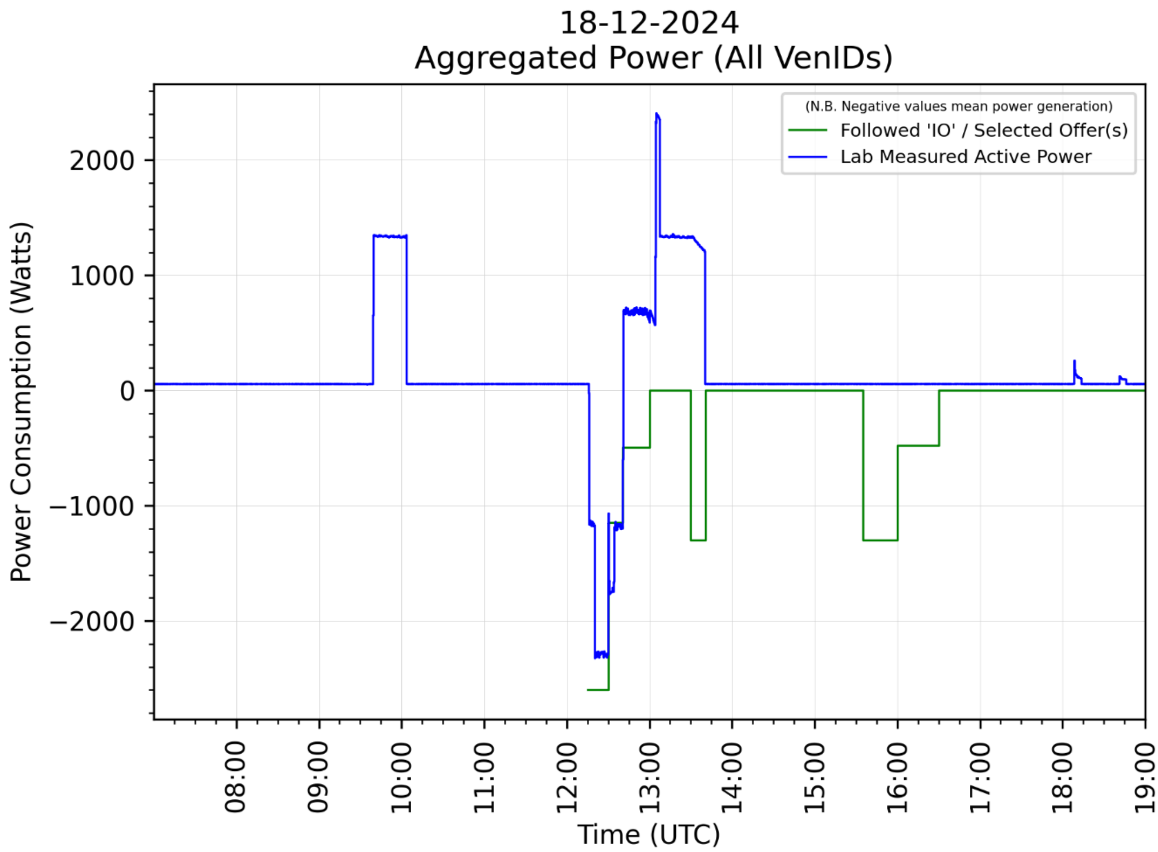
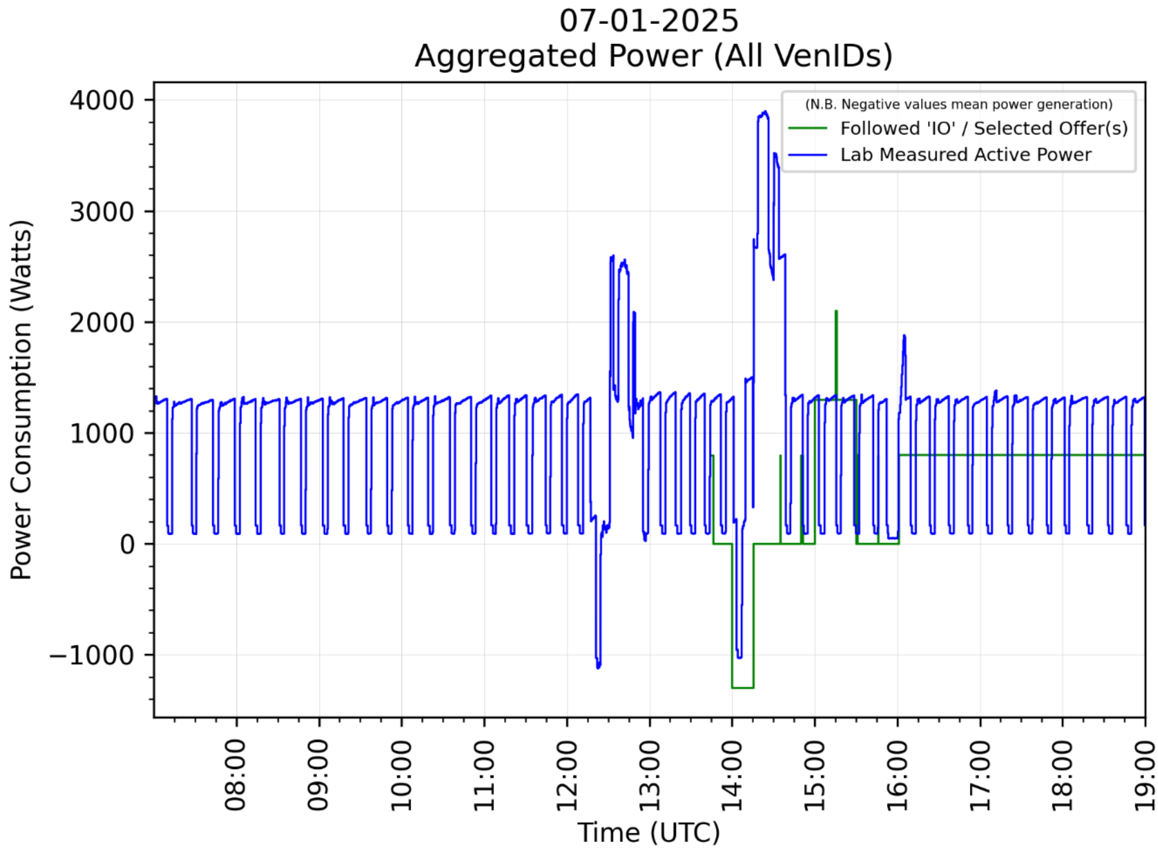
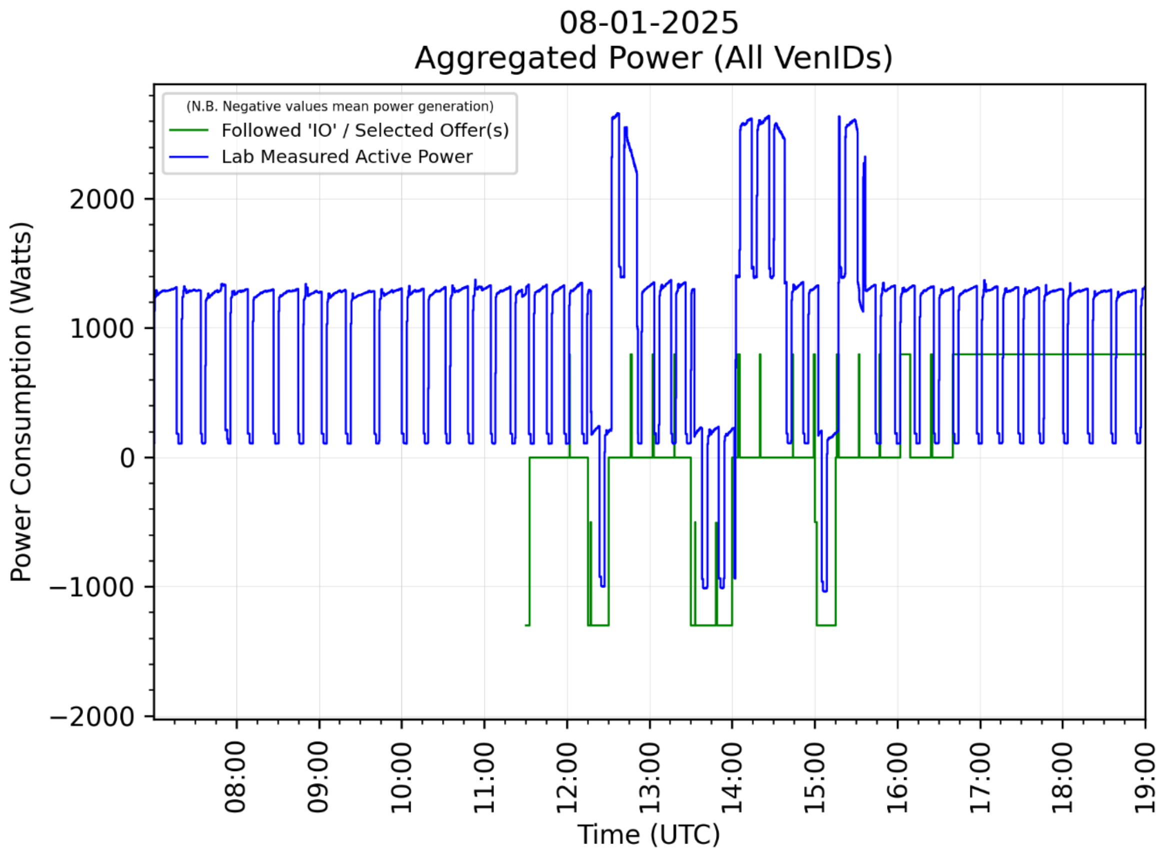
18:00
19:00
Time (UTC)


17-12-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
2000
1750
1500
1250
1000
750
500
250
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


18-12-2024
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
2000
1000
0
−1000
−2000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


07-01-2025
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
4000
3000
2000
1000
0
−1000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)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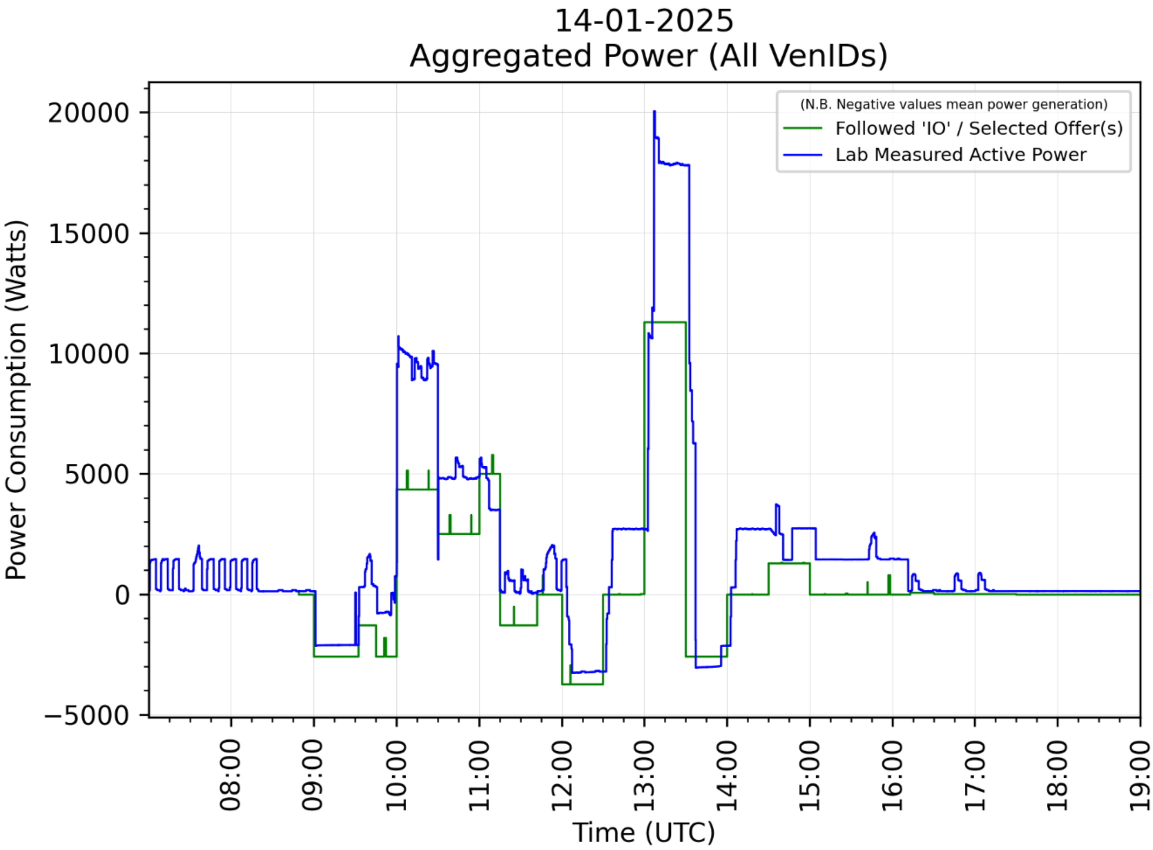
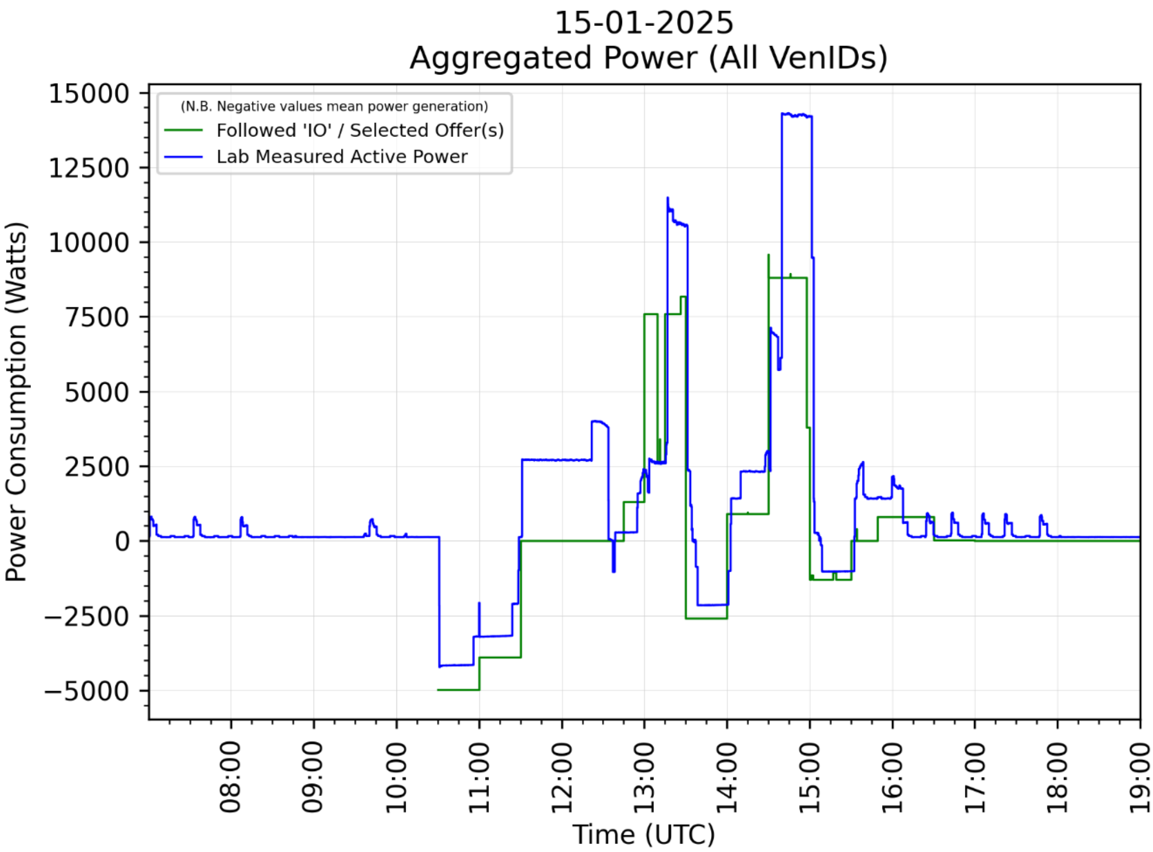
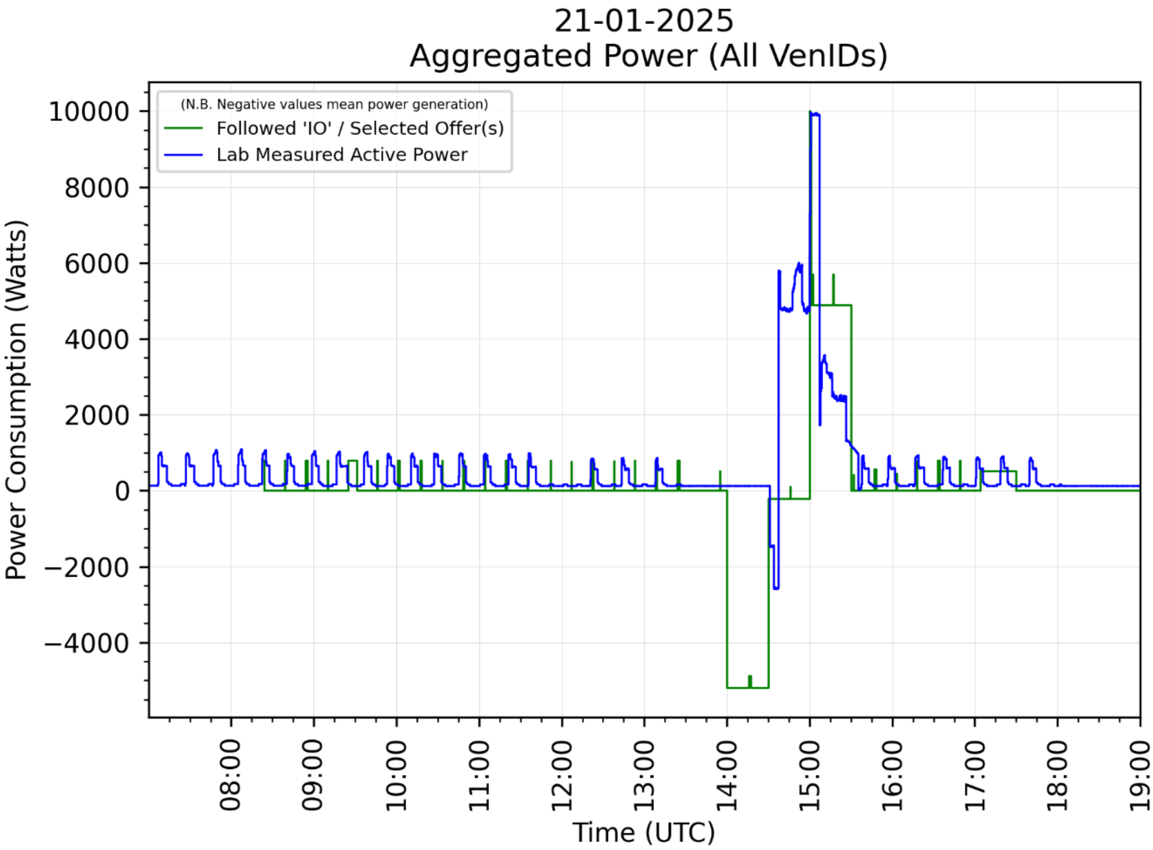
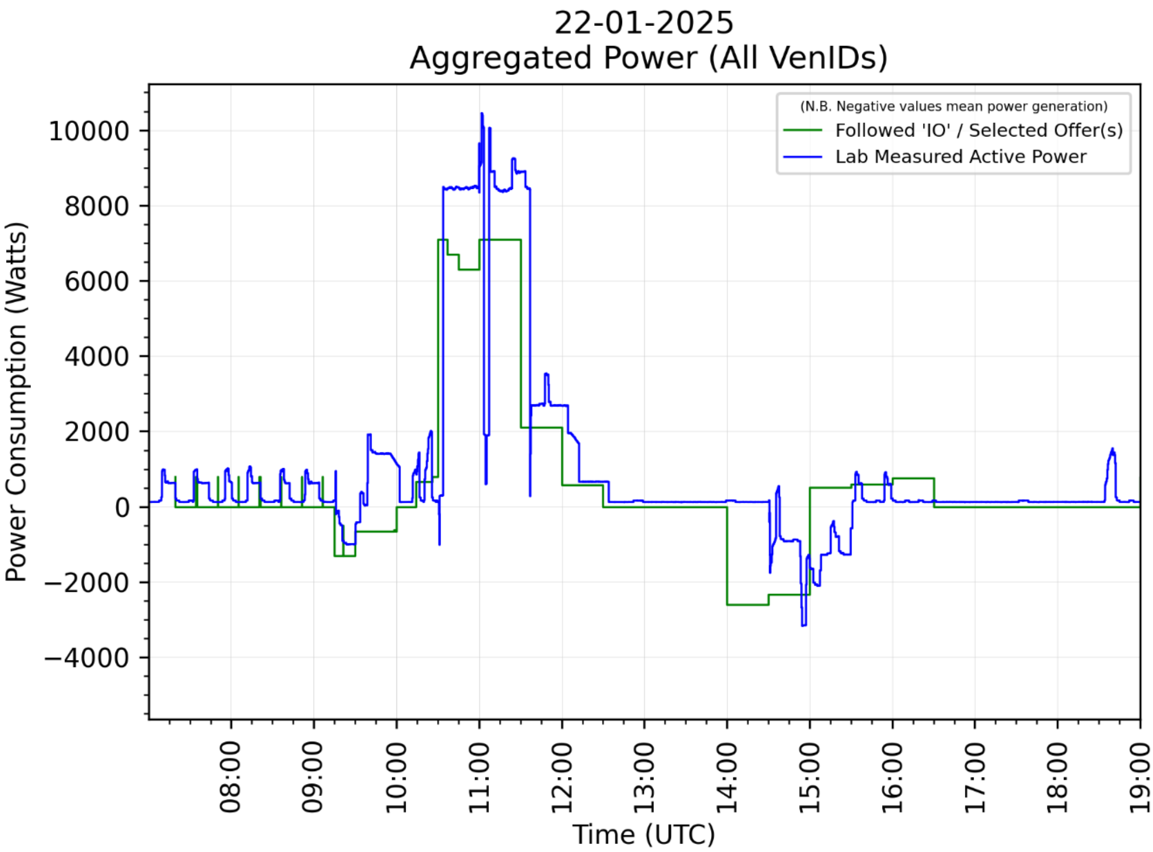
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
2000
1000
0
−1000
−2000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


14-01-2025
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
20000
15000
10000
5000
0
−5000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


15-01-2025
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
15000
12500
10000
7500
5000
2500
0
−2500
−5000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


21-01-2025
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
10000
8000
6000
4000
2000
0
−2000
−4000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)


22-01-2025
Aggregated Power (All VenIDs)
(N.B. Negative values mean power generation)
Followed 'IO' / Selected Offer(s)
Lab Measured Active Power
Power Consumption (Watts)
10000
8000
6000
4000
2000
0
−2000
−4000
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (UTC)