People's Power Station 2.0

Developing a digital environment that creates value through Smart Community Energy Systems

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Executive summary

This report documents the ongoing development of the People's Power Station 2.0 (PPS2.0), a highly innovative digital environment that acts as an enabler for both creating and capturing value through a focus on Smart Community Energy Systems (SCES).

The approach taken is based on the premise that greater overall value can be created and distributed equitably when individuals, local businesses, community organisations, network operators, and other local stakeholders cooperate and collaborate for mutual benefit.

The value created through local interaction can be translated into benefits such as lower energy bills, improved services or brand image, faster deployment of electric transport and heat, lower network infrastructure costs, or enabling individuals who wish to contribute actively to a zero-carbon energy system.

It is widely argued that a zero-carbon energy system will require a highly decentralised model, with greater emphasis placed on the edge of the network where energy is used, in combination with increased use of small-scale local generation, storage, and flexible demand. Smart Community Energy Systems can be both a vehicle for and accelerate the transition to a mostly electrified energy system.

Such model would require a radical transformation of the entire energy system, not dissimilar to the one that changed the internet and telecommunications systems at the turn of the century, with opportunities until them unimaginable being opened up in an environment driven by innovation, disruptive technologies, and entrepreneurial spirit.

The scale of such systemic changes is not achievable without fundamental transformations and, if equity and wider sustainability are indeed as important as resilience and zero carbon, those changes must reach individuals and involve how they make decisions related to energy use, inside and outside their home.

The PPS 2.0 is a cloud-based digital platform developed as part of Local Energy Oxfordshire (LEO) project, and built upon technology developed by Fractal Networks, to help solve a number of interface issues, in particular around controlling renewable technology systems as part of the flexible, smart energy system of the future. Setting the context for the choices made in the conceptual design of the PPS 2.0, an attempt is made to describe the energy system with often-used analogies from natural ecosystems, with the energy system as a biome and communities micro-climates within that biome. From this perspective Smart Community Energy Systems are ideally suited to meeting the specific requirements of local areas in relation to their particular energy needs, as well as accelerating the deployment and uptake of zero-carbon technologies.

The ecosystem analogy helps set the strategy for Smart Community Energy Systems and two business models are described, one based on an incremental approach, and the other focused on rapid market penetration and scaling-up. Both models take into account the critical role disruptive digital technologies play in the transformation of the system, alongside what has been identified as a technology gap. Using the internet as an example once more, its transformation from a small niche tool to its current pervasive presence would not have happened without the innovations and wide-spread deployment of digital telecommunications technologies able to exploit as well as add to it.

The PPS 2.0 fills that technology gap within the current energy system. Fractal Network's use of an iterative and agile process with rapid cycles of design, deployment, testing, and user-feedback, shows how it can speed up deployment times, reduce risk and upfront costs, as well as maximise the value creation potential of any new products.

At the core of this agile development process lies our unique approach of defining the energy system as composed of fractals, which allows for a high degree of flexibility and adaptability, and ensures our development stays focused on what drives value creation. Live trials provide real use cases to develop new functionality and gain invaluable feedback from users that inform further developments. A summary for each of the trials in this report describes their objectives and outcomes, with dashboards being used to show in visual format what is being trialled and some of the outcomes.

These live trials have also demonstrated technical feasibility, revealed some significant challenges, as well as the significant opportunities afforded by working directly with local residents and communities. Indeed, the evaluation of the trials has also provided important insights into challenges and barriers to the implementation of truly decentralised smart energy systems of *any* type, challenges which span the entire policy, regulatory, and technical domains. Most encouragingly, though, they show Smart Community Energy Systems afford many opportunities for value creation.

The trials also allowed to gather information needed for a cost analysis, which feeds into the business models being analysed, including projections for the long-term cost curve as well as further investments required in the innovation phase of development.

The last part of the report provides a high-level description of the implementation of the IT backbone that supports the PPS 2.0's entire digital environment, and how scalability and accessibility can be achieved through the use of state-of-the-art open-source software tools.

The required pace and scope of transformation in the energy system, critical for meeting the needs of a zero-carbon energy matrix as well as countries' binding carbon targets, present many challenges in different domains including technical ones, equity, policy, and the regulatory framework among others. This pressing need also presents unique opportunities for communities of local stakeholders to shape and accelerate this much needed transformation through a model where value creation is based around mutual benefits and is distributed equitably.

The role of technology in the transformation of the energy system cannot be underestimated, not for technology's sake, but as an enabler of value creation and realisation. The Project LEO trials demonstrate that highly innovative and accessible technology can be developed guided by, and supporting the aims of, Smart Community Energy Systems. Furthermore, these trials have also helped to identify potential business models not only for the technology being developed, but also for the multiple complementary roles necessary in such a system.

Fractal Networks is extremely proud to have played its role in undertaking these trials with Project LEO partners. We are pleased to be able to present this report summarising the learning and future opportunities to make the most of the People's Power Station 2.0 platform we continue to develop.

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1. Introduction

The concept of a Smart Community Energy System can be traced back to the very beginning of the Low Carbon Hub, which coincided with the announcement in 2009 of the decommissioning of the 2.0 GW Didcot-A coal-fired power station, which generated the equivalent of the total annual energy use of Oxfordshire[1].

The People's Power Station translates that concept into something tangible, proposing that the generation capacity of that old, fossil-fuel Didcot Power Station could be replaced in future by a combination of energy efficiency measures (Powering Down) and generation of energy from local renewable sources (Powering Up).

The urgent need for action in reducing CO_2 emissions led many self-organised community groups to seek ways to become active agents for change in their local areas. The Low Carbon Hub's vision of the People's Power Station proved to be a compelling one for catalysing the development of the then nascent concept of community energy organisations.

Fast-forward to 2018 and the Low Carbon Hub finds itself playing a leading role in assembling the consortium of organisations and setting some critical objectives for what then became Project Local Energy Oxfordshire (LEO). This role and the organisation's input into the project are based on its experience in investing in and deploying community-owned, small-scale renewable generation assets, as well as its close relationship with organised local communities in the county.

The stated overarching objective of Project LEO has been the development of market mechanisms for the provision of flexibility services at the distribution network level, particularly through small-scale assets. However, the Low Carbon Hub took a wider perspective in also seeking systemic change that ensured equitable outcomes, meaning therefore it was necessary to work closely with communities at very local level.

It might not have been described as such at the time, but implementing that

[1] In September 2012 RWE nPower, the owners of Didcot-A, announced the power station was to be closed in early 2013.

original vision would lead to the creation of virtual power plants acting both as aggregators of large numbers of small-scale distributed energy resources (DERs). Moreover, such plants would also coordinate the complex interactions among those DERs, seeking to optimise the whole system.

The outcomes from the deployment of such concept would be highly dependent on a number of factors, including how people and organisations participated in and interacted with the system, what value could be created and how it could be captured, the development of business models that would ensure the financial viability of such enterprises, as well as innovative digital technology that would act as enabling tools.

Those innovative technology tools could be seen as a necessary prerequisite to achieving the goal of a new energy system that is equitable, sustainable, and resilient, while at the same time unleashing the potential for wide-ranging innovation in the sector. However, the cost of such technology could easily make it accessible only to large organisations with the financial resources required to afford it and therefore represent a barrier to participation by small players, which in turn could lead to reducing the scope of potential innovation.

Different to large-scale assets, where operating and transaction costs are relatively low compared to available revenue streams, small-scale DERs face the opposite scenario and require a model of portfolio management which minimises those costs while allowing for the aggregation of multiple revenue streams.

The existing technology available was designed for a centralised system based on few large-scale assets and relatively small number of transactions. It not only seemed inadequate for dealing with the complexity of a highly decentralised network of DERs, but also indeed to be compounding the challenges of developing financially sustainable business models for small to medium sized organisations due to the high cost of software licences and of the hardware used for communicating with and controlling those assets remotely.

As a result it became apparent to the Project LEO team there was a strong case to be made for developing instead innovative technology, or a new version of the People’s Power Station (PPS 2.0) within a different design paradigm, based on:

- a decentralised network operating model constituted of a large number of multi-party transacting DERs
- being flexible and quick in its ability to adapt, to capture new revenue streams as they become available
- being multi-purpose in its ability to cater for different value-added services derived from its core functionality
- and delivering low transaction costs for small and medium market players.

The overarching concept behind this design paradigm which Fractal Network introduced considers the electricity network as arranged as fractals, where different hierarchical levels present a high degree of self-similarity and follow simple rules, be it a single asset, the combination of all assets behind a single meter, or all assets connected under a substation. Assets can be combined and arranged according to multiple and diverse criteria, as well as being grouped in geographically bound or virtual pools of assets. Regardless of how those assets are grouped, the number of assets, or the hierarchical layer in the network, they can be represented by using the same basic rules.

The need for flexibility and adaptability led Fractal Networks to choosing a modular design for this innovative virtual power plant, consisting of a core set of software tools that together are able to provide an open standard and high-rate data exchange mechanism. Additional tools for specific purposes can then be developed and added to system, such as for integrating proprietary systems or for data analytics.

To address the need for scalability and low cost, an open-source[2] software stack[3] was chosen which provides best-in-class performance and at the same time can be deployed in hardware platforms ranging from a tiny Raspberry Pi[4] all the way to large clusters of cloud-based servers.

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[2]Raspberry Pi is a low-cost hardware platform (computer) often used by hobbyists, but with enough processing power to run a community energy virtual power plant consisting of tens of assets.
[3]Actors are defined as any active participant in the system, be it persons, organisations, policy decision-makers, market regulators, or any other stakeholder.
[4]The term biome is used within more precise categories used by many scientists, which list dozens of different biomes around the world. https://education.nationalgeographic.org/resource/biomes/

Alongside the infrastructure design, Fractal Networks developed a set of protocols to ensure consistency in implementation as well as the capacity to be interoperable with systems owned and/or operated by other parties using the same overall design.

Starting in April 2021, a collaboration between the Low Carbon Hub and Fractal Networks R&D embarked upon the development of a digital environment. This work has led to the implementation of a first live demonstrator that is actively in used in several different pilot projects and trials led by Low Carbon Hub and part of major deliverables within Project LEO.

The ongoing development and staged implementation of the platform so far has demonstrated that it is feasible to create a system that meets the objectives set out in the high-level design specifications. Most encouragingly, it meets those aspects related to being able to provide a service at low unit cost.

It is equally clear that there is the need for significant and ongoing development of the system to move from a small demonstrator to a scalable platform, development which includes both technical and process-related aspects.

The ability to use real and live pilot projects has led us to identify several aspects of the system's design and implementation that can be improved, with direct impact on both functionality and overall performance, which in turn can lead to higher service levels and/or cost reductions.

The financial viability of Smart Community Energy Systems as a whole is critical if they are to have a significant presence in the energy system, and viable business models must be developed for multiple parts in the value chain if a suitable eco-system is to be successful. The technology being developed for the PPS 2.0 is critical as an enabler for the whole SCES environment; so its own business model viability must be demonstrated alongside the tangible value it creates and feeds into other business models within the system.

The work done to date has been mostly focused on the technical aspects of the digital environment. The next phase of its development should increase the focus on demonstrating tangible value creation and be subdivided into three broad areas:

- ongoing strategic review of value creation potential, how best to enable that value to be realised, and the associated implications for defining a sustainable business model for the PPS 2.0, from the perspective of its owner, Low Carbon Hub
- detailed design for use-case-based functionality with clearly defined desired performance outcomes and associated technical and process specifications
- focused and specialist input into preparing the platform for being scaled up from the current 300 or so connected assets to 10,000, at which scale it might be possible to operate as a standalone business.

At Fractal Networks R&D we believe that nothing beats collaboration, cooperation, and the fostering of mutually beneficial relationships. The development of this technology would be severely hampered without real-world projects, and the opportunity we were offered by **Low Carbon Hub** in our joint development of the PPS 2.0 simply cannot be quantified. Equally, we would also like to thank and acknowledge the invaluable input from and joint work with the **Energy and Power Group** at the **University of Oxford**.

2. Smart Community Energy Systems as ecosystems

Definitions of what constitutes a Smart Community Energy System (SCES) may vary to some extent, but one theme is common to all: essentially it consists of a decentralised system where the primary focus is on the periphery of the network. That grid edge is where most energy use takes place, where people directly interact with the system, and where local communities formed of individuals, businesses, community energy organisations, local authorities, network operators, and other relevant stakeholders work together to maximise value creation in the local area.

An example of such joint value creation could be coordinating the use and operation of energy assets, be it generation, storage, demand, or distribution infrastructure, in such a way that it maximises the total value created for local stakeholders, value which may be manifested in savings, improved use of existing network infrastructure, reduction in lead times for installing new electric loads such as EV charging points, or even intangible value such as being part of a community acting on addressing the climate change challenges.

Low Carbon Hub and Fractal Networks are fully invested in the concept of SCES and instinctively believe that it is the way to achieve the three equally important objectives of a system that is equitable, environmentally sustainable, and resilient. Nevertheless, it remains a quite abstract concept when it comes to how it can be translated into something that is viable and replicable, particularly as this implementation has to take place within a system that is not only live, but which also functions within a fundamentally different framework driven by markets where scale does matter.

Finding viable ways for implementing SCES is a formidable challenge and one that will not be overcome through adaptations of the current model. Fundamental changes are required across the spectrum, from macro-level policies all the way to individual behaviour.

Due to the complex nature of the interaction between all the actors[5] in the energy system, a strategy based upon a conventional linear approach where causal relationships can be designed to achieve some pre-determined long-term outcome is flawed, since the transformation of a system is a dynamic process where cause and effect are interrelated.

A first step in developing a successful strategy for the implementation of SCES is to acknowledge that feedback loops will be the determining factor in the long-term outcomes, and that those feedback loops can inform action to encourage or discourage nascent patterns of interaction, allowing for the transformation to adapt to changing circumstances while at the same time influencing the changes in circumstances. This is where SCES are unique, and no centralised or purely market-driven model can match its potential.

Still, it can remain tricky to develop strategies based on this somewhat abstract concept. That's where often-used analogies from natural ecosystems could provide insights into how complex feedback loops work, how they are intrinsically local, and how positive feedback loops manifest themselves.

[5]Liberty is taken to include human geography as a fundamental part of a microclimate.

If a biome[6], such as the Pantanal wetlands which covers a large geographical area, is taken as a proxy for the energy system, its microclimates could be taken as proxies for small local areas or even households. Despite the biome's common broad characteristics, how biodiversity expresses itself at very small scale differs enormously depending on the specific local microclimate[7]. We can explore how powerful this analogy can be by making a significant part of that biome a monoculture, which is based around large-scale, low-biodiverse, industrial farming. In such a scenario, the different more local biospheres would need to be transformed into sustainable ecosystems to turn around the success of the entire biome.

To do so, policy changes that address, at macro level, the structural drivers that favour economies of scale over biodiversity are necessary, but they will by no means be sufficient on their own. In the case of restoration of natural habitats, even the adoption of well-intentioned blanket directives will not achieve the final objectives if the very local conditions are not taken into account: physical geography alone is one such factor, a small patch of wetter ground compared to another, 500 m away, but on higher ground and in the shade of a hill will be very different from each other. Those very small differences matter and will have a direct impact on how long it takes to restore the area and associated costs.

On the other hand, when very local conditions are taken into consideration and allowed some freedom to self-regulate and -organise, positive feedback loops can quickly emerge, spontaneously or with very little intervention, through patterns manifested as a combination of competition, symbiosis, and the exploitation of niches.

Insights could also be gained by comparing a value chain in a business context with the food chain within parts of the biome, and how value created by different actors is transferred throughout the value – or food – chain.

The same analogies can also help to address the question of equity in the system. In very simple terms a monoculture, by eliminating biodiversity, creates the

[6]In the form of community energy organisations, which can play many different roles, such as convening people, raising funds for investment, owning and operating energy assets, etc.
[7]Although it could equally create mutual dependency that increases overall risk.

conditions for a dominant species to capture most of the primary energy available, to the detriment of all others, not unlike oligopolies. Conversely, local biodiverse environments allow for the distribution of that primary energy to take place within a self-sustaining ecosystem.

Taking those insights into account, strategies for the implementation of SCES often refer to the creation of a ***SCES ecosystem*** where:

- local communities are seen as the equivalent of micro-climates within a larger biome
- organised community energy organisations[8] are like keystone species
- specialist trades compare to species that operate in specific niches
- and joint ventures resemble symbiotic relationships.

If the analogy is further extended to take into account the *smart* piece of a SCES (the first 'S'), then data flows become equivalent to water as the medium for nutrients exchanges. Data itself becomes the equivalent to the nutrients that enable and shape the food chain.

What seems to remain as the most elusive and critical element in developing a business strategy refers to what provides this ecosystem with its primary source of value. A natural ecosystem depends on those species able to capture energy from its primary source (for example through photosynthesis) and form the base of the entire food-chain. In the context of a SCES, any successful strategy for its implementation must identify the primary source of value, or the foundation upon which the entire value chain is built.

Since the energy system exists to meet the needs of people, the value chain could be seen as originating with the individuals, and the total aggregate value being distributed along the value chain through exchanges with other actors within the system. How much value an individual apportions to a particular benefit varies according to their own criteria, which include both tangible and intangible aspects. This, in turn, calls for a broader definition of what constitutes value, how it can be captured, and how it can be distributed equitably within the value chain.

[8]Leveraging economies of scale to access specialist skills, reduce transaction costs, and improve bargaining power in procurement.

The use of storytelling could also help in developing narratives that can be more widely relatable, and using nature might just be a format that reaches the widest audience. In that sense the narrative could be summarised as:

- community energy organisations (keystone species) create the right environment for a particular community (microclimate)
- connected DERs and monitored devices provide the data (nutrients) via interconnected, open-standard data streams (waterways)
- those with local specialist skills (niche species) process and distribute value that stays local
- joint ventures (symbiotic relationships) emerge through complementary and mutually beneficial relationships, creating momentum through positive feedback loops, and able to better apportion risk to the party best able to manage it[9]
- people (the foundation of the food chain) derive value from products, services, and wider interactions (exchanges), value which can be distributed throughout the value chain.

It is within an equitable value chain that the positive feedback loop for a sustainable system is created: people have their needs met by the system, in their homes, place of work, and communities, and at the same time equitably share the total value derived from their needs being met.

3. Business models

The minimum viable systems (MVS) framework, developed by the Engineering Science team (University of Oxford) and used in most trials in Project LEO, is ideally suited to the implementation of an ecosystem-type strategy as it establishes agile feedback loops that take into account complex interactions within the system. The implementation design is based on iterations that seek tangible intermediate outcomes which in turn guide future iterations and their desired outcomes.

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[9]Leveraging economies of scope specifically through the use of common systems and processes.

The MVS is a robust framework for agile development and, at the same time, very pragmatic in how it is driven by tangible outcomes, and how it allows for unpromising activities to be quickly dropped without compromising the overall outcome and minimising resource waste.

Within the context of technology development all the trials carried out during Project LEO sought to exploit existing resources and, at the same time, to develop new ones where gaps exist, most notably in the lack of a local body of specialist skills, and open and accessible data.

Important learning, gained in real life and with tangible examples, has been gained from observing how the interdependency between the desire for action and the ability of the ecosystem to act can manifest itself, and how some outcomes can be influenced by the degree of intervention applied at local level. The LEO trials have also provided insights into very practical aspects where interventions at policy level become critical.

Many of the individual components for the implementation of an ecosystem strategy for the electricity network already exist. However, there is a need for a new generation of catalysts to trigger the chai -reactions that enable positive feedback loops to get established. A major challenge is that the catalysts themselves require their own resources.

This challenge, at its core, lies in devising forms, or business models, that allow for those resources to be assembled, taking into account the appetite for risk by individual organisations, their reach, and the pace of transformation sought.

The experience gained from the trials in project LEO shows how important a role there is for a digital environment as an enabler for the successful implementation of SCES, but the development of such technology is also constrained by the same challenges in accessing the resources required for its development. Nonetheless, two possible business models have been identified and merit further exploration:

- a service model where value is monetised directly from the user, which incrementally grows as the ecosystem develops, and which has a relatively low risk profile requiring low initial investment
- a dual model where a body of users benefit without financial costs, while value

is monetised through intelligent services to other; this model relies on quick rollout of a digital infrastructure, which has a higher risk profile with significant upfront investment.

3.1 End-user services model

The first model, which is well suited for incremental change and requires relatively low initial investment, would start by making use of existing levers for value creation, focusing on market segments composed of small to medium-scale energy users, and/or energy asset owners, such as households, small and medium-sized enterprises, or social housing providers, with benefits and value derived from aggregation[10], consolidation[11], cross-referencing[12], and co-operation[13].

Tangible products are designed to provide:

- performance monitoring and early fault-detection
- process-automation (for example automated alerts or reporting)
- financial and asset-use optimisation
- and local-area whole-system visibility.

This revenue model consists of income streams generated through ongoing fees. The cost model is heavily reliant on scale, with rapidly diminishing marginal costs. Equally, the main risks are associated with scale, both in achieving the minimum required to produce an operating profit, and in dealing with stepped cost increases as the customer base grows.

The market already provides similar services; however, the ability to consolidate

[10]Leveraging synergies originating from multi-source data through standardisation, co-location, and data analytics.
[11]Initially manifested in intangible ways such as "taking part" or "being associated with".
[12]Hardware related to IT processing functions, such as servers and microcontrollers, as well as data comms devices.
[13]Actors are defined as being capable of autonomously performing transactions with other actors through the use of messages. Examples of actors could be the control module of a single physical asset such as a EV smart charging device; the coordinator of a pool of physical assets assembled within a defined boundary of the electricity distribution network, or a pool of assets assembled regardless of their location in the network; a software tool providing analytics, or forecasting; the control interface of a market aggregator, etc.

multi-source data could enhance its value proposition. Moreover, the reach and local knowledge of communities could provide access to end users, and being associated with community-led initiatives could create extra intangible value.

3.2 Intelligence services model

The second model, which could potentially provide the conditions for a significantly faster pace for ecosystem development, has two aspects: for one, those who derive benefits without necessarily incurring financial costs, and the other where value is monetised from users of premium services or targeted intelligence-driven services.

The value provided by those services is derived from the multi-source data combined with local knowledge. Free-of-charge basic services are provided to users, allowing for fast market penetration and for access to the scale and diversity of data required for extended capabilities. Users can also opt to access advanced functionalities through paid-for extended services, which can make a significant contribution towards the running costs of the entire technology.

Data-driven services can also be monetised via products offered to third parties, where local communities take an active role in deciding how best to leverage their own data and how it feeds into services such as market segmentation and trends, joint procurement, provision of flexibility services, local energy trading, etc. Active participation in determining the final shape of those products, and the local ecosystems it relies upon, ensures that value is equitably apportioned. Of course, safeguards must be in place to ensure individuals have full knowledge of how their data is used and such protection must also be integral to the design of final products.

Whole communities could also derive value from knowledge of how the energy system functions in their very local area, leveraging that knowledge in co-designing solutions for their particular needs, or even increasing their collective bargaining power.

Communities may have major differentiating factors working in their favour: trust from the users that provide the data in the first place, knowledge of local needs and resources available, and the ability to identify and act in filling the gaps in their specific ecosystem.

The success of this model relies on rapidly creating a critical mass of users that allows for the assembly of datasets to be used in extracting the intelligence required for the services being offered to business. Significant investment would be required to build a digital environment capable of handling the large number of connected datapoints, the actual connection of those datapoints to the digital environment, and the development of the machine-learning algorithms that extract intelligence from the data and form the basis of the products to be offered.

The main risk lies in the uncertainty of revenue streams available and how much financial value can actually be captured.

It is almost inevitable that this type of service will be present in the market in some form, whether it is driven by communities or large corporations. There is an opportunity cost for communities in devolving the development of those services to the market, particularly one dominated by few large corporations, as it will undoubtedly dilute how much value can be captured locally, and the extent to which those communities can act in coordinated ways and to their maximum potential.

Even though the risks are high there are ways in which communities, acting together, can mitigate them. In either model the co-creation of an ecosystem is essential for its viability and having such an ecosystem in place can quickly create positive feedback loops speeding up participation. An effective way to create that momentum and minimise risk would involve close working partnerships, or even joint ventures, with a small number of organisations that provide highly complementary services, and can jointly design and create a development programme for the skillset specific to meet the needs of smart grids.

4. Technology gap

Much of the technology being used in smart grids or smart local energy systems seems to be adaptations of existing models used in the current highly centralised energy system. Those tools follow a design paradigm which is focused on relatively small numbers of large-scale assets with specialist use, and high capital investment, where most of the revenue comes from a small number of transactions. In this model service availability is a critical factor and the assets must be ready to provide the service, when called upon. Ensuring high service availability relies to a great extent on high availability remote operation of those assets which, in turn, requires the use of specialist IT platforms and data comms equipment which tend to be, if anything, very expensive. This approach doesn't seem appropriate to meet the needs of a decentralised system based around very large numbers of small-scale assets, with relatively low capital costs, and use of which will be much more generic.

The development of nascent smart grid technologies does tend to take into account the fact that small-scale assets, individually or grouped into fleets or pools, have very different requirements due to how they are used, how value-added services might be constructed, and how risk is managed in the case of services provided through aggregating multiple assets.

It seems clear that service flexibility, interoperability, and the ability to manage large numbers of multi-party transactions, combined with low transaction costs, are critical factors if assets are to be used in a smart and coordinated way. Through interoperability and coordination greater overall value can be created.

However, the focus remains on specialist areas – manufacturers that develop closed management systems that only apply to their own equipment, or service providers that focus on their niche product, such as EV charging fleets – creating a gap in integration technology that goes beyond the individual household or building.

Another aspect of many of those nascent pieces of technology is that, in general, they don't seem take a system-wide approach, one where technology is a part of the system, but not the centre piece.

The single-minded focus on technology itself and consequent oversimplification of the multiple complex interdependencies present in the energy system not only leads to a lack of interoperability, but also results in missing out on the enormous potential for innovation when design allows for direct input from local communities while, at the same time, acting as a catalyst for further local engagement.

Notwithstanding how it fits in the overall system, the enabling technology we need must be able to meet performance outcomes already mentioned as well as high levels of complex optimisation, automation, and coordination. It must be able to do so by processing vast amounts of data privately, securely, and very rapidly – not dissimilar to digital payment systems or global finance-trading platforms.

It is therefore not difficult to envisage such technology becoming the domain of the few large corporations that can afford it due to their existing large customer base and resources, leading to oligopolistic behaviour to the detriment of other stakeholders.

While oligopolistic behaviour leads to market asymmetries that favour the concentration of bargaining power, its decentralised opposite could help in addressing those asymmetries and be instrumental to creating a more equitable system as well as speeding up the transition to a zero-carbon model through active participation.

When taking into account the fitness for purpose of existing and nascent technologies, and the consequences of exclusion of small organisations, there is a strong case to be made for the development of new technology to fill a gap in the market and to ensure that the value creation it enables allows for that value to be shared widely, rather than favouring social-demographic groups that can afford to participate in this new system.

5. The People's Power Station 2.0

Early on in Project LEO it became clear that technology has to, and will, play a major role in the new smart energy systems of the future, with the caveat that technology should not take centre stage, nor should it be the privilege of larger organisations that can afford high price tags.

Instead, for Smart Community Energy Systems to flourish an approach to technology is required where the role technology plays is an enabling one, with a clear focus on value creation and accessibility regardless of scale.

The concept of the People's Power Station goes back to the very beginning of the Low Carbon Hub, and Project LEO provided both the means and medium for starting to turn that vision into reality, as set out in the Introduction.

The technology being developed consists of a digital environment that enables monitoring and controlling large numbers of diverse types of DERs, at multiple layers of the physical electricity network.

Its ultimate purpose is to create value by aggregating, automatically coordinating, and optimising DERs. It is able to do so through its flexibility to cater for multiple services, its agility in adapting to external market conditions, and its suitability and accessibility to small-scale operations.

It is important to stress that the technology under development is more than a IT platform and can be better described as creating what is called a 'digital environment' due to the way it operates; the fact that it consists of distinct pieces of hardware[14], software, and energy resources; as well as to how it integrates multiple subsystems to achieve its performance and functional specifications.

This particular digital environment consists of subsystems that fall into the following groups:

a) a core IT system that acts as a coordinator of multiple functionalities
b) multiple interfaces for data exchange and controlling diverse types of DERs
c) a fleet of connected DERs
d) specialised value-added service modules, such as performance monitoring, settlement services, or real-time operational compliance of hydros
e) interfaces to markets and/or other third-party value-added services.

[14] So-called live data is better described as data being acquired at relatively high temporal resolution, in this case every 10 seconds.

5.1 Low Carbon Hub and Fractal Networks R&D collaboration

The People's Power Station 2.0 (PPS 2.0) was key to Project LEO trial objectives, and the Low Carbon Hub and Fractal Networks entered into a collaboration agreement in April 2021, to co-develop the technology and representative demonstrators of what the complete digital environment would be like.

Such collaborative development has a number of advantages:

- complementary contributions – the Low Carbon Hub has a fleet of operational DERs while Fractal Networks brings its IT and data comms expertise
- isolating and allocating risk to whoever is best placed to manage it
- allowing feedback loops to emerge for the co-creation of value-added services and how the platform itself had to be built to enable these.

The programme of trials in Project LEO allowed for the development of the PPS 2.0 to be based on use cases with specific and tangible objectives not achievable without the appropriate supporting technology. This has led to benefits for both organisations that would not have materialised otherwise:

- developing technology without the real-world challenges or use cases can easily result in purposeless pieces of IT
- live trials call for agility in thinking, design, implementation, and speedy correction, which keeps momentum and invites innovative approaches to solving challenges.

5.2 Performance objectives

As mentioned, the focus in developing the PPS 2.0 has been on value creation and how accessibility plays an important role in allowing small organisations to access to markets where scale is a major component of being competitive.

Accordingly, a set of objectives was agreed in terms of its expected performance on distinct aspects of the overall digital environment. So those performance objectives related to how it would meet its purposes, how it would function, and how it would enable value creation, rather than any specific technical specifications of it how it was being implemented or numerically based performance targets.

As the PPS 2.0 is such an innovative and experimental piece of technology, those performance objectives had to be designed in such a way as to be generic enough to allow for adjustment during the development process, while making them as clear as possible by ensuring they fitted into understandable and identifiable categories.

5.2.1 Accessible

How feasible is it for small-scale organisations to make use of this technology in terms of its affordability in upfront costs, minimum scale, and ongoing operation?

5.2.2 Agile

A design that allows for quick reconfigurations to keep pace with and make the most of changes in the external environment; agility can manifest itself in modular implementation, or the use of interchangeable components.

5.2.3 Flexible

A design that allows for multi-purpose use, is easily adaptable with quick deployment of new functionalities, as well as painless discontinuation of others.

5.2.4 Interoperable

Asset-, technology-, manufacturer-, ownership-agnostic, and based around industry-standard Internet-of-Things (IoT) protocols and open-data.

5.2.5 Replicable

Based around easy-to-procure hardware and software parts, wherever possible with strong existing support communities, and able to be implemented and operated with widely available rather than niche skills.

5.2.6 Resilient

A system that is operationally robust, offers high availability, and comes with long-term support for component parts.

5.2.7 Scalable

A system based on the very same core set of modules that can be deployed from very small scale, for example a single household, all the way to clusters of cloud-based servers.

5.2.8 Secure

A product that meets highest industry standard cyber security methods and is fully compliant with data privacy requirements.

5.3 Design paradigm – linking performance objectives and technical specifications

Having identified the performance objective categories, the next step was to define a design paradigm to guide the PPS 2.0's functional requirements and technical specifications of its component parts.

This new digital environment would need to be designed with three key principles in mind. These are set out in what follows, together with their main characteristics which reflect the objectives set out above.

5.3.1 Simplicity of concept

The entire system should be designed following a 'fractal' principle, meaning [add your definition of the word], with characteristics including:

- physical network conceptualised as composed of fractal nodes
- fractal nodes can be organised in hierarchical layers, with those at the same hierarchical level treated as peers
- any fractal node can be simplified as having exactly the same characteristics, regardless of hierarchical level
- hierarchical layers can be mapped directly onto the physical electricity network
- fractals at the same hierarchical level are treated as peers
- fractals at the same hierarchical layer can be grouped to form a higher-layer fractal in its own right
- such higher-level fractals can be created according to any common

characteristics – e.g. network location, geo location, equipment type, group association, energy supplier etc.

5.3.2 Decentralised decision-making

In a system where there could be very large numbers, possibly tens of thousands, of participating assets, devices, and software modules constantly interacting among themselves, decentralised decision-making becomes critical for overall system resilience and local adaptability. Interactions and the decisions made are expected to be characterised by:

a) actors[15] in the system which are able to interact with others performing direct transactions

b) no single entity or actor holding information for the whole system, which could also be described as the absence of global states. The advantages of such being that there is no central control of how peers interact, actors have the ability to chose their level of participation and how much information they wish to share, and ultimately forcing the system to be decentralised by design.

5.3.3 Low transaction costs

Everything is as low cost as feasible:

a) hardware – from servers to data acquisition widgets: commercially available, generic, basically whatever is the most cost effective while fit-for-purpose

b) software: best-of-class, industry-standard, open-source licence

c) development environment: industry standard, non-proprietary, and employing widely used programming languages

d) external interfaces: based on widely used open-source protocols

e) external interaction: agnostic in terms of the development environment, based upon common open-source protocol.

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[15]Low-cost monitoring devices for direct data acquisition were developed during the project's implementation phase. They are in use for residences without smart meters, for direct monitoring of PV installations, and capturing generation data from the hydro.

6. Pilot projects and trials

As part of Project LEO, Fractal Networks and Low Carbon Hub co-designed and then implemented several live projects as demonstrators for the capabilities of the PPS 2.0. In line with the performance objectives set, those trials at the same time informed the development of the environment itself, as well as potential sources of value beyond network flexibility services, in useful feedback loops.

All the trials followed a common approach to their development cycle, even though each trial sought to demonstrate different outcomes. This common approach greatly increased the speed of implementation and delivery, allowed for cross-utilisation of tools, and for learnings from one trial to be easily transferred to others, and consisted of simple steps:

- collect relevant data
- translate data into information
- use information to improve decision-making by users of the system
- create interfaces co-designed with users and other stakeholders
- review outcomes based on use experience
- restart the cycle.

The next section of this report reviews the 6 pilot projects in which the PPS 2.0 was involved, both helping deliver them and in turn being developed and improved through helping facilitate them.

6.1 Osney Supercharge

The most comprehensive and arguably the most innovative of the pilot projects run by Low Carbon Hub, Osney Supercharge demonstrates a small-scale Smart Community Energy System in operation, with different members of the community actively taking part in it.

This project is particularly neat because of its clearly defined geographical and community boundaries. Osney Island is indeed an island in West Oxford, connected to the distribution network by a single secondary substation. In addition, local participants in the LEO trials here were diverse and representative, including:

a) thirteen households
b) a local pub
c) a local community energy organisation
d) the Low Carbon Hub, which offered capital finance for new assets
e) the distribution network operator.

Energy resources taking part in the trials include:

a) small-scale rooftop PV generation
b) local flow-of-river hydroelectric plant
c) domestic batteries
d) a larger-size battery used as a community asset.

The trials also involved the integration of 'live'[16] data from smart meters, low-cost power monitors[17], PV generation, batteries, and the hydro, as well as from the monitoring of the low voltage distribution network within Osney Island.

Osney Supercharge aimed to demonstrate the viability of:

a) aggregating multiple small-scale DERs to provide flexibility services to the distribution network
b) a commercial model for third-party capital financing of generation and storage assets.

With these unique characteristics, Osney Supercharge is an ongoing demonstrator and truly representative of a Smart Community Energy System of

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[16]The financial viability of such projects remains extremely challenging due to the low financial value paid for many flexibility services, the long-term uncertainty of revenues due to short-term service provision contracts, combined with high transaction costs. However, the detailed review and analysis of the financial viability of such services is beyond the scope of this report and is dealt with separately.
[17]WOCoRe was registered as an Industrial and Provident Society for the Benefit of the Community in June 2009. Under the Co-operatives and Community Benefit Societies Act 2014, it became a Registered Society, run for the benefit of the community; see https://wocore.org.uk/.

the future. As such, it has provided unique insights into practical aspects of how it may implemented, potential motivating factors for participation, the invaluable role of local individuals and groups that act as catalysts for participation. The trial has also provided tangible evidence for the evaluation of potential new business models for community energy (section 3).

Some of what has been observed includes:

a) triggering of private investment in PV generation and battery storage
b) deployment of new PV generation and battery storage via capital investment by a local community energy organisation
c) voluntary enrolment – wanting to take part – of residents who already had PV generation and storage
d) the willingness of householders to engage in the development of use cases to be trialled and to provide feedback
e) translating data into meaningful information can lead to better decision-making by the participants in how they use energy or how to actively respond to current network conditions
f) the significant positive effect that coordinated use of DERs can have in reducing network demand during peak times.

Understanding the interaction between different parts of the energy system can be challenging and the overuse of technical language can be off-putting to many individuals.

However, having some understanding of how the system works, how our decisions and behaviours manifest themselves collectively, and how relatively small changes can quickly lead to positive outcomes, could allow for the acceptance of the high levels of automation required for realising the full potential offered by SCES.

As mentioned, one of the aims of Osney Supercharge was to identify the potential for value creation through synergies if DERs were to be used in a coordinated way. One barrier participants faced was the inability to *see* the effect that changes in their behaviour could have, starting within their own households, in particular those with multiple DERs. In particular, residential participants fed back that it was very difficult to get a full picture using two separate apps showing their solar PV and domestic battery are doing, while also having to look at the smart meter display to see how much energy was drawn from the grid.

In line with the objectives and design principles agreed for developing the PPS 2.0 we attempted to use it to bring these different pieces of data together and translate it to something that could be meaningful.

Fractal Networks created dashboards that could display the combined effect of the different DERs acting together, at different layers of the network, starting with a household and then widening it out. They were designed in such a way that the same format can be used to communicate how the system is behaving as a whole at different layers of the electricity network.

Some sample snapshots of dashboards we developed for Osney Supercharge at the individual household level will help illustrate this:

- one showing the near real-time flow of energy in a household, combining imports and exports from the grid, PV generation, charging and discharging of domestic battery, and the that of an EV battery (yet to be implemented; see Fig. [1])
- a graph showing the sources of energy in meeting household demand, clearly indicating how much is coming from the PV, a battery, and imported from the grid (see Fig. [2])
- a graph offering yet another perspective, to show how the energy being generated by solar PV is being used, clearly indicating how much is meeting household demand, charging a battery, or being exported back to the grid (see Fig. [3])
- a graph showing how choices in when energy is used has a direct impact on the actual carbon intensity of the electricity in use: t. The greater the proportion of demand met by energy generated by solar PV the lesser the individual household’s carbon intensity (In this case the dashboard shows the household’s carbon intensity matching that of the whole of the South of England as 100% of

the demand is being met through electricity supplied by the grid; the other extreme, where the carbon intensity for the household shows a value of zero, indicates that the total household demand is being met through PV generation; e. Everything in between shows the carbon intensity as the weighted average between imported and self-generated energy needed to meet demand (see Fig. [4])

- a more simplified dashboard also showing carbon footprint information, but using absolute values taking into account the household carbon intensity at any given time (see Fig. [5])
- a graph showing day-ahead forecast generation for a household, which could guide decisions on the best time to put on discretionary loads, such as a dishwasher or washing machine (see Fig. [6]).

True to the design principles set for developing the technology, similar samples are available at a different hierarchical layer within the network, i.e. a wider community or street level, including:

- a graph showing how energy demand is being met for all the participants in a given street, following the exact same format used for displaying the same information for a single household (see Fig. [7], compare Fig. [2])
- a graph showing how the energy generated by all participants in the community is being used, following the same format used for showing an individual household or the combined generation in a given street (see Fig. [8], compare Fig. [3])
- a graph showing the effect that coordinating use of DERs use can have on the wider network, This case clearly shows that peaks in demand, at peak time, can be reduced significantly through the coordinated discharge of batteries, as well as the fact. It also shows that local community generation is making a significant contribution in meeting the total demand for the street – not only the trial participants, but all its households in that street (see Fig. [9]).

An important piece of feedback was the extent to which visualisation tools could be so informative and valuable, and its impact went beyond what we had hoped for. Specifically, feedback included:

- how meaningful the information became once it was all brought together through the PPS 2.0 and its various dashboards
- how much easier it becomes to understand and to explain how all the different parts act together whether it be within a household, street, or community
- how individuals feel proud of their contribution.

The feedback from this trial underlines that the role of visualisation in effectively communicating complex interactions cannot be underestimated. It doesn't mean that people will be constantly watching dashboards. Rather, such tools can be extremely valuable when a community is interested in working together to identify their energy needs and where collaboration and coordination might create value.

The interplay between information, knowledge, and trust, and how coordinated action can lead to maximising collective value shows that technology tools can be used to great advantage in creating Smart Community Energy Systems, even before any automation is taken into consideration.

Fractal Networks believes that future phases of the Osney Supercharge project could attempt to further trial active participation shaped as identifying common needs, co-creating local solutions, and accepting different levels of automation as a potentially helpful tool in meeting the desired outcomes.

6.2 Rose Hill Primary School

Rose Hill Primary School is located in Southeast Oxford and was one of the very first maintained schools in Oxfordshire to have community-owned solar PV installed on its roofs. The capital investment came from the investor members of Low Carbon Hub, so through locally sourced finance where the investors receive a fair return on their investment, the school benefits from significantly lower prices for any PV-generated electricity that it uses, and financial surpluses are reinvested as community benefit.

This LEO innovation project included the installation of a new battery funded by the Low Carbon Hub alongside the existing solar PV array. It also encompassed developing software tools for integrating the system into the PPS 2.0, and the creation of an energy settlement system able to allocate energy use and payments to all parties involved in commercial transactions involving these DERs.

One of the main objectives of Project LEO was to demonstrate the technical feasibility and financial viability of using small- scale DERs to provide flexibility services at the periphery of the distribution network. The trials involving the school focused on the viability of combining behind-the-meter DERs to provide flexibility services to the DSO and create additional revenue streams for the community energy organisation owning the assets, in this case Low Carbon Hub.

The LEO innovation trials have demonstrated that it is technically feasible to do so, but not yet financially viable[18].

Despite what may be considered a failure in demonstrating its financial viability, the trial has been successful in producing clear evidence for the challenges in using small-scale assets for such services. It has generated invaluable learnings for project partners on possible ways to overcome them via different means: policy, commercial, and technical.

Fractal Networks' focus in this particular trial was on the technical feasibility of fully integrating legacy assets, not designed for live monitoring and control, into a new digital environment, i.e. the PPS 2.0. We were unequivocally able to demonstrate that it can indeed be achieved. However, the technical integration also proved to be quite challenging as well as costly, which further undermines the financial viability of such services.

The details of this pilot integration, and its outcomes, can be best seen through a few samples of dashboards developed for the trial:

- one showing an overview of the energy flow behind the meters at the school (see Fig. [10])
- a graph showing data collection from multiple data points; in the case of PV generation there are two sources for the same data which improves the resilience of the system, and allows for cross-referencing and calibration of

[18]The Environment Agency is the statutory body responsible for the management of waterways in the UK and the operation of hydroelectric plants must abide by conditions set in its Abstraction Licence and Operating Agreement.

each source (see Fig. [11]).

With the addition of the battery to the overall system at the school, on occasion the battery would be charging overnight and therefore consuming energy from the grid for which the school pays for. This led to the need for an energy settlement mechanism to be put in place to ensure that the school was not being disadvantaged by having a battery on site as part of the Project LEO trials, having to pay for that electricity from the grid.

So Fractal Networks developed an energy settlement algorithm and engine as part of the PPS 2.0, to ensure accurate assignment of energy use to the relevant party as well as detailed billing information to reassure the parties that everyone was being treated fairly. This settlement process had to take into account:

- who has priority use of PV generated energy
- how to allocate energy imported from the grid to either the school or battery
- how to account for energy exported back to the grid
- how to calculate amounts to be reimbursed to the school for energy used by the battery
- how to apply different time-of-use rates for electricity costs both for reimbursing the school and for charging for energy used either from the battery or PV.

The dashboards and reports developed (for a sample see Fig. [12]) were later replicated for other sites where energy trading takes place behind-the-meter and have shown to be easily replicable. Other reports were also created, enabling detailed analysis of the settlement showing energy allocation for different parties.

6.3 Osney Lock Hydro

Osney Lock Hydro is a 50kW hydroelectric power plant located in central Oxford which is owned and operated by West Oxford Community Renewables (WOCoRe)[19]. WOCoRe is a local community energy organisation which identified

[19]Demonstrating compliance required the cross-referencing of data from Osney Lock Hydro itself, a neighbouring hydro – Osney Mill Hydro, and river flows and water levels available through the EA's telemetry system.

the potential for the project, raised the necessary capital through a share offer where people in the wider community could invest and receive a fair return on their investment, while financial surpluses are reinvested in the local community.

As mentioned in section 6.1, this hydro was one of the participants in the Osney Supercharge project. A separate issue arose, however, which the PPS 2.0 was drafted in to solve, once again demonstrating its flexibility. Previously, the hydro had had used a physical connection wired to the EA's telemetry network, to demonstrate to the Environment Agency (EA)[20] that the hydro was compliant with the conditions set in its Operating Agreement. However, not only the wires had been damaged, but the EA was also undergoing some major changes to their telemetry system. So a new mechanism to reassure the EA was required.

Fractal Networks was able to identify a simple solution despite the need to cross-reference data from multiple sources[21] in order to demonstrate compliance. This consists of direct acquisition of data from the hydro control systems (both Osney Lock Hydro and neighbouring Osney Mill Hydro) using a low-cost device[22], retrieving data from the EA's own telemetry system, processing and feeding the combined data, in real time, to a dashboard that EA employees could access using any device that has an internet browser. The new dashboard (see Fig. [13] and Fig [14]) helps the EA see their own river conditions data, supplemented by that from the hydros of course. In fact, the information on river levels and flow hadn't been available to their staff for a while due to the ongoing changes to their telemetry system.

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[20]This device, hardware and software, was also developed as part of the project.

[21]The Neutral Market Facilitator's is one of the roles of the Distribution System Operator in the future energy system. It seeks to obtain best value for money in attending to specific network needs, of which the contracting of flexibility services is one example. The development and testing of a fully automated end-to-end process for the qualification, contracting, bidding, delivery, verification, settlement, and billing for services provided to the NMF was the single most visible part of the scope of Project LEO and TRANSITION; see https://project-leo.co.uk/what-were-doing/market-trials/.

[22]A run-of-the river hydro does not have a reservoir behind it, instead using the flow available in the river to generate power. The hypothesis being tested was if enough energy could be stored in the form of gravitational potential by allowing the river level to rise upstream of the hydro by deliberately reducing power output. At peak demand times the power output would then be increased, lowering the river level to normal operating conditions, which would then release more energy than it would otherwise done.

This simple solution created by Fractal Networks was considerably cheaper than attempting to replace the original damaged cables. It also meets the overall needs of the EA with respect to the ongoing changes to their telemetry system, while providing an easily accessible way for their staff monitoring compliance with hydro licences as well as those responsible for river management. In fact, the dashboard implemented for Osney Lock Hydro has now become a template for monitoring compliance of other hydros in the Upper Thames area.

Returning to Osney Lock Hydro, once the initial data integration had been completed and the compliance dashboard was operational, it became apparent that with a relatively small amount of work a full dashboard could be put together for WOCoRe showing how the hydro, PV panels and battery were working together. With this, the PPS 2.0 made it possible for the first time for the team responsible for its operation to have all the elements in one single control room dashboard.

True to the performance objectives set for the PPS 2.0, a small amount of work has created significant additional value. The new operations dashboard gives both an overview of the plant and detailed information on its component assets, resulting in a comprehensive virtual control room. The following are examples of various perspectives available within it:

- the overall one giving a complete overview of the operational status of the entire power plant (Fig. [15])
- one showing historical generation data for the hydro and river conditions (Fig. [16])
- dashboard showing historical generation data for each of the two PV arrays (Fig. [17])
- another one showing the cycles of charge and discharge for each of the two batteries, as well as state of charge (%) and amount of energy stored (Fig. [18]).

6.4 NMF Settlement

The full range of trials undertaken by the Low Carbon Hub for Project LEO and TRANSITION included multiple DERs participating in providing flexibility services to the Neutral Market Facilitator (NMF)[23] also part of the trials. The entire process for providing flexibility services via the NMF includes not only technical but also commercial aspects of delivering the service.

In this particular trial involving the PPS 2.0, the focus was on the tools required for reports used for the verification and settlement of services provided – so a crucial element of a successful NMF system looking to automate such processes.

The main objective in the initial phase was to automate the generation of the required reports to be used in the verification of service delivery for a single site. As the example from Rose Hill Primary School in Fig. [19] shows, this included the processing of raw data captured from the operation of a battery, showing the power output and energy dispatched for each 10-minute period during the service delivery window.

The Low Carbon Hub estimated that the automation of reporting through the PPS 2.0 reduced staff time input from 45 minutes to less than 2 minutes per service delivery. This directly translates into a significant reduction in transaction costs for assets to take part in delivery flexibility services.

In accordance with the design principles of the PPS 2.0, it was a simple step to move from a single site to an entire portfolio. So, once the initial template had been developed and tested, it was rolled out to include multiple sites and for events covering both the charging and discharging of batteries. Options incorporated include to report on single assets, certain sets of assets, or an entire portfolio (see Fig. [20]).

For a final iteration, once again it was another simple step to include different types of assets, using the same template for automated reporting now including PV installations participating in flexibility services (see Fig. [21]).

The tools Fractal Networks developed to verify service dispatch and settlement for the NMF trials demonstrated both the impact automation can have in reducing transaction costs, as well as the flexibility of the PPS 2.0 in being able to add value

[23]The hydro uses asynchronous generators which allows for variation in the generators rotating speed which translates into the flow through the turbines in- or decreasing accordingly, allowing for the river level upstream of the hydro to be managed.

by quickly introducing new functionality.

6.5 Sandford Hydro

Sandford Hydro is a 440kW hydroelectric on the river Thames, just south of Oxford, owned and operated by the Low Carbon Hub. The plant, funded through capital raised from community investors, was commissioned in 2017. Low Carbon Hub saw that it held significant potential for innovative ways to provide flexibility services to the DSO, by basically turning the river into a battery, so ensured it was part of the Project LEO trials[24].

The hydro consists of three separate generators, initially only one with variable speed drives[25], with the two others also fitted with them as part of Project LEO. That, together with the automation of sluice gates in the adjacent weir, made it possible to test the feasibility of using the river itself to store energy. The idea was that by reducing power output, through the use variable speed drives, it would be possible to hold water upstream from the hydro which could then be released increasing the power output, during peak demand times.

In order to allow for automated remote control of the power output and full integration to the PPS 2.0 the central control system of the hydro had to be reconfigured once the electrical works on the drives had been completed. Multiple data points were integrated, including active controls, river level sensors, and the generation meter to be used for verification and settlement of services provided. Two sample dashboards illustrate the range of the PPS 2.0's functionality:

- one provides an overview of the hydro's operational status, including power output, water flow through the turbines, and river conditions are shown all in one place; note that. timestamps show the difference in lag between data

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[24]The hydro control system constantly adjusts the water flow through the turbines as it tracks the target river level upstream.

[25]The smart meter specifications provide for devices able to communicate directly with the meter wirelessly. Those devices are referred to as In Home Display (IHD) and Consumer Access Device. An IHD simply displays some data on a screen, but the data is not accessible in any other form. A CAD is able to connect to a local WIFI network, providing a bridge for the data between the smart meter and a server accessible via the WIFI network.

obtained directly from the hydro, i.e. every 30 seconds, and information obtained from the EA telemetry system which has a maximum resolution of 15 minutes with the lag being of up to 1 hour. (Fig. [22])

- another provides detailed information is also shown for each of the different data points, i.e. power output, flow, and turbine speed, for each one of three generators (Fig. [23]).

Operational controls are also available, providing the ability to alter the river level set point[26] which in turn allows for water being stored upstream, a key requirement to test the 'river as a battery' proposition:

- The way to use the river as a battery consists of setting the target river level higher than normal, which will force the hydro to decrease the flow through the turbines therefore holding water upstream as the river level increases
- Once a greater power output is required the river level target is set back to its normal which forces the hydro to increase the flow through the flow through the turbines and as a consequence increasing the power output.

The PPS has demonstrated the technical feasibility of controlling power output (Fig. [24]) by varying the river level set point, an approach suggested by Fractal Networks. Although it has only been applied manually and under human supervision, the power output could be controlled automatically.

The outcomes of the Sandford Hydro LEO trials show that it is technically feasible to:

- use the river as a battery
- use the PPS 2.0 to schedule and adjust the set points to deliver DSO flexibility services
- use the PPS 2.0's functional flexibility to make use of the same datasets for service delivery, and both operational and compliance monitoring.

However, the trials have also shown that using variable power output at Sandford

[26]Measurements of voltage, current, power factor, reactive power and frequency are not made available to the domestic energy user. Availability of this subset could provide opportunities for new services to households, such as remote performance monitoring of different types of appliances through non-intrusive load monitoring techniques.

Hydro may be technically feasible, but its financial viability is challenging in the present environment, due to:

- the low financial value paid for the flexibility services
- uncertainty over frequency of service delivery and therefore revenues
- short-term contracts offered by the DSO.

Fractal Networks also collaborated in work led by Dr Elnaz Azizi of the Energy and Power Group, University of Oxford, on using machine learning algorithms for short-term forecasting of service availability. To enable this, further data was collected from rainfall stations in the Thames basin catchment area to feed into the modelling which already included river levels and flow, as well as hydro output. The PPS 2.0's capabilities allow for unlocking synergies that come created from combining data from multiple sources, as is illustrated by Fig. [25].

The first models showed encouraging results between observed and predicted values as shown in Fig [26]. However, inter- and intra-seasonal variability in river conditions means further work is required to render the short-term forecasting sufficiently accurate to have a noticeable effect on service availability risk management.

6.6 Springfield Meadows

Springfield Meadows is a new housing development in South Oxfordshire where all houses have been fitted with PV generation. However, the actual generation by the solar panels is being reduced due to constraints in the distribution network.

One of this trial's objectives was to allow for greater generation from the PV panels without the need for the network capacity infrastructure to be upgraded, so avoiding the need for further capital investment. The approach taken to help build a solid evidence base was to analyse actual demand and generation, to verify the design assumptions that had led the DNO to conclude that the existing network did not have the capacity to allow for unconstrained generation of all the PV fitted across the development.

Initially, this was not expected to involve Fractal Networks or the PPS 2.0. However, despite the fact that all houses had smart meters, getting hold of the data through each household's energy suppliers was proving to be a time-consuming and arduous process. After six months of trying to access it for as many households as possible without success, the team at the Low Carbon Hub managing this trial decided to check if it would be feasible to utilise the PPS 2.0 to bypass the energy suppliers and access the data directly.

A very simple process was devised for homeowners to give consent for use of their data. Rapid implementation of a new interface allowed for data starting to flow within one week (Fig [27]) from when Fractal Networks were first approached about using the PPS 2.0 in this way – one week compared to 6 months of unsuccessful attempts by other means.

Although the PPS 2.0 involvement in the Springfield Meadows LEO trial consisted of nothing more than acquiring the raw energy data from households, which is unarguably something very basic, the trial's actual analysis of the situation would not have been possible without this data which in turn could have led to investment in infrastructure *by default*.

The value of being able to act quickly – as encapsulated in the performance objectives set for the PPS 2.0 – was demonstrated by overcoming barriers imposed by incumbents, in this case energy suppliers giving customers access to their own data. This shows how communities can challenge the status-quo and bypass incredibly complicated and bureaucratic processes created for the benefit of very narrow interest groups.

7. General trial learnings

One of the main purposes of running trials in Project LEO was to gather evidence from real use cases that could provide insights into how the energy system transition is taking place and at the same time use those insights to inform interventions that could improve outcomes for the transition itself.

Many of those learnings have been put to very good use in the trials themselves and led to noticeably improved outcomes, while others might not yet be fully understood, might require interventions directly related to policy, or might be intrinsically related to the maturity of a nascent market.

The evidence gathered helps in the identification of tangible challenges and opportunities, and it is not surprising that many challenges do exist as it would be expected in a system transformation of such scale. On the other hand, with transformation will come opportunities and innovation which are probably difficult to grasp, similarly to what took place during the transformation of the telecomms and internet system.

7.1 Challenges and structural barriers

The development and implementation of the PPS 2.0 as part of the LEO trials, as well as the results obtained, are very encouraging (see section [x]). However, part of our learning has been to identify a number of challenges and barriers which, if not addressed, could easily prevent the realisation of full potential of Smart Local Energy Systems in general, but even more so that of Smart *Community* Energy Systems.

These challenges come in different forms from technical and market to policy aspects. Unless they are addressed in a coherent, consistent, and strategic way, the end-result will, at best, entail many missed opportunities particularly in relation to equity and, at worst, make the system even more unequal than it currently is.

As it is, the uptake of many low carbon and energy efficient measures is disproportionately skewed towards those in the higher income brackets which can afford the upfront costs and will accrue the benefits over longer periods of time. It is already noticeable how energy suppliers are creating new products targeted at narrow segments of the market, for example where homeowners can be paid to reduce demand at peak times.

The tendency for those who can afford it to get the benefits and those who can't to pick up the costs is consistent with the notion of a 'prosumer'. Network operators will buy flexibility to alleviate network constraints, which translates into costs for them (though potentially lower than upgrades), costs which are later spread out to all electricity users through their electricity bills. That means those who already benefit from efficient heat pumps and electric vehicles receive further financial benefit, while those who don't are bearing the costs.

If in the short-term we are already noticing inequitable outcomes, in the long term the majority of the population will be worse off, unless major structural changes take place. This is because of how net value is distributed within the value chain, or the ratio of value-to-cost at each value exchange transaction.

7.1.1 Lack of data

A smart energy system relies on data to drive aggregation, dynamic management, automation, optimisation etc., so one of the first challenges faced when implementing the digital environment of the PPS 2.0 was the lack of data.

To help analyse this challenge it is helpful to look at data as a process flow, starting with what data might be needed all the way down to the decisions it then allows for and the ultimate value creation sought. Ideally that process would be determined by that final step, the value creation sought, but sometimes in real life it might be that the data we can get our hands on will determine what value can be created.

To summarise, looking at the data challenge we identified, the following need to be considered:

- ***availability***: is the data required being measured and captured anywhere in the first place?
- ***accessibility***: if the data is available in principle, how can it be accessed, or made use of?
- ***reliability***: how reliable is the data once accessed? How has it been measured? Has it been pre-processed – if so, how? What are the channels for accessing it? What do they depend on and who controls them?

The first technical challenge Fractal Networks encountered in developing the PPS 2.0 was the availability of data. The vast majority of legacy equipment has been designed without giving much consideration to measuring and/or capturing data for later use. For instance:

- the sources for measurements are there but they are not being measured – think of analogue meters
- or if they are measured they are not being captured – think of a circuit breaker

that has to measure current in real time for it to work, but is not recording that data.

This is a difficult challenge to overcome, but one that may ease up over time as legacy equipment is replaced. In the meantime, additional specialist monitoring equipment may be needed so that at least some essential data can be captured.

The second challenge we encountered as that of data being available but either inaccessible or not accessible in a way that was fit for purpose. Examples include:

- many digital meters (not smart meters) that simply don't provide the means for accessing data that is being captured
- or the same digital meters where the data is available but only visible through the meter display.

The same applies to other pieces of equipment, such as PV inverters or battery control systems, where data is being captured and remotely accessed by manufacturers but the only access provided, even to the owners of the equipment, is through visual dashboards in an app, or at low temporal resolution if the owner wishes to download the raw data.

Smart meters deserve special mention as a missed opportunity; in fact, one might call them the 'not so smart smart-meters'. Residential smart meters are being rolled out as part of the changing energy system infrastructure, with the associated costs eventually socialised through energy bills. Smart meters measure, capture, and store valuable sets of data, but restrictive rules, such as the need to request data via energy suppliers, the limited subsets made available to a bill payer, or the need for purchasing additional pieces of equipment[27] from a licensed third party, make accessing that data time consuming and costly, not to mention the limited scope of data types.

As part of the Osney Supercharge trials residents had consumer access devices installed so the smart meter data could be accessed, bringing extra costs as the

[27]Data interfaces incorporated into the smart meter hardware could be used to access the data directly without the need for any third-party involvement. Manufacturers which supply smart meters to different markets will have those interfaces already built into the hardware, but they are covered when supplied to the UK market.

new devices had to be purchased and recurring service fees payable for accessing the data, as well as creating dependency on the device supplier as the data is sent to their servers and they control the terms for providing access.

Another aspect of the existing rules determines what data can be made available to whom. The root of the problem lies in the fact that least consideration has been given to the energy user, or bill payer, and their choice of what use they might wish to make of their data. Despite the abundance of data being captured, different subsets are made available to the DNO[28] but not the energy user, or, as discussed previously, some might appear on a display but not be accessible in a raw format that can be manipulated. Indeed, the little data accessible in raw format is of low temporal resolution and has to be accessed via the energy supplier, which as the trials at Springfield Meadows have demonstrated is as good as being inaccessible.

Simple modifications to the rules could lead to the sort of innovation claimed in widely advertised campaigns. Examples of changes could be in specifying that smart meters have a standard interface for direct[29] data collection, or that whenever a new smart meter is installed a CAD is also provided.

This presents a huge opportunity for the market regulator, Ofgem, to overcome this challenge and truly facilitate the UK's transition to the smart energy system we need for the future, to:

- redraw the specifications for smart meters in the UK, for instance smart meters could also have a serial port to provide local, hard-wired, access to the data as it is the case in many other countries
- revise what the energy suppliers have to supply to homeowners when a smart

[28] Strongly worded as it may sound, some equipment manufacturers hold the owners and users of their equipment to ransom: data being collected from the equipment at high resolution is being stored by the manufacturer but only made available through visual dashboards, or for download at low temporal resolution. If the very owner of the equipment wishes to access their data at the resolution it is stored in the manufacturer's servers, they have to forgo additional payments.
[29]Non-intrusive load monitoring (NILM) is a generic term for tools and techniques that can disaggregate loads from a combined signal and identify whether a particular piece of equipment – or appliance – is present in that signal. As an example, NILM machine learning algorithms can be trained to identify what appliances are in use by analysing the total energy demand measured at a household meter.

meter is installed – the in-home displays (IHD) provided with every meter could, without any significant extra costs, be a CAD, but they are not and all they do is to show the data on a screen.

Great effort in the trials was placed on accessing data, but in many cases where data became accessible its availability was unreliable. In this context reliability can be expressed in terms of both the uptime of the connection (is the data flowing from source to intended destination?) as well as confidence to be able to access the data. This confidence can often be lacking, be it for technical reasons – the reliability of the data comms infrastructure – or the need to rely on third-party platforms which presents technical and commercial challenges.

Another challenge faced is the lack of common standards across the industry for how data is measured, captured, stored, pre-processed, formatted and exchanged, making it very difficult for different pieces of equipment, in some cases even from the same manufacturer, to be fully interoperable or it might require so much work in translating data into a common standard that costs easily spiral out of control, destroying value.

7.1.2 – Data ownership

The biggest challenge, though, seems related to data ownership and what the current arrangements can lead to. It's not uncommon for equipment manufacturers to hoard user data and block access, particularly in domestic settings. Worryingly, it seems to be a growing trend where equipment manufacturers hold data within their proprietary black boxes and prevent the very users that own and pay for the equipment to access it. If anything, this type of arrangement creates a dependency of the user on the data access provider who single-handedly controls access[30]. Such arrangements, irrespective of whether it's fair or not, present significant risks as the manufacturer's service could be suddenly withdrawn, or the cost of access become prohibitive.

[30]Initially the whole system was running on a single server and at later stages of the implementation the system was sub-dived into four servers, each dedicated to delivering a specific functionality. The purpose of splitting up into four servers was to test the feasibility of using clusters of cloud servers to improve resilience as well as demonstrating scalability. The migration from a single server to a cluster was carried out without interruption to the operation of the live system.

The question of data ownership, what can be done with that data, and what is being done with that data cannot be left for the market to decide. Market asymmetries put individuals and small and medium-sized businesses at great disadvantage and exposed to exploitation by bigger players. If data is part of the foundation of a smart energy system, that foundation needs to be built on solid ground. There are significant technical challenges when it comes to being able to have appropriate data in a fit-for-purpose manner.

However, if the wills of regulators and wider industry coalesced, those could be relatively easy to overcome – the GSM standards for mobile telephony offer a powerful example of how it is not only possible to do so, but also how such change can increase the value creation potential for an entire system. Based on the experience of the LEO trials, Fractal Networks strongly believes that policy interventions to balance the power between energy users and product/service providers are not only called for but will have benefits both in terms of innovation and equity.

Energy use patterns can easily be used to extract features[31] which could potentially create financial value to other parties and be traded without the originator of the data necessarily knowing. Those same patterns could also be used to infer behaviour which could be equally monetised without the explicit knowledge or consent of the individual or business who generated the data in the first place.

There is a great lack of transparency when it comes to the use made of data that arguably should be owned by who generated it, or whose behaviour led to the patterns being observed, which is the end user. A householder may have signed some small print in the Terms and Conditions when buying a new PV system or battery, but it is not clear if they would all have either read in detail or understood precisely what they contain. So, two key questions we have seen arise for the end users of energy at the grid edge from our work in developing the PPS 2.0 are:

- Do I really know how my data is being used?

[31]Raspberry Pi is a low- cost hardware platform (computer) often used by hobbyists, but with enough processing power to run a community energy virtual power plant consisting of tens of assets.

- Is my data being sold without my knowledge or informed consent?

7.1.3 Skills

Last but not least comes the challenge posed by the lack of skills in the industry. During the trials it became clear and evident that the availability, or lack of, people with the appropriate technical knowledge and skills translates directly into long delays and unnecessary costs, even for most basic equipment specifications or installation of data related comms, such as connecting two 5VDC cables to a serial port in a piece of hardware. Skills shortages we have observed include:

- a very poor skills base when it comes to knowledge of data and data comms required for a *smart* energy system to operate
- a technical skills gap throughout the supply chain – design, installation, and operation – of smart systems, including for instance the installation of equipment such as heat pumps and batteries.

Such lack in key technical skills which will no doubt delay the rollout of any meaningful transition unless addressed as a matter of urgency.

7.2 Opportunities

The Project LEO trials involving the PPS 2.0 so far indicate that the opportunity for value creation by working closely with communities does exist and that communities are keen to take part and participate actively in the energy system. Whether the communities involved are representative or not of a wider range of neighbourhoods is a question that cannot be answered as is, but the results obtained so far certainly justify further trials.

It is equally encouraging that the trials have been able to demonstrate that technology can indeed play an important role in that value creation. Indeed, they have shown how co-development and collaboration in the design of specific tools can help enable further engagement and participation, creating important feedback loops.

A complex system, like the energy system, does not need to be complicated and the more *complication* can be removed the better the outcomes. This is the case in particular as societal change needs to be a key feature of our transition to a smarter and more flexible zero carbon future. The use of powerful visualisation tools is a case in point, where complex interactions are greatly simplified through the use of, superficially, rather simple dashboards. At the same time, they bring together seemingly disparate elements or subsystems, showing data in different combinations, and using the feedback provided by users to translate that data into meaningful information. Fractal Networks believes these trials have already proven that technology can help, but simplicity is key and people must be firmly in the driving seat.

The PPS 2.0 is also demonstrating how it is technically feasible to aggregate a multitude of DERs, of different scales and technologies, to create collective value, be it in freeing up network capacity, reducing a building's carbon footprint, increasing local self-consumption of energy generated, or the provision of flexibility services. So the vision of replacing an enormous coal-fired power station with a multitude of DERs is a real possibility, at least with regards to technology.

Finally, the trials of the PPS 2.0 in different strands of Project LEO have demonstrated that synergies can be created by joining up the dots. There is a significant potential for value creation by bringing together and combining multiple sources of data, different pieces of equipment, and different subsystems.

One of the best examples we have seen so far is through the aggregation of the power output of multiple DERs and how, acting together and in a coordinated way, they can create tangible value for the electricity network. Fig [28] shows a map combining the location of community-energy assets in relation to the distribution network, which can be used a visualisation tool to demonstrate how small scale assets offer the opportunity to create dynamic pools targeted at specific needs of the electricity network, which can easily vary in capacity (based on the number of assets taking part), and the service they provide (based on the type of assets). The resilience of the system can also be improved since it is not dependent of a small number of larger assets, and also how complexity can be reduced in optimising the system by acting at very local level.

The approach being taken for the development of the PPS 2.0 is paying dividends. Clarity of purpose combined with well-defined performance outcomes led to an innovative design model, starting with the treatment of the energy network as composed of fractals. This was then realised through the design and creation of a digital environment that does enable the implementation of Smart Community Energy Systems, which we call the PPS 2.0. What we at Fractal Networks want to see is agile communities creating a smart energy system enabled by flexible technology such as this.

8. Cost analysis

Detailed analysis has been carried out while running the live system and trials to evaluate the development and operational costs of the system. The objective of the analysis is to provide transparency, to inform the forecasting of unit costs in relation to scale, and ultimately to inform the revenue requirements for the financial viability of the PPS 2.0 either as an in-house system used by smart community energy organisations, or in a software-as-a-service business model.

8.1 Cloud computing running costs

This section details the direct costs associated with running the cloud servers for the live demonstrator.

Four small-scale cloud servers[32] as shown in Table [1], each of which has a specific functionality, are currently in use as a cluster. The service is provided by AWS under its *Elastic Compute Cloud* model.

THIRD PARTY COSTS CANNOT BE PUBLISHED EXTERNALLY DUE TO CONTRACTUAL OBLIGATIONS

Server functionality	Instance type	OS	RAM	Storage	Monthly cost (USD)
TOTAL COSTS					

[32]Actors are defined as any active participant in the system, be it persons, organisations, policy decision-makers, market regulators, or any other stakeholder..

Table [1] showing cloud servers' functionality and costs in USD.

Costs incurred in running the cloud servers have been captured in different ways, showing evolution of total monthly costs broken-down by categories (Graph (1)], which gives indications to how those costs vary in relation to scale of deployment.

While data storage costs increased as expected as the number of connected datapoints increased (Graph [2]), costs associated with computer processing capacity remained relatively stable (Graph [3]), indicating that the servers deployed can handle significantly higher numbers of connected datapoints with no significant additional costs.

The current system has approximately 200 individual devices connected, with the amount of data per device varying significantly depending on both the temporal resolution of the accessible data and the number of measurements in each device.

Although the costs depend not only on the number of records being processed and stored, but also the total transfer of data, querying and reporting, as well as the amount of data analysis, the figures shown in Table [2] are useful in estimating the marginal cost of adding new devices or data points.

THIRD PARTY COSTS CANNOT BE PUBLISHED EXTERNALLY DUE TO CONTRACTUAL OBLIGATIONS

Month	Number of records	Average records per day	Average records per minute	Data cost (USD)	Total cost (USD)
Apr 2022	7,735,522	257,851	179		
May 2022	6,992,333	225,559	157		
Jun 2022	8,308,125	276,938	192		
July 2022	11,834,837	381,769	265		
Aug 2022	13,701,852	441,995	307		
Sep 2022	9,510,274	317,009	220		
Oct 2022	13,003,788	419,477	291		
Nov 2022	17,882,239	596,075	414		
Dec 2022	21,463,075	692,357	481		
Jan 2023	20,845,213	672,426	467		
Feb 2023	63,105,753	2,253,777	1,565		
Mar 2023	67,082,445	2,163,950	1,503		

Table [2] showing the number of records processed in each month from April 2022 to March 2023. Costs are shown in US dollars.

Further analysis of costs relative to the number of records processed per hour shows steep reduction in the marginal costs for computing processor capacity and, while not quite as steep, a reduction in the marginal cost of short-term data storage, as shown in Graph [4].

Regression analysis shows that a logarithmic curve provides a good fit to the actual observed costs (Graph [5]) giving a higher degree of confidence in making cost projections and in estimating a long term cost curve for services related to cloud computing, even though the use of data is not yet representative of multiple orders of magnitude.

Those projections are also in line with the expectation of achieving a final cost of £ per month as the system scales up.

8.2 Third-party platform costs

The PPS 2.0 currently relies on accessing data via third-party platforms which are paid for, a summary of which can be seen in Table [3], which could represent material risks related to the reliability of access, quality of the data, and also by adding significant costs to the operations. The cost of access risk is compounded by a lack of clarity from the providers of the data on how those costs vary in relation to scale.

What has been observed so far is that the monthly cost for accessing data from third-party platforms are invariably high, at least at small scale deployment, and makes the financial viability of any business model even more challenging (Table [3]). If directly connected to the PPS 2.0 the projected cost per site would fall between £ and £ per month.

THIRD PARTY COSTS CANNOT BE DISCLOSED DUE TO CONTRACTUAL OBLIGATIONS

Platform	Max res	Max systems	Live systems	Total	Per allowed system	Per live system

Table [3] showing current costs for accessing data via third-party platforms, which is disproportionately higher than those incurred by the PPS 2.0 when data is accessed directly.

8.3 System operation and management

Human resources required for operating and managing the live system can be considered a fixed cost which varies in discrete steps as the system scales up (Table [4]), the consequence of which being that every time a threshold has been passed a rapid increase in scale is required in order to absorb those extra fixed costs.

COMMERCIALLY SENSITIVE INFORMATION

Units	Ops	Tech support	Admin	Over-heads	Sub-total	Cloud costs	Total costs	yearly cost per unit
500								
1,000								
5,000								
10,000								
100,000								

Table [4] showing forecast costs in £ for the PPS 2.0 running as an autonomous business unit, based on scale of deployment. Costs shown are represented as total yearly costs, total yearly cost per unit, and total monthly cost per unit.

8.4 Innovation development

The ongoing developing of the overall digital environment carries significant R&D costs which should be treated and funded differently to the day-to-day operation and in assessing the long-term viability of the business. However, those development costs do exist and must be taken into account while carrying out a full financial appraisal which includes the incubation phase.

The development of the digital environment such as the PPS 2.0 requires many different skills and an estimate of the true development costs to-date was made using market values and the respective allocation of time per area of expertise as shown on Table [5].

COMMERCIALLY SENSITIVE INFORMATION

Area of Expertise	Annual pay	Payroll costs	Total payroll costs	time allocation	Allocated cost
System architecture					
Full stack software engineer					
Database design					
Senior software engineer					
Experienced software engineer					
Junior software engineer					
Data comms engineer					
HW development engineer					
TOTAL ANNUAL COST					

Table [5] showing annual pay and total payroll costs for different areas of expertise required in the development of the PPS 2.0. An estimate of the time allocation per area of expertise is also shown.

The human resource costs in the first two years of the development of the PPS 2.0 is estimated at approximately £ per year and it is likely to continue at a similar magnitude while highly innovative functionality is added.

As the system evolves and scales up there will also be some shifting from pure development of new functionality to ensuring the complete environment continues to be reliable and resilient.

9. System implementation

The development and implementation approach being taken is one where all of the software tools included are open-source, free of charges for licensing or use and supported by the open-source development community.

The software tools being used are stable versions, robust, reliable and with proven quality of service for the functionalities offered by each one and widely adopted by companies around the world.

This approach also takes into account the need for constant review and optimisation, for individual software tools to be replaced without compromising the system as a whole, as well as having the ability to be scalable, resilient and secure.

9.1 System architecture

The generic system architecture is composed of the following building blocks:

- data comms and integrations layer: data input and equipment control
- translation layer: proprietary standards ↔️ common standards
- data storage: relational and time-series databases
- user management: account information, personal details, systemwide access control
- data management: data access, data security, data storage optimisation, data persistency
- services layer:
- internal, specific-purpose data processing
- internal, outfacing value-added services
- external interaction layer: MQTT server or API-driven value-generating services.

From the first prototype implementation of the PPS 2.0 the same structure has been used, with only minor changes. Even though the protocols for data exchange were being developed in parallel, and continued to be reviewed, improved, and in some cases going through significant changes, adapting the core platform proved to be relatively simple, which further demonstrates that the design of the environment keeps meeting the performance objectives of being agile and flexible as shown in Diagram [1].

That initial implementation shared a test cloud environment provided by AWS, which was free for 12 months and within some thresholds for data storage and data traffic. However, each of the main building blocks (MQTT Server, Database, and visualisation engine) could be set up and run in different servers, which later on was implemented.

9.2 Hardware platforms

The hardware parts of the main platform consist of servers and low-cost monitoring devices, all developed to meet the performance specifications of the PPS 2.0, with great emphasis placed on scalability and low cost.

The servers at the core of the PPS 2.0 are configured using a carefully chosen set of software modules capable of running on different scale hardware platforms, with the same complete system able to be deployed, in exactly same way, as micro-server based on a Raspberry Pi, or powerful clusters of cloud servers. The smallest server hardware costs around £350 (Photo [1]) and is able to run a small-scale PPS 2.0 with up to 50 connected DERs. Larger clusters of cloud-based servers could scale up to run millions of connected DERs.

The hardware components of the digital environment also include low-cost monitoring and data acquisition devices developed to overcome the challenges associated with accessing data. Different variations of the same underlying design have been produced as prototypes and continue to be used in trials. Photo [2] shows one of those variants, used in residences without a smart meter. Diagram [2] shows the electronic design schematics, making it replicable by other community organisations.

The devices are run with software modules created as part of the development of the PPS 2.0, collecting data directly from source and automatically publishing into the PPS using IoT standard MQTT protocol. The modules can be assembled for around £20 for a one-off device, with significant opportunity for cost reduction if manufactured in large quantities. Both the hardware design and the software source-code are available to community organisations under open-source licence.

9.3 Platform operating system

The core server is specified to run on a **Linux Operating System**, a state-of-the-art operating system available under open-source licence. Linux is the most widely used operating system in the IT industry and sets the standard for high availability, high capacity, cyber-secure and scalable IT platforms.

9.4 Core system software stack

Software stack is the term used to describe the multiple software tools used to provide the full functionality of an IT system. The software stack chosen for the PPS 2.0 consist of tools available under open-source licences with long-term support, widely used in the industry, and with strong open-source community support.

The main components of the software stack consist of:

- **PostgreSQL**: one of the most widely used relational database engines for large scale IT services
- **TimescaleDB**: an equally powerful and widely used extension to PostgreSQL specifically designed for managing large quantities of time series data
- **Druid**: an engine designed for fast processing of large quantities of data and particularly efficient when used for data analytics
- **KeyCloak**: an integrated tool for user registration and authentication providing the ability to link user accounts from other services, such as Google or others, without the need to create a specific account for the PPS 2.0
- **Let's Encrypt SSL**: an open-source encryption certificate authority which enables secure transactions over https
- **Nginx**: provides reverse-proxy functionality to direct web address subpaths to the relevant application
- **Grafana**: a visualisation engine used for system management and dashboards for displaying complex data.

10. PPS 2.0 sample dashboards

Figure 1

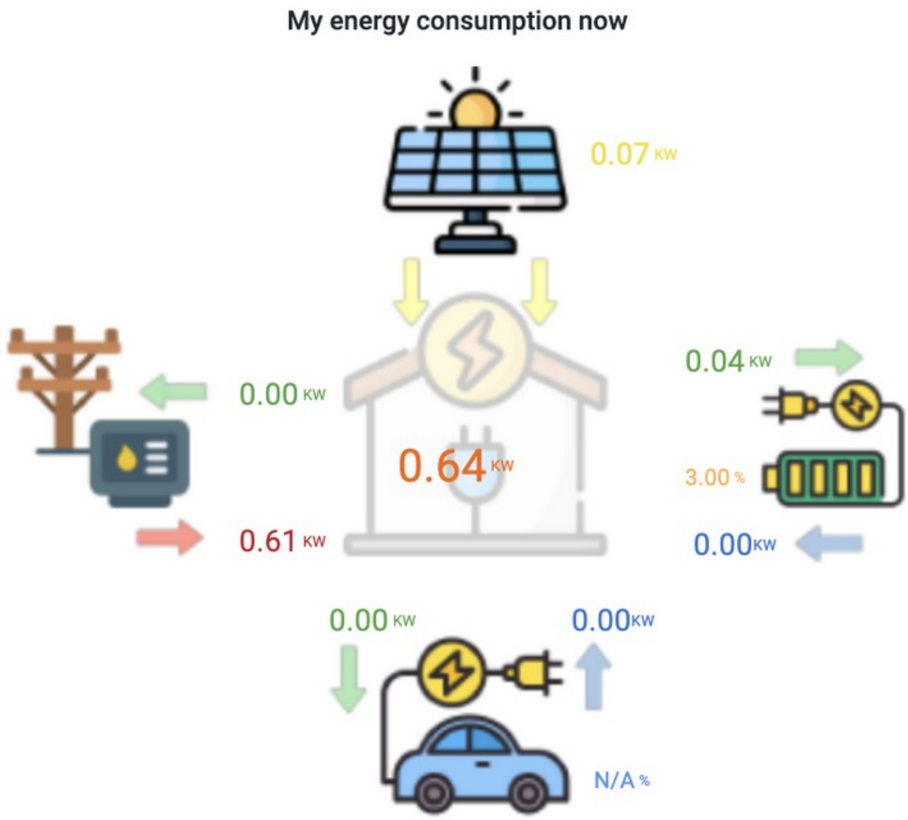

Figure [1]: PPS 2.0 dashboard showing the near real time flow of energy in a household (Osney Supercharge).

Figure 2

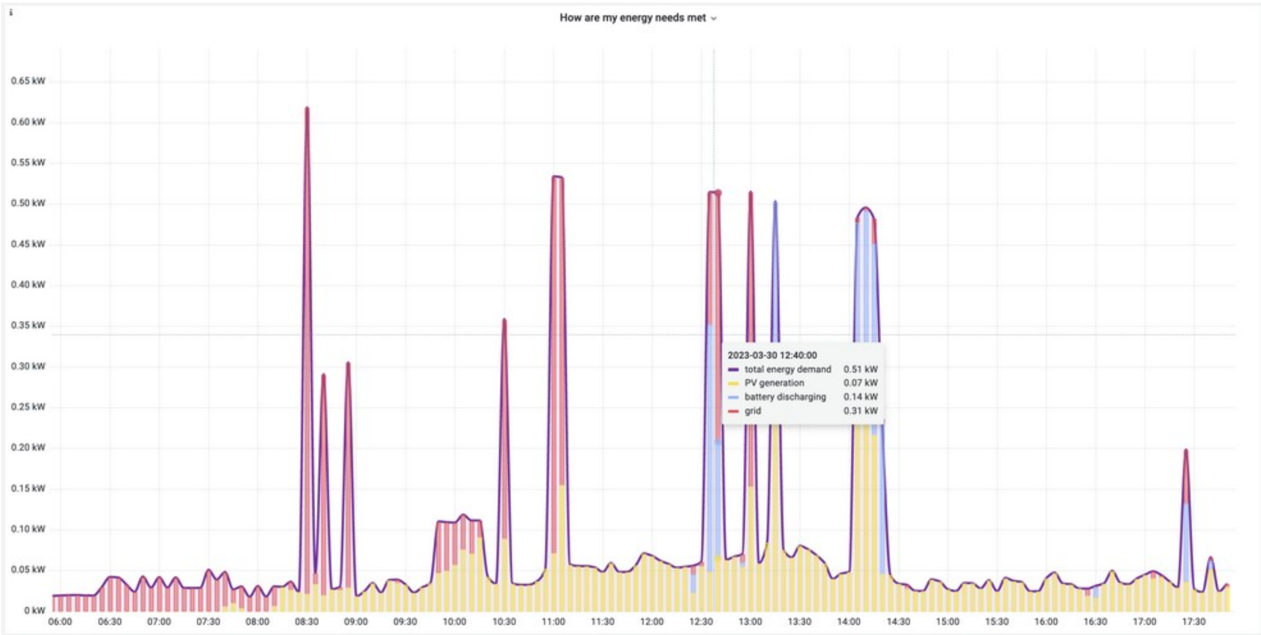

Figure [2]: PPS 2.0 dashboard graph showing the sources of energy to meet the household demand (Osney Supercharge)

Figure 3

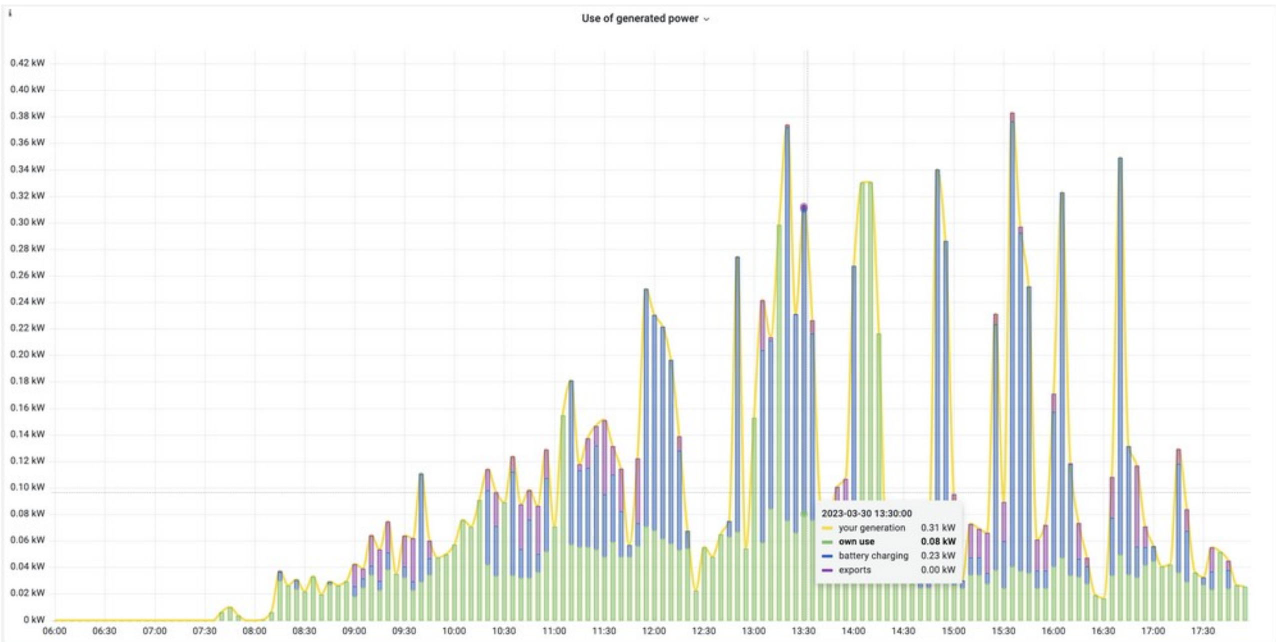

Figure [3]: PPS 2.0 dashboard showing how the energy being generated by PV is being used (Osney Supercharge)

Figure 4

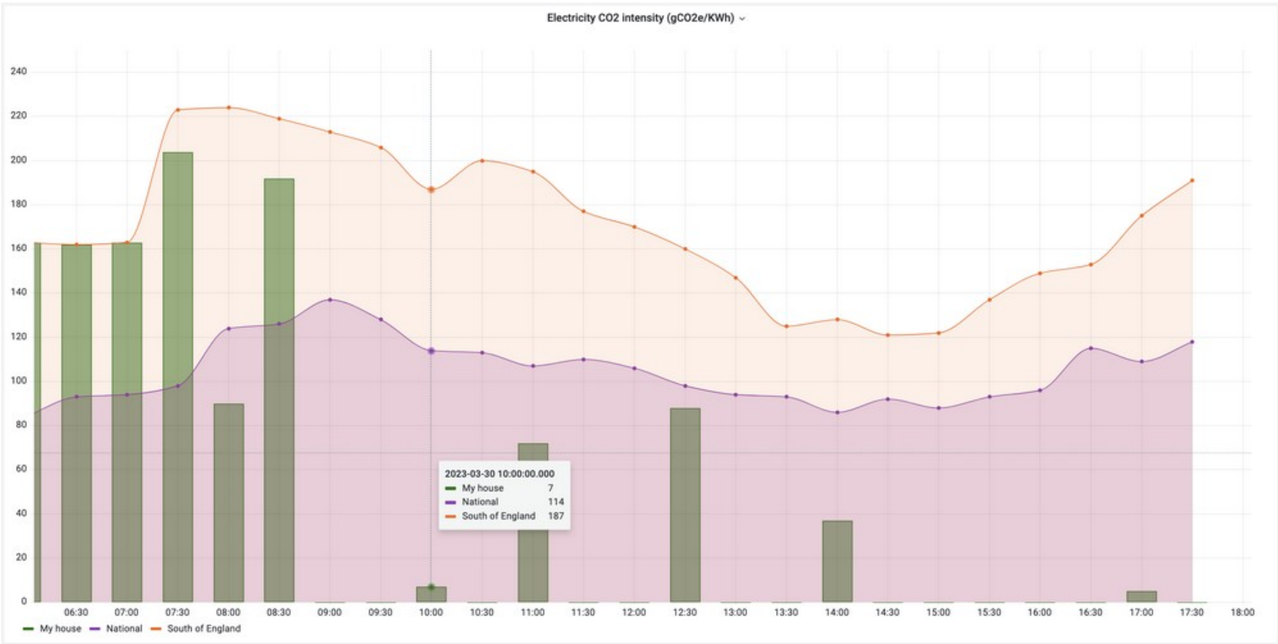

Figure [4]: PPS 2.0 dashboard showing how a household's energy use behaviour translates into the carbon intensity of electricity used and the absolute value of its carbon footprint (Osney Supercharge)

Figure 5

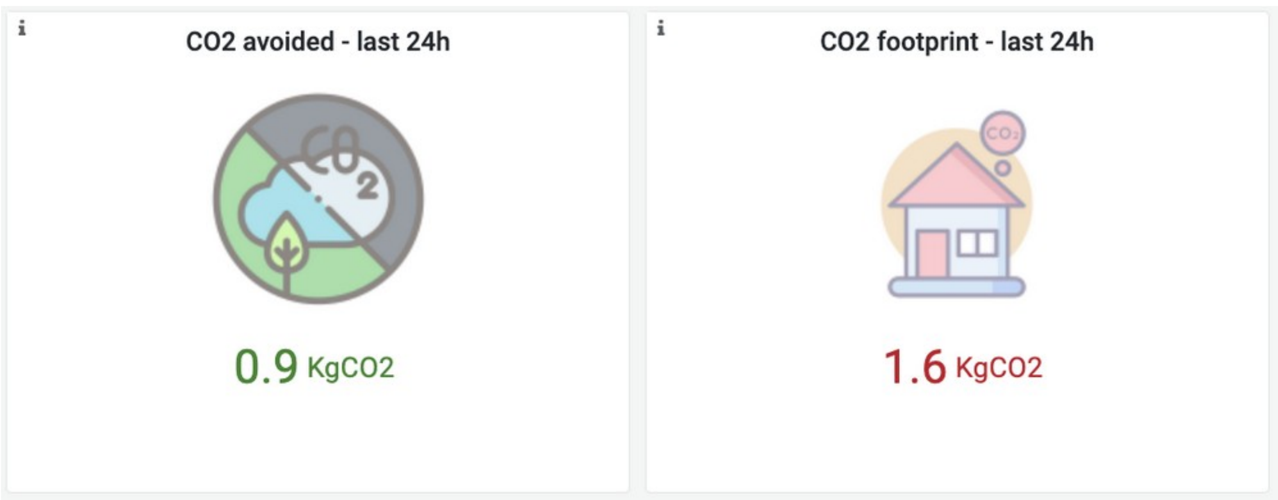

Figure [5]: PPS 2.0 dashboard showing the amount of CO_2 emissions avoided through self-generation and the actual carbon footprint due to imported electricity from the grid (Osney Supercharge)

Figure 6

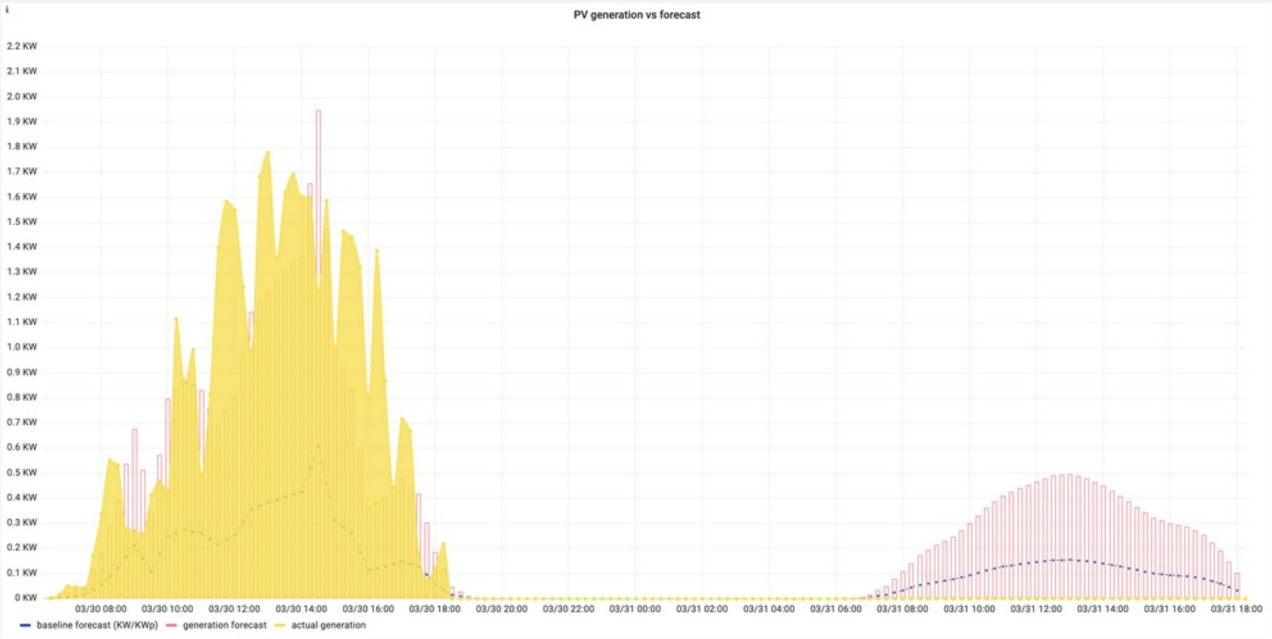

Figure [6]: PPS 2.0 dashboard using forecast generation to guide decisions on when the best time is for turning on discretionary use (Osney Supercharge)

Figure 7

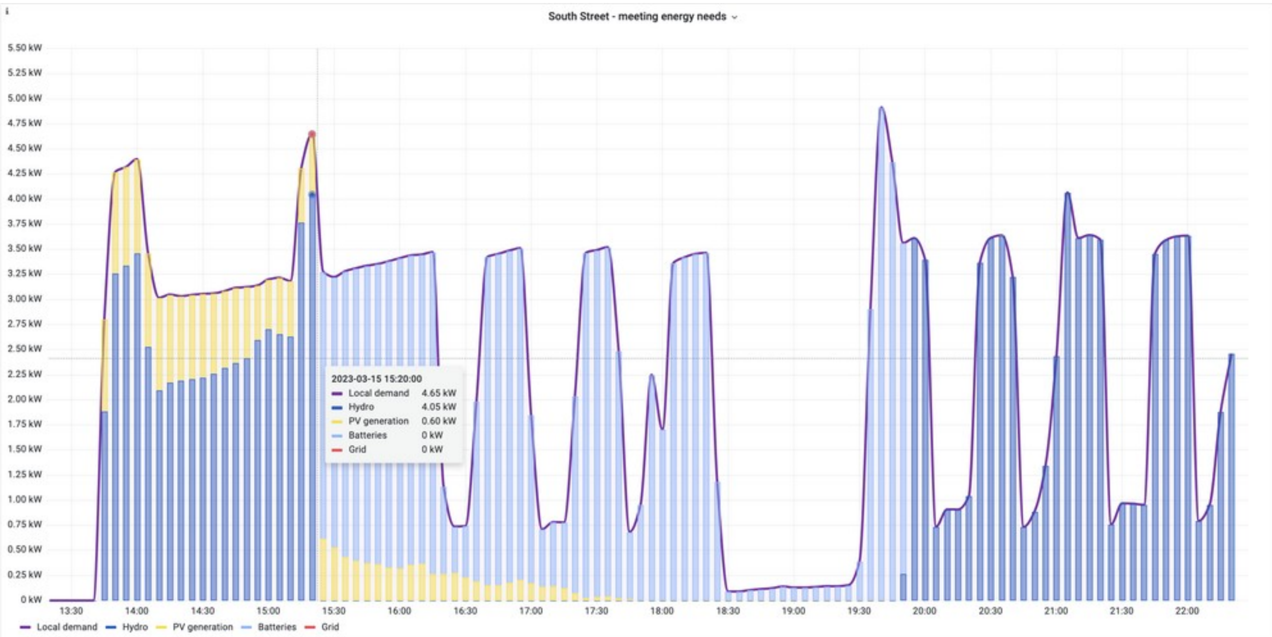

Figure [7]: PPS 2.0 dashboard showing how the energy demand for a given street is being met (Osney Supercharge)

Figure 8

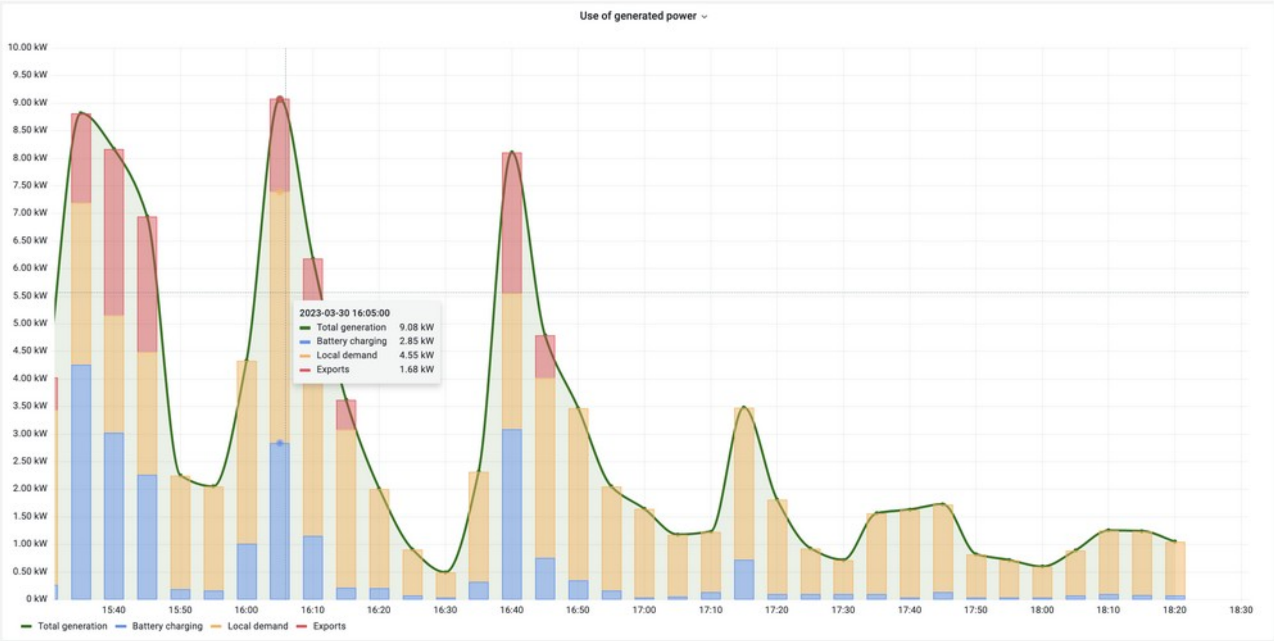

Figure [8]: PPS 2.0 dashboard showing how the total energy being generated by all participants in the community is being used (Osney Supercharge)

Figure 9

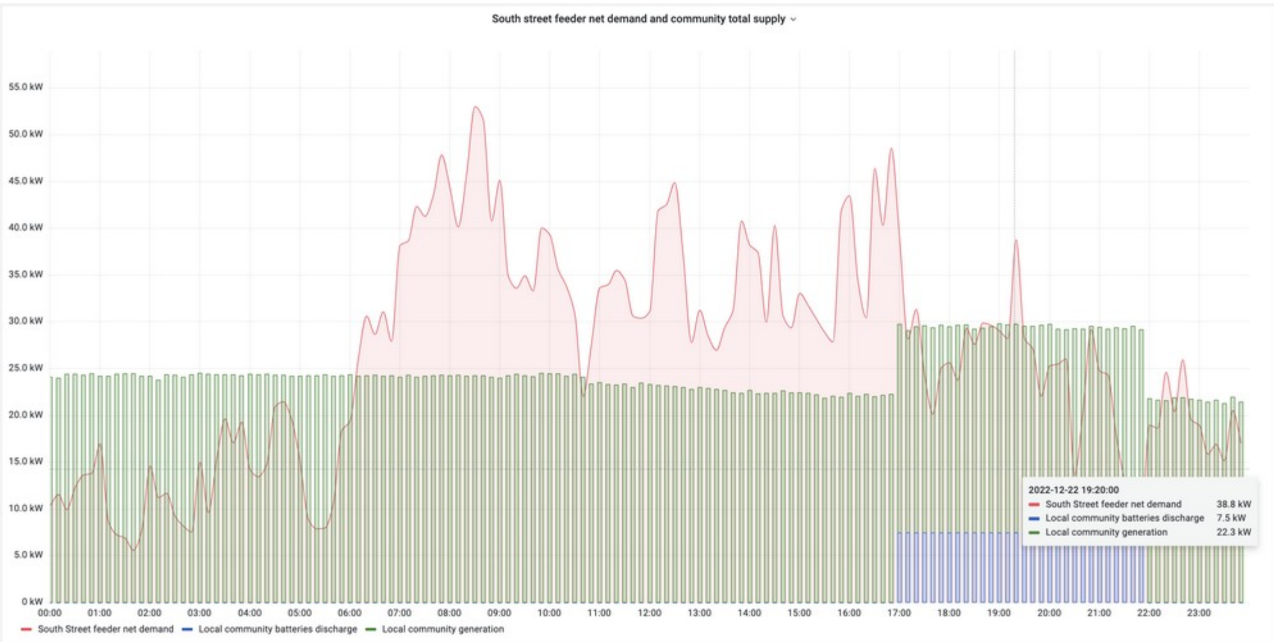

Figure [9]: PPS 2.0 dashboard showing the effect coordinating the use of DERs by participants in a community can have on the local network (Osney Supercharge)

Figure 10

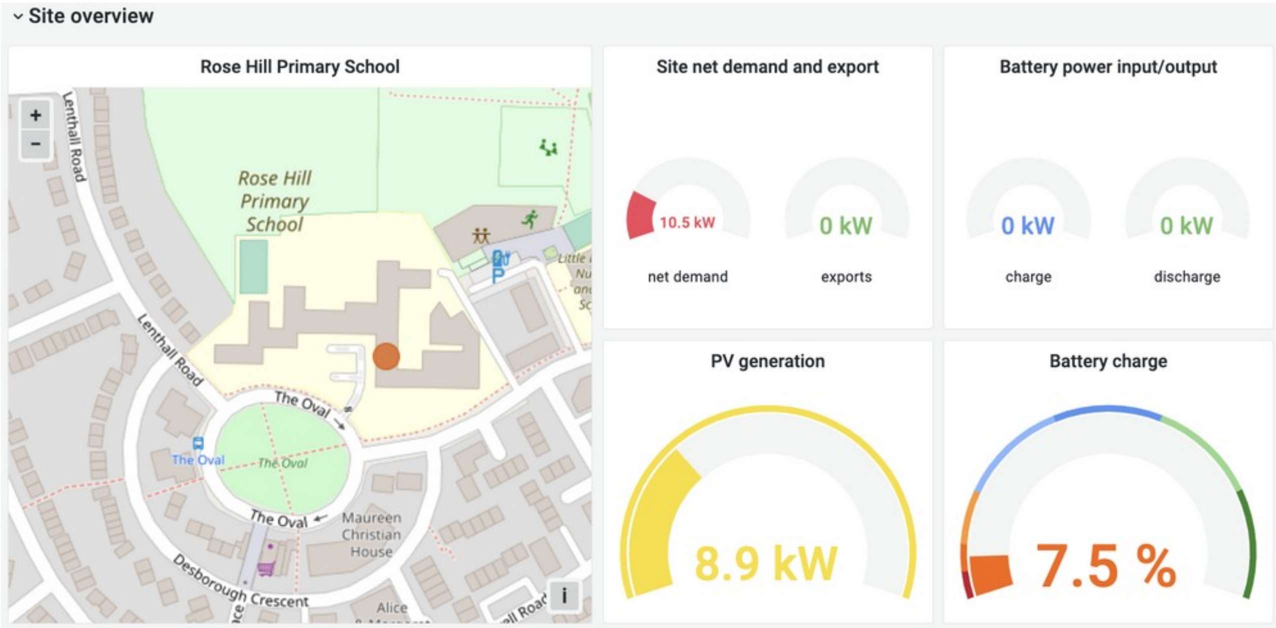

Figure [10]: PPS 2.0 dashboard showing an overview of the energy flow behind the main site meter (Rose Hill Primary School)

Figure 11

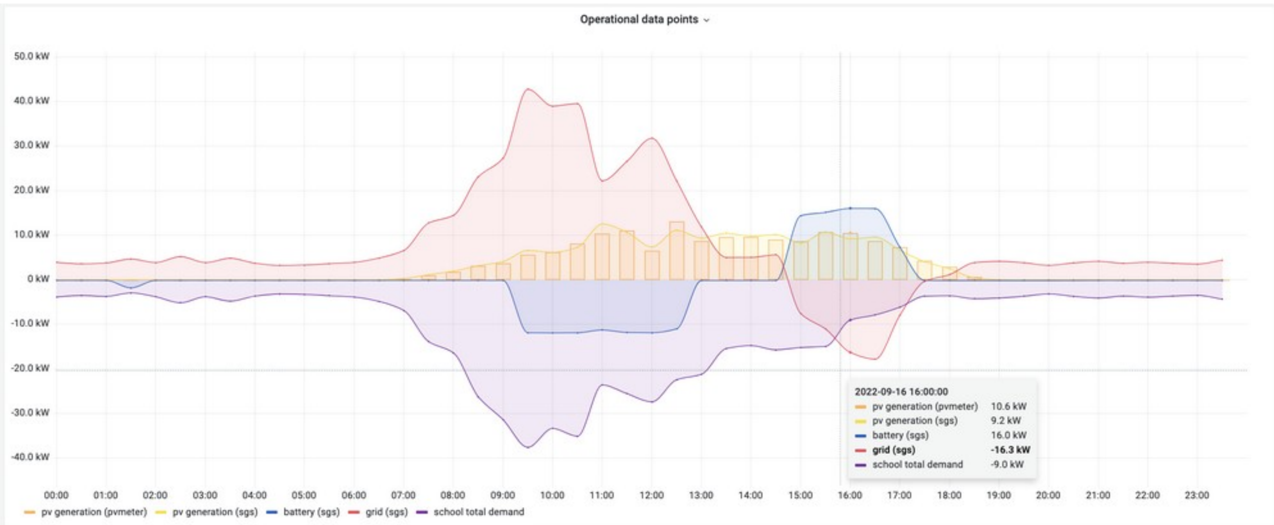

Figure [11]: PPS 2.0 dashboard showing details for data being acquired from multiple data points, or sources (Rose Hill school)

Figure 12

Detailed billing data

time	RHP DR - GRID (£)	RHP CR - LCH (£)	RHP DR - LCH (£)	Grid imports (KWh)	Grid exports (KWh)	Generation (KWh)	Deemed exports (KWh)
2022-08-02 05:00:00	0.1700	0	0	1.6600	0	0	0
2022-08-02 05:30:00	0.1700	0	0	1.6400	0	0.0100	0
2022-08-02 06:00:00	0.1300	0	0.0200	1.2900	0	0.2600	0.1300
2022-08-02 06:30:00	0.1200	0	0.0500	1.2000	0	0.6100	0.3000
2022-08-02 07:00:00	0.0800	0	0.0800	0.7900	0	1.0500	0.5300
2022-08-02 07:30:00	0.1600	0	0.0900	1.5800	0	1.1400	0.5700
2022-08-02 08:00:00	0.1900	0	0.1000	1.3300	0	0.9900	0.5000
2022-08-02 08:30:00	0	0	0.1600	0.0400	0	1.5500	0.7700
2022-08-02 09:00:00	0	0	0.2600	0	0.0600	2.5600	1.2800
2022-08-02 09:30:00	0	0	0.1900	0.0400	0.0200	1.8600	0.9300

Figure [12]: PPS 2.0’s overview of energy settlement and billing information for half-hourly periods (Rose Hill school)

Figure 13

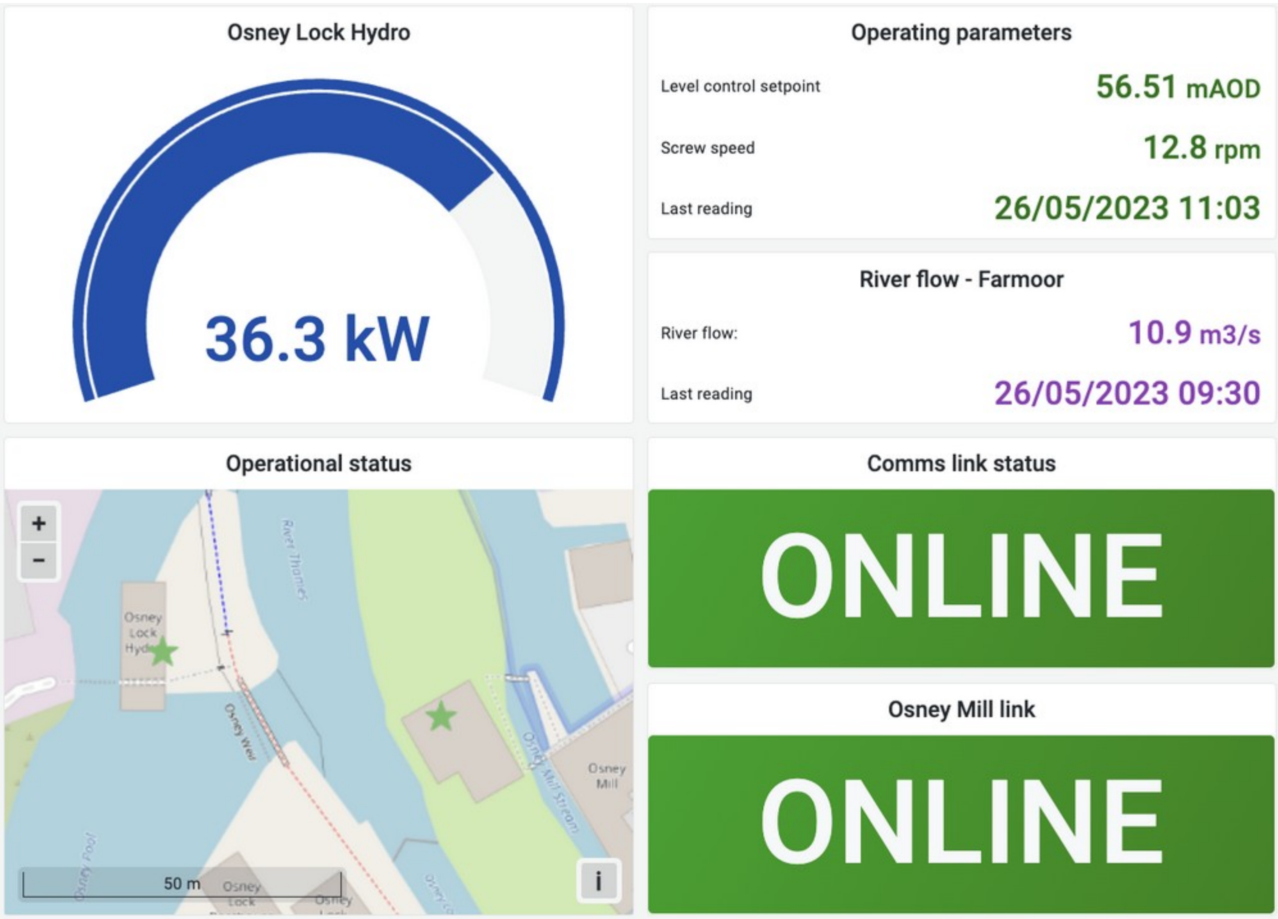

Figure [13]: PPS 2.0 dashboard showing an overview of the operational status of both Osney hydros, river conditions as well as the health of data comms links (Osney Lock Hydro)

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Figure 14

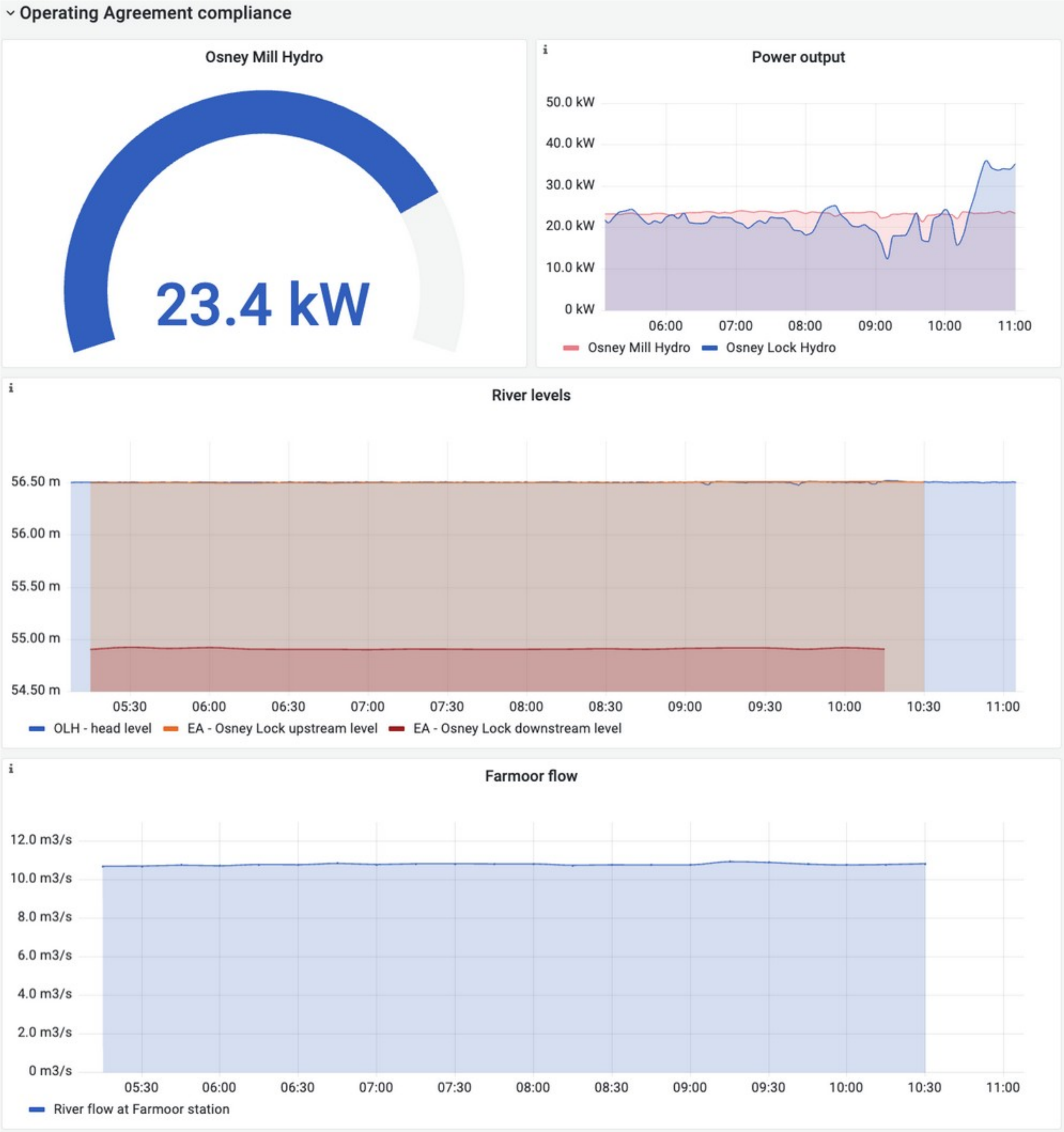

Figure [14]: PPS 2.0 dashboard showing details of the power output of Osney Mill Hydro, river levels, and river flow (Osney Lock Hydro).

Figure 15

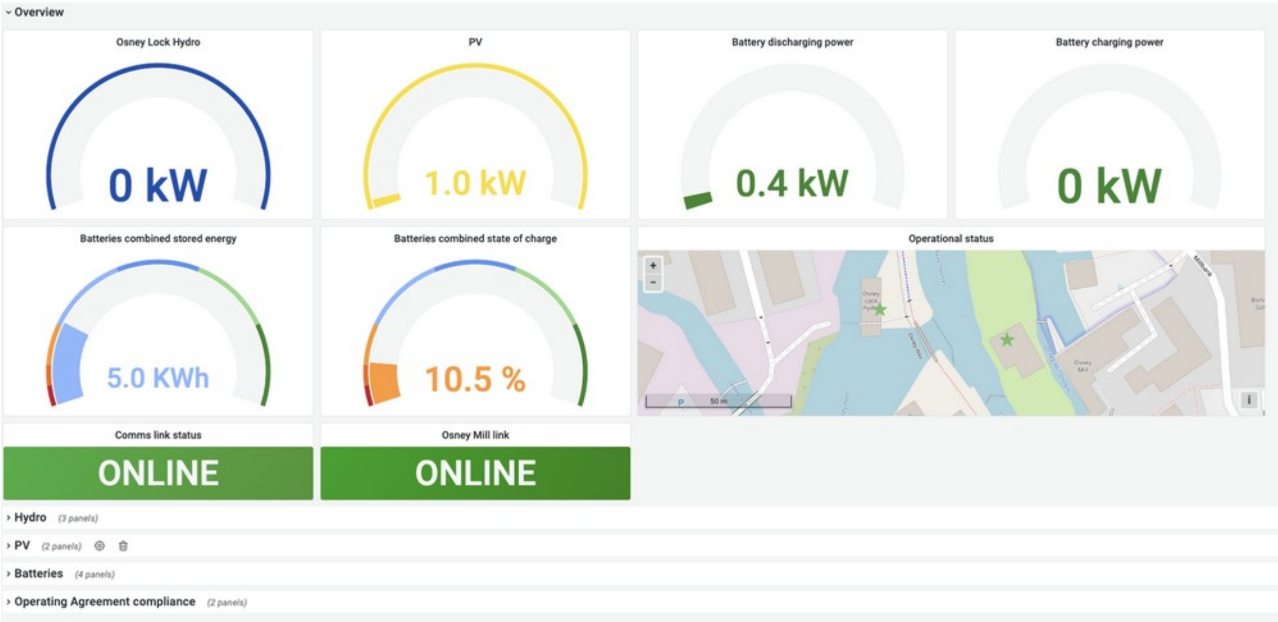

Figure [15]: PPS 2.0 dashboard showing a complete overview of the operational status of the power plant which includes the hydro itself, solar PV, and batteries (Osney Lock Hydro)

Figure 16

Figure [16]: PPS 2.0 dashboard showing historical generation data for the hydro and river conditions (Osney Lock Hydro)

Figure 17

Figure [17]: PPS 2.0 dashboard showing historical generation data for each of the two PV arrays (Osney Lock Hydro)

Figure 18

Figure [18]: PPPS 2.0 dashboard showing the cycles of charge and discharge for each of the two batteries, as well as state of charge (%) and amount of energy stored (Osney Lock Hydro)

Figure 19

NMF Report for Rose Hill Primary School

utc_time	local_time	KW	KWh
2022-09-09 16:00:00	09/09/2022 17:00	3.668	0.611
2022-09-09 16:10:00	09/09/2022 17:10	2.766	0.461
2022-09-09 16:20:00	09/09/2022 17:20	1.816	0.303
2022-09-09 16:30:00	09/09/2022 17:30	1.704	0.284
2022-09-09 16:40:00	09/09/2022 17:40	0.993	0.165
2022-09-09 16:50:00	09/09/2022 17:50	0.000	0.000
2022-09-09 17:00:00	09/09/2022 18:00	0.359	0.060
2022-09-09 17:10:00	09/09/2022 18:10	2.148	0.358
2022-09-09 17:20:00	09/09/2022 18:20	1.734	0.289
2022-09-09 17:30:00	09/09/2022 18:30	2.429	0.405
2022-09-09 17:40:00	09/09/2022 18:40	3.456	0.576
2022-09-09 17:50:00	09/09/2022 18:50	2.589	0.432
2022-09-09 18:00:00	09/09/2022 19:00	1.782	0.297

Figure [19]: PPS 2.0 automated reporting for verification of flexibility service delivery (NMF)

Figure 20

Select participant | Enter variable value | Select temporal resolution | 10 | DISCHARGE only? | NO

Selected (1)
All

NMF Report for All

utc_time	local_time	KW	KWh
2023-03-31 11:50	31/03/2023 12:50	-4.064	-0.677
2023-03-31 12:00	31/03/2023 13:00	-0.536	-0.089
2023-03-31 12:10	31/03/2023 13:10	-1.140	-0.190
2023-03-31 12:20	31/03/2023 13:20	0.088	0.015
2023-03-31 12:30:00	31/03/2023 13:30	0.564	0.094
2023-03-31 12:40:00	31/03/2023 13:40	0.862	0.144
2023-03-31 12:50:00	31/03/2023 13:50	-0.515	-0.086
2023-03-31 13:00:00	31/03/2023 14:00	-2.053	-0.342
2023-03-31 13:10:00	31/03/2023 14:10	-1.549	-0.258
2023-03-31 13:20:00	31/03/2023 14:20	-0.323	-0.054
2023-03-31 13:30:00	31/03/2023 14:30	0.405	0.067
2023-03-31 13:40:00	31/03/2023 14:40	0.363	0.061
2023-03-31 13:50:00	31/03/2023 14:50	0.302	0.050

Figure [20]: PPS 2.0 automated reporting for verification of service delivery showing a range of options for single or combinations of assets (NMF)

Figure 21

Selected (3)

- [ ] All
- [x] Bure Park Primary School
- [ ] Charlbury Primary School
- [ ] Cheney School
- [x] Edward Feild School
- [ ] Fir Tree Junior School
- [ ] Oxford Bus Company
- [ ] Stonesfield School
- [x] West Kidlington Primary School
- [ ] Wheatley Park School
- [ ] Windmill Primary
- [ ] Wykham Park Academy

NMF Report for Bure Park Primary School + Edward Feild School + West Kidlington Primary School

utc_time	local_time	KW	KWh
2023-03-29 14	29/03/2023 15:00	0.000	0.000
2023-03-29 14	29/03/2023 15:10	6.810	1.135
2023-03-29 14	29/03/2023 15:20	6.171	1.029
2023-03-29 14	29/03/2023 15:30	6.921	1.153
2023-03-29 14	29/03/2023 15:40	7.293	1.216
2023-03-29 14	29/03/2023 15:50	8.212	1.369
2023-03-29 15	29/03/2023 16:00	10.656	1.776
2023-03-29 15	29/03/2023 16:10	10.285	1.714
2023-03-29 15:20:00	29/03/2023 16:20	8.852	1.475
2023-03-29 15:30:00	29/03/2023 16:30	8.106	1.351
2023-03-29 15:40:00	29/03/2023 16:40	6.626	1.104
2023-03-29 15:50:00	29/03/2023 16:50	5.136	0.856
2023-03-29 16:00:00	29/03/2023 17:00	4.503	0.750

Figure [21]: PPS 2.0 automated reporting for verification of service delivery by PV assets participating in flexibility services (NMF)

Figure 22

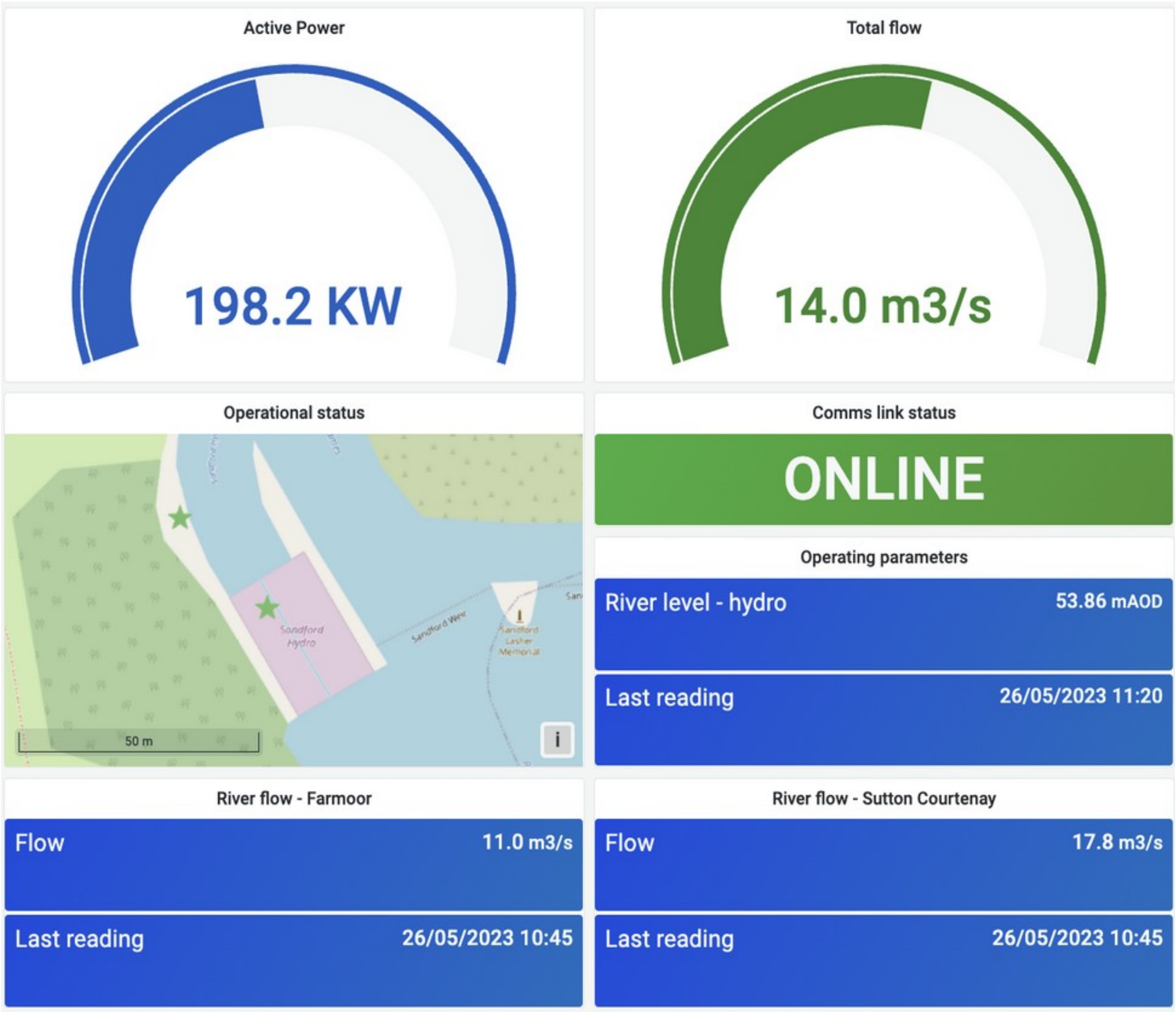

Figure [22]: PPS 2.0 dashboard showing an overview of operational status (Sandford Hydro)

Figure 23

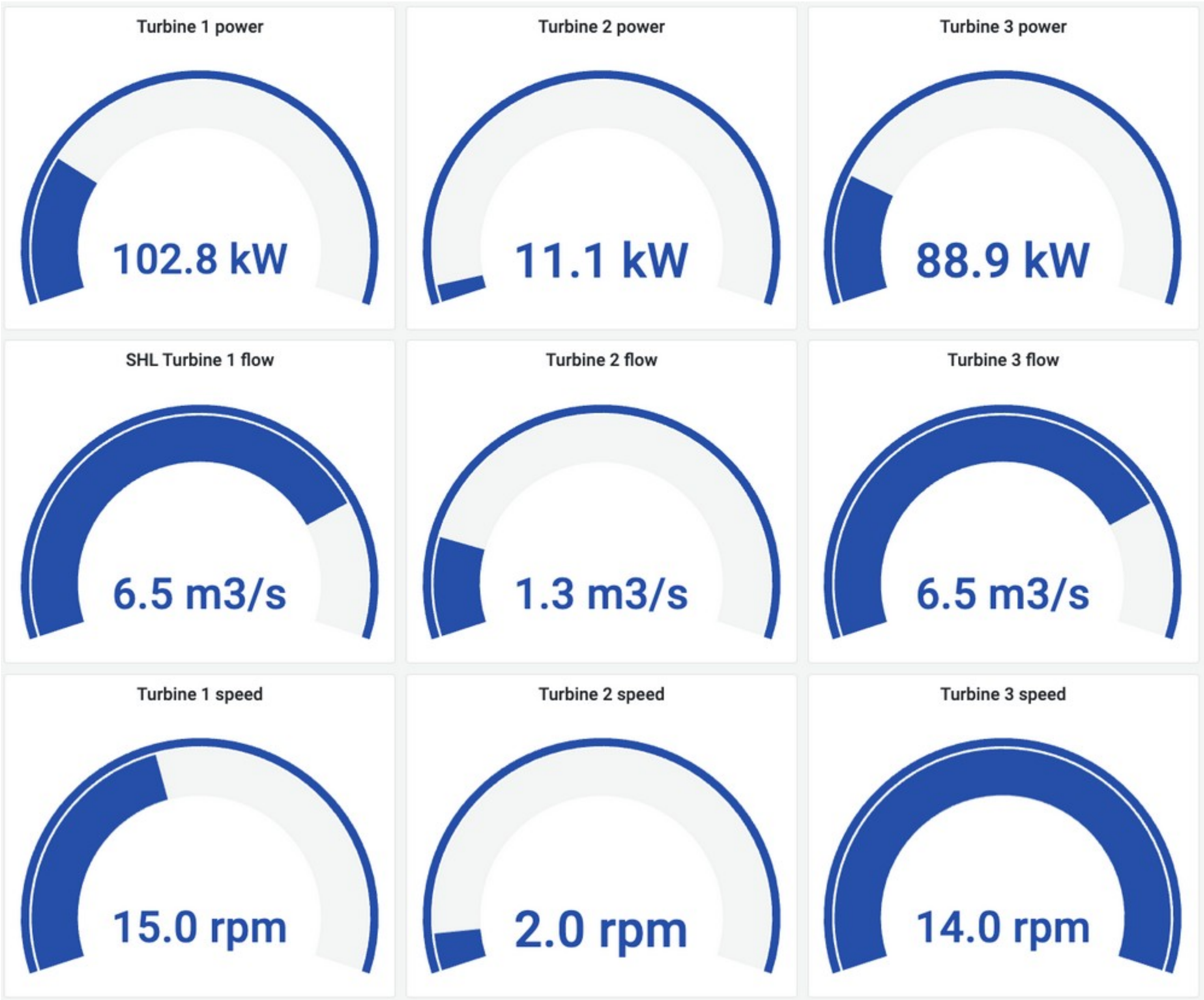

Figure [23]: PPS 2.0 dashboard showing power output, flow, and turbine speed, for each one of three generators (Sandford Hydro)

Figure 24

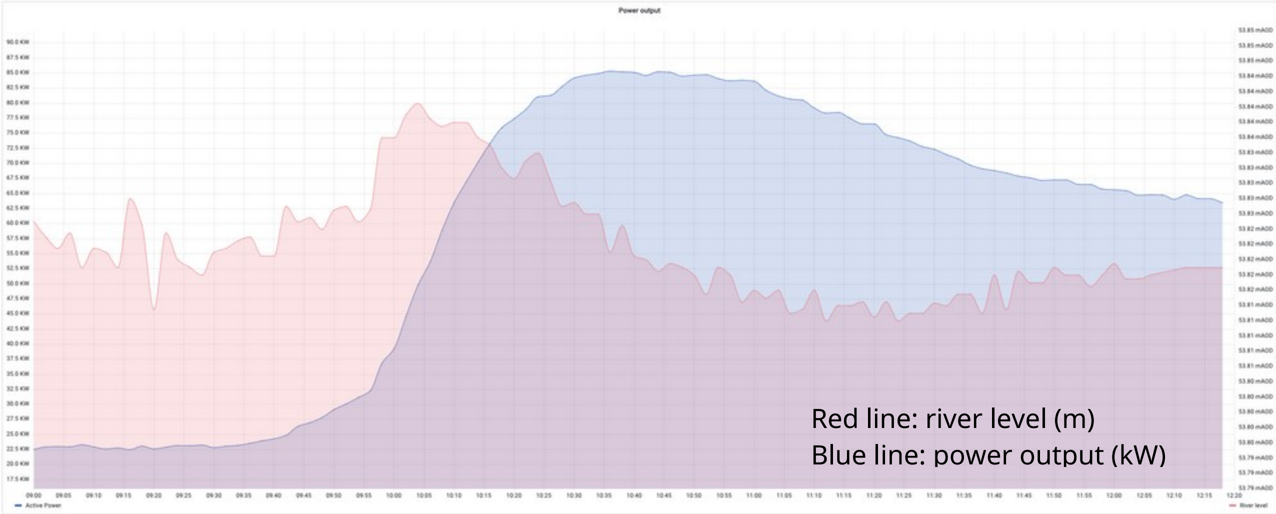

Figure [24]: PPS 2.0 dashboard showing changes in river level as a result of changes in power output. Lower power output leads to a rise in the river level, which can be used as a form of energy storage. At peak demand times the power output is then increased and the river level is dropped accordingly (Sandford Hydro).

Figure 25

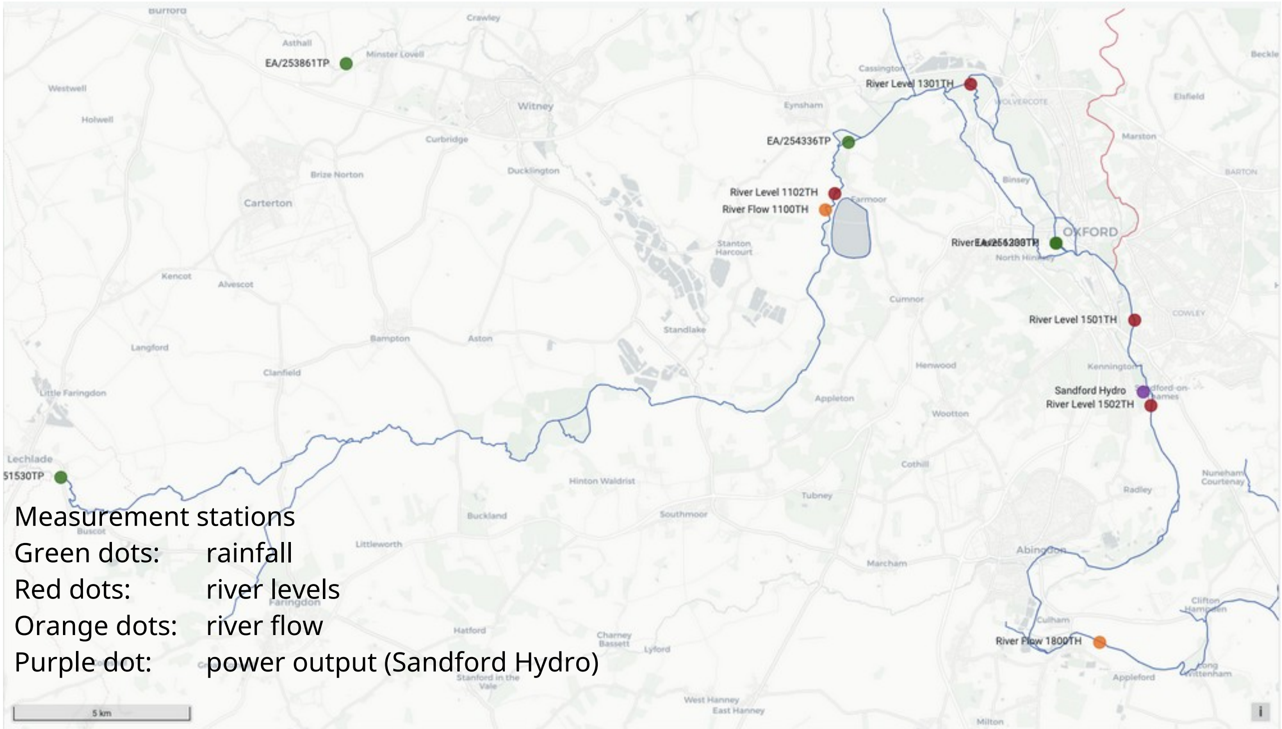

Figure [25]: PPS 2.0 map showing the location of stations providing different parameters for forecasting models (Sandford Hydro). Type of data is shown by colours of the dots.

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Figure 26

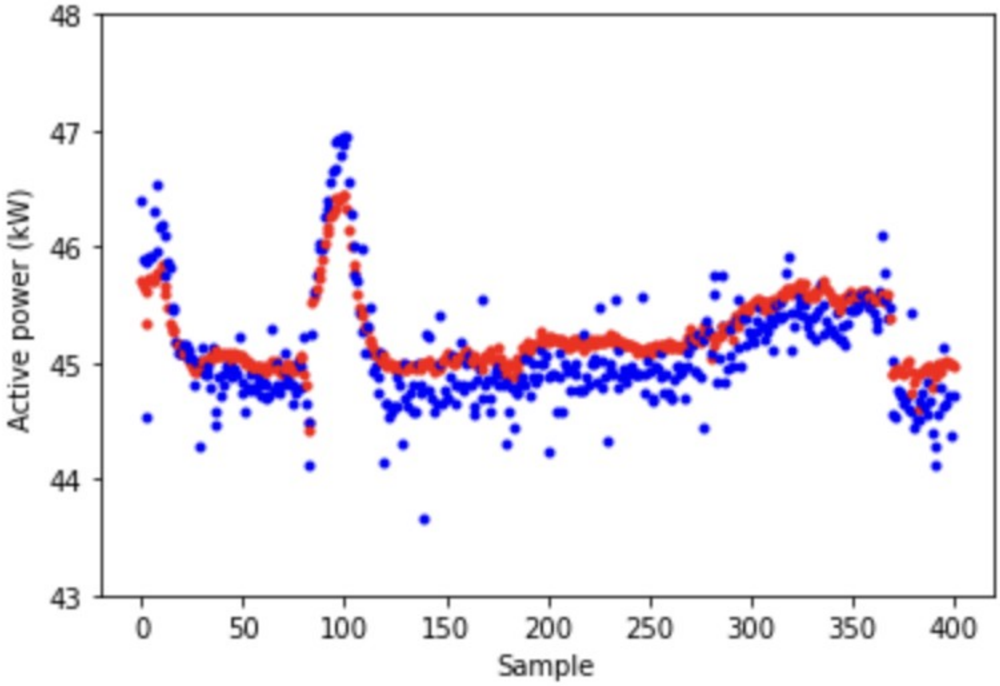


Figure [26]: People's Power Station graph showing actual power output values, in blue, compared to forecast values, in red (Sandford Hydro)

Figure 27

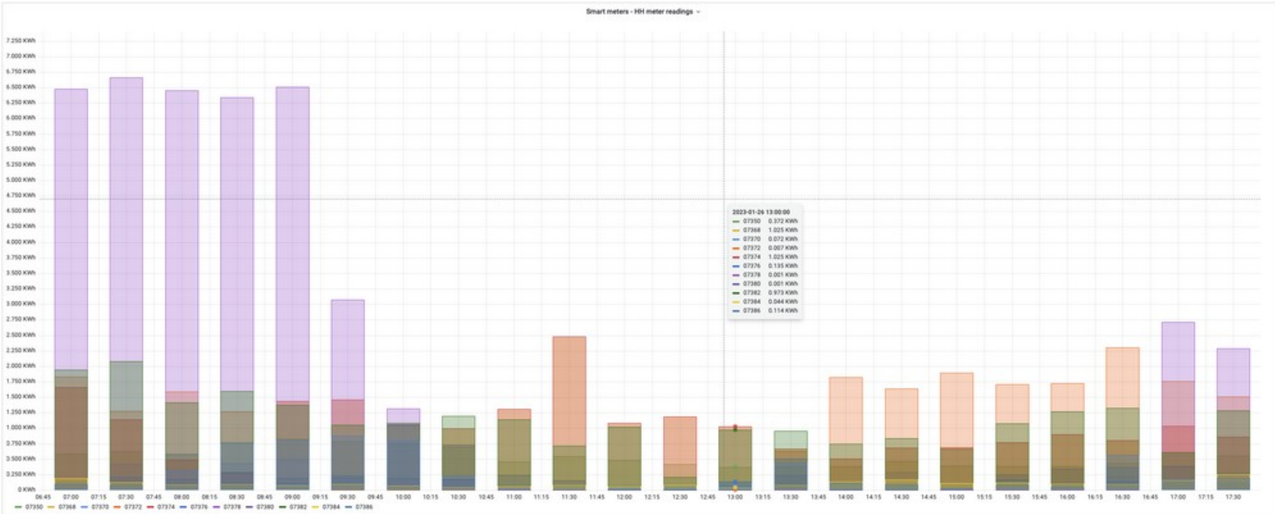


Figure [27]: People's Power Station dashboard showing 30-minute energy use data with bar colours representing an individual households (Springfield Meadows)

Figure 28

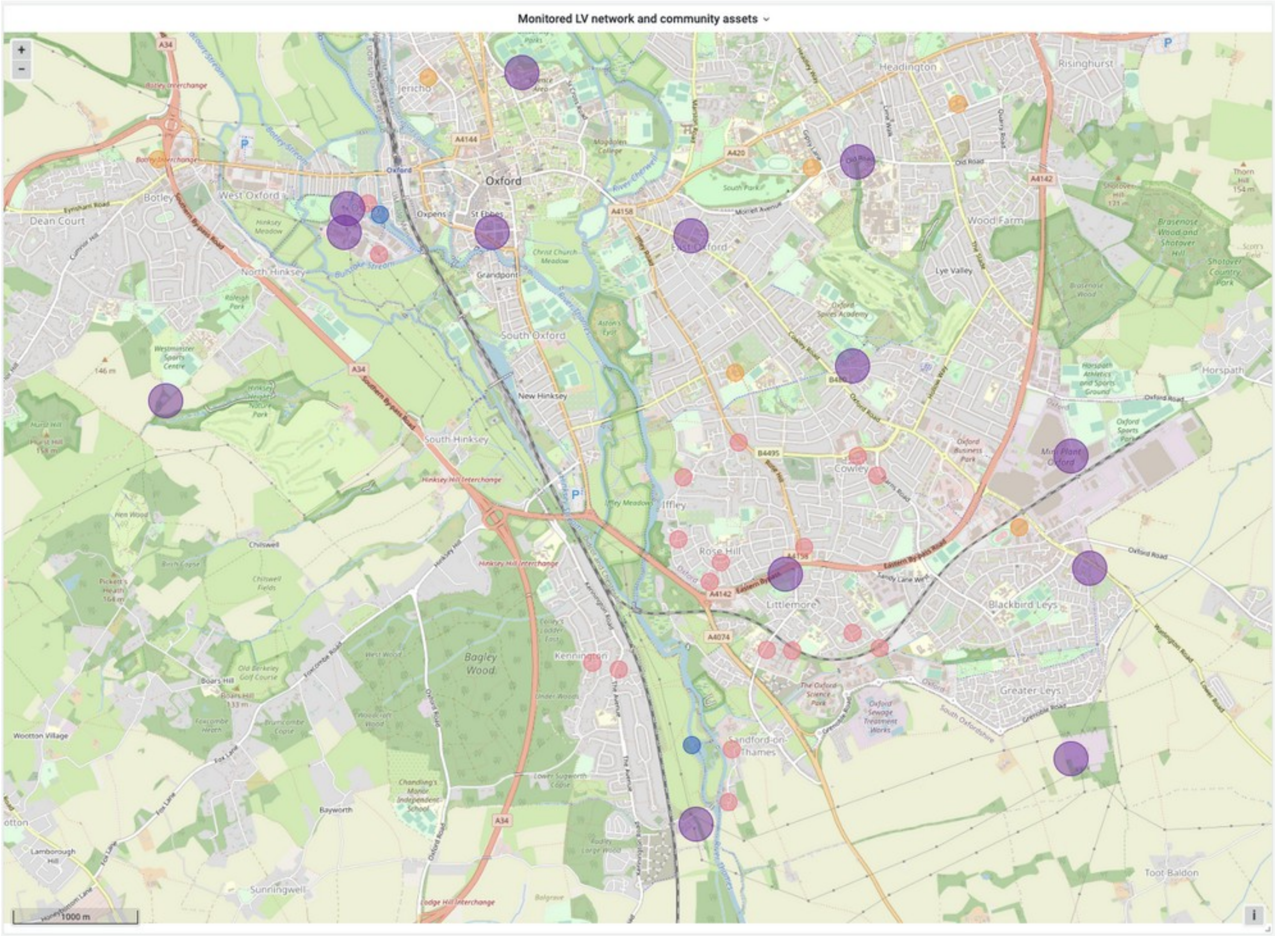
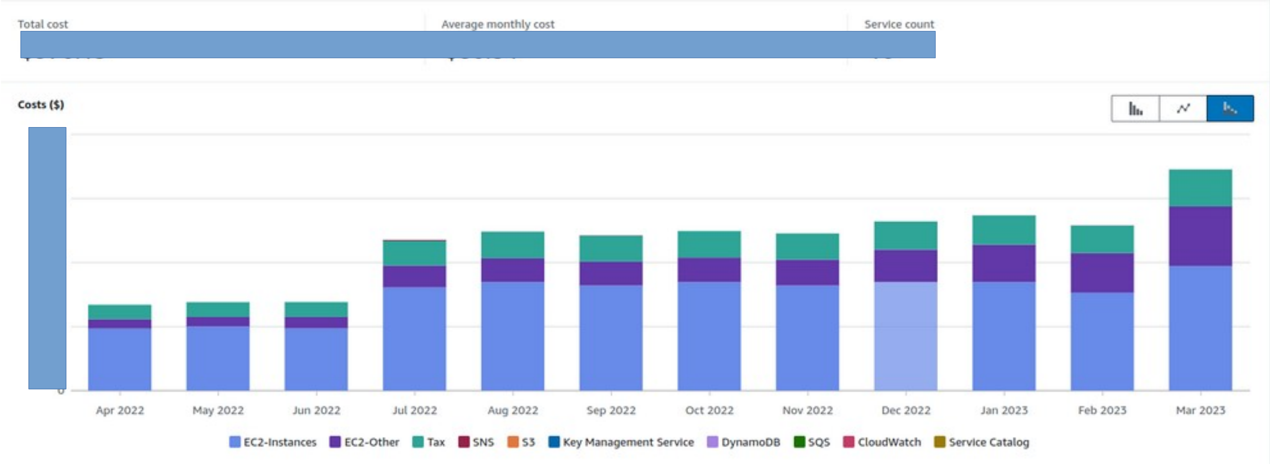


Figure [28]: PPS 2.0 map of Oxford plotting the location of community generation assets (yellow and blue dots), secondary substations (light red dots), and primary substations (purple dots)

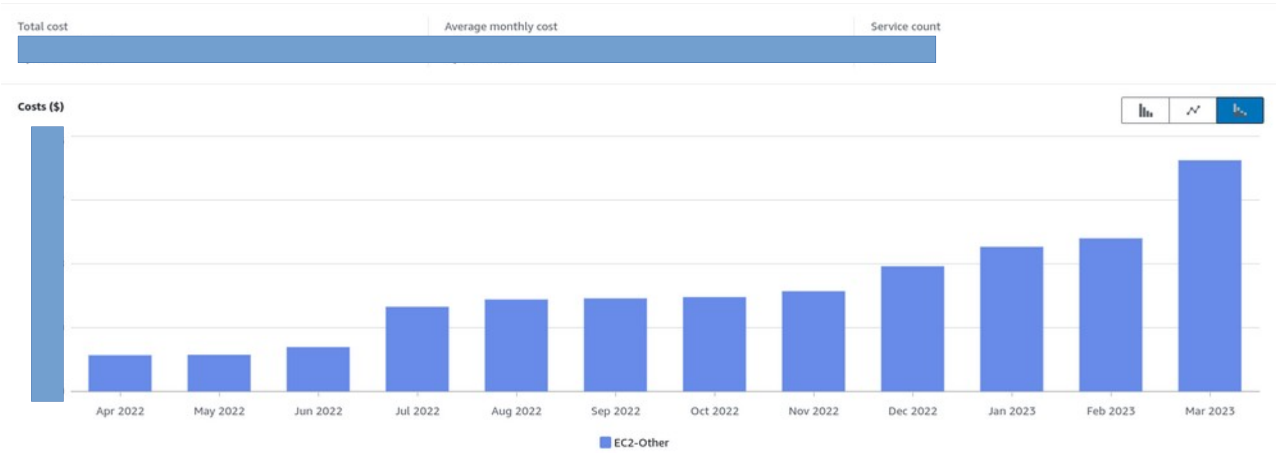
11. Cost analysis graphs

Graph 1



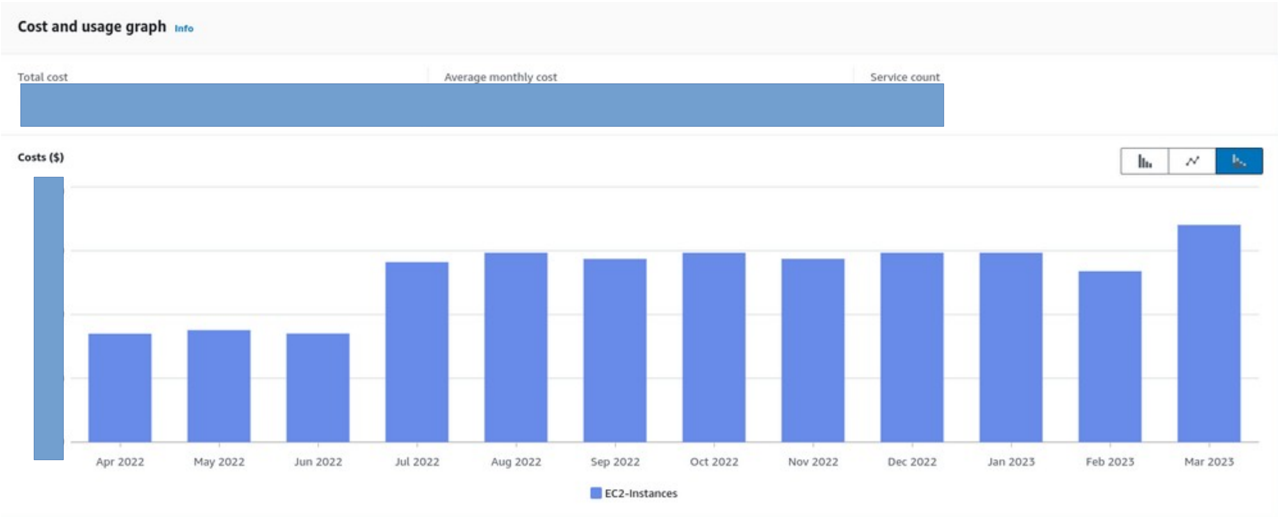
Graph [1] showing evolution of total costs over the past 12 months. In July 2022 the system was migrated from a single server to a cluster of four servers. A noticeable increase in costs took place in March 2023 due to increased storage capacity required in the database server to receive data from all available substations through SSEN's deepGrid LV monitoring.

Graph 2



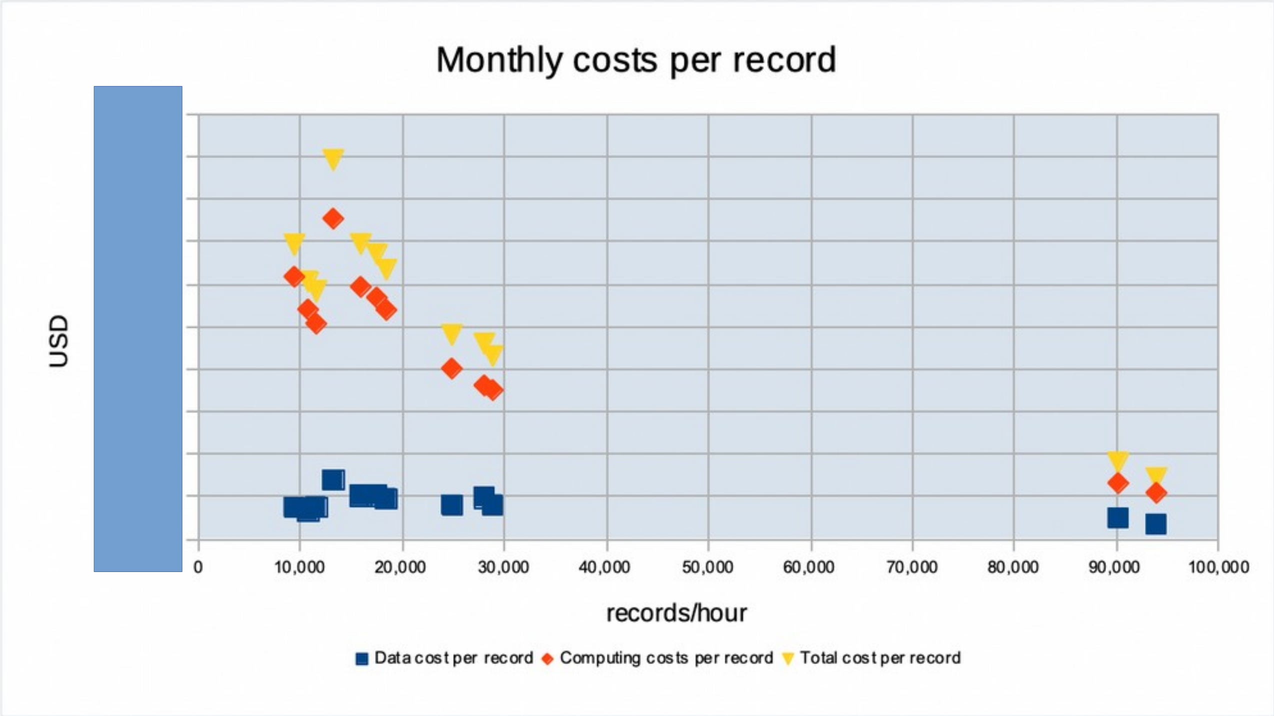
Graph 2 showing evolution of storage costs over the past 12 months, which shows a consistent increase proportional to the number of devices connected and the number of parameters measured per device or data point. The range varies from a simple meter that provides the value for one parameter (active power) every 10 seconds (6 per minute) to a substation that provides 30 measurements for each phase of a feeder, once a minute – the LV monitoring for Osney Bridge substation alone provides 30 (parameters) * 3 (phases) * 5 (feeders) every one minute (450 values).

Graph 3



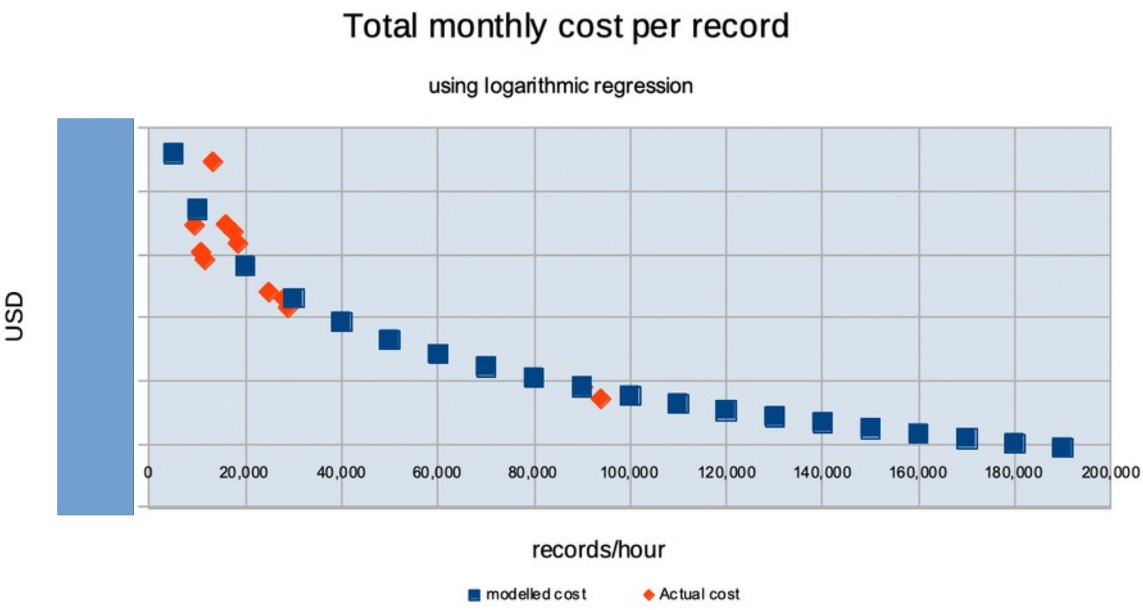
Graph [3] showing evolution of computing costs over the past 12 months, which refers to servers' processing capacity. Costs have remained stable despite the increase in number of devices connected and users accessing power-hungry visualisation tools.

Graph 4



Graph [4] showing breakdown of the monthly cost per processed record, in US dollars, into three categories: data costs, computing and total costs including taxes.

Graph 5



Graph [5] showing the fit between actual and projected total monthly cost in US$ for cloud computing per record. The projection is based on logarithmic regression.

12. Diagrams and photos

Diagram 1

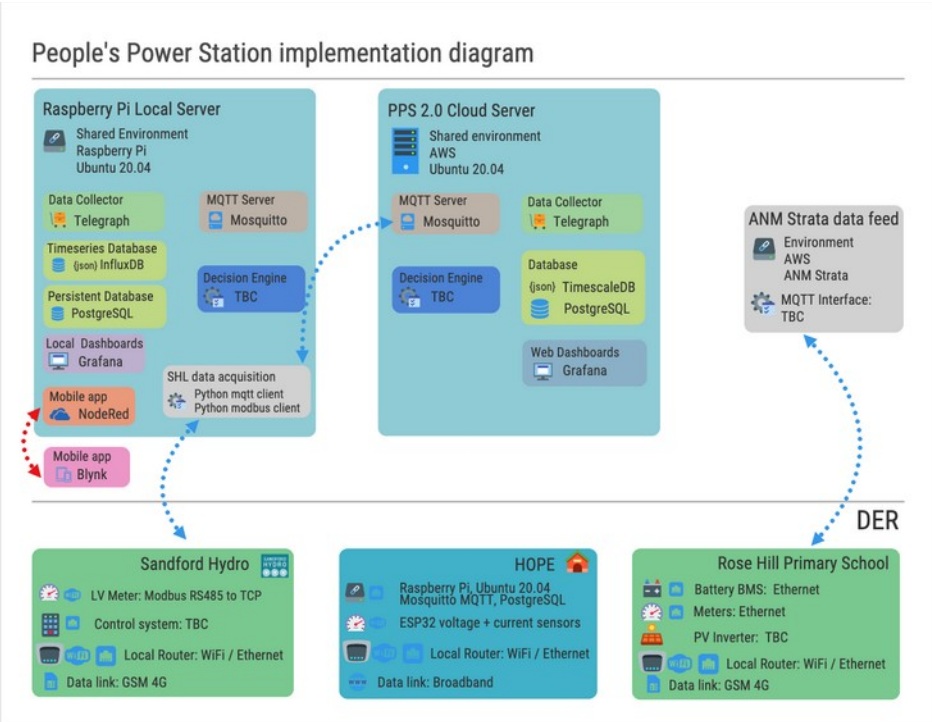


Diagram [1] showing the implementation of the first prototype of the PPS 2.0, which deliberately made use of a combination of cloud servers and a Raspberry Pi as a way to demonstrate the ability of the same architecture being replicated in both powerful cloud-based servers and a small and low-cost piece of hardware.

Diagram 2

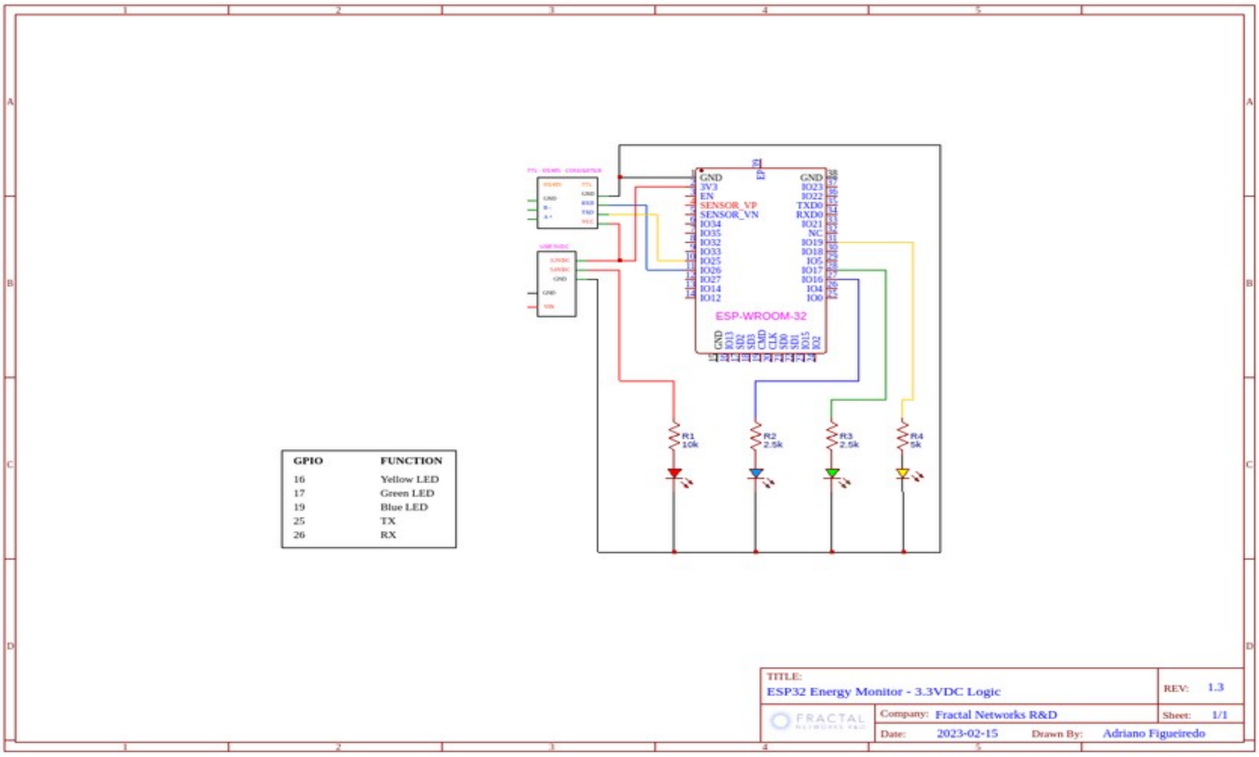


Diagram [2] showing the hardware design schematics for an energy monitor using a RS485 interface. The schematics show the simplicity of the design, the component parts, and all the information required for configuring the physical data interface within the software.

Photo 1

Photo [1] showing a micro-server, capable of servicing up to 50 DERs, based on a Raspberry Pi 4B, 8GB RAM, 128GB SDRAM and 2TB external storage. The total cost of the hardware was approximately £350. Detailed step-by-step instructions documented by Fractal Networks would allow a community organisation to set up a replica within a day's work.

Photo 2

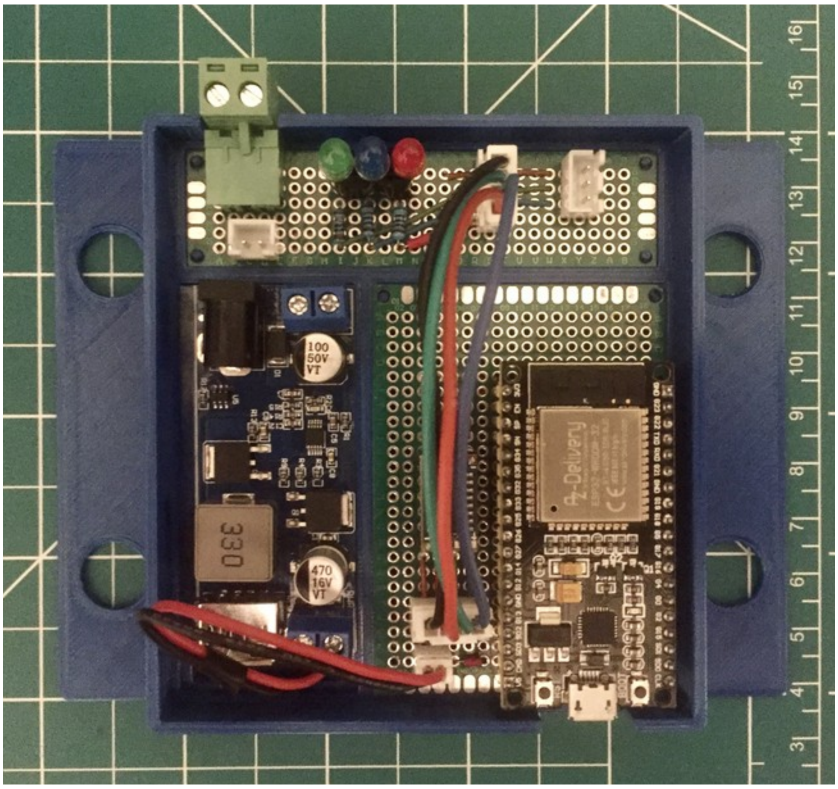


Photo [2] Working prototype monitoring device using a ESP32 microprocessor and capable of integrating multiple types of interfaces, such as RS485, RS232 communicating over Modbus protocol. Regardless of the physical interface, both the microprocessor and the software developed for running the module remain the same, demonstrating the viability of such simple, flexible and low-cost design.

Appendix 1 – Proprietary system integrations

Several integration interfaces have been developed for accessing data through third-party platforms:

Fully functional proprietary systems integrations:

- Emig
- Enlighten
- Enphase
- Environment Agency flood monitoring
- LV monitoring – DeepGrid
- LV monitoring – Nerda
- National Grid Carbon Emissions
- Open Weather
- Powervault
- PVMeter
- SGS ANM Strata
- Smart meters – Bright App
- Smart meters – GlowCAD
- Solcast.

Appendix 2 – DER control system integrations

Specific integrations have been developed to cater for specific OEM equipment:

- EASTROM SDM230 digital meter
- FRER C70QTL005E three-phase digital meter
- FRER C70QTL080E three-phase digital meter
- MetersUK EM415 digital meter
- MetersUK EM418 digital meter
- Osney Lock Hydro HMI

- Sandford Hydro PLC TCP/IP interface
- Sandford Hydro PLC RS485 interface.

Appendix 3 – Full set of documentation for the PPS 2.0

An extensive set of documents has been and continues to be developed with detailed technical information for every aspect of the specification and implementation of the PPS 2.0.

High-level documentation

- PPS 2.0 concept
- PPS 2.0 protocol
- PPS Infrastructure
- Using tags for grouping and filtering
- Consistent configuration of device interfaces.

Setup instructions

- Micro-server setup
- AWS cloud-server setup
- Persistent database setup
- Zigbee hub setup
- Node-red setup
- MQTT bridge setup
- Grafana front-end customisation
- Micropython firmware flashing.

Automated processes

- Registrar services

- Bulk addition of new users
- Reporting queries
- End-to-end device registration
- Billing and settlement engine.

Integrations

- Emig
- SSEN DeepGrid
- SSEN NeRDA
- Enphase Enlighten
- Enphase Local
- EA Flood monitoring
- Hildebrand GlowMarkt
- Hilderbrand CAD MQTT
- Openweather
- Powervault
- PVMeter
- SGS DB link
- SHL HMI
- OLH HMI
- SolarEdge
- PPS1.0
- National Grid Carbon Intensity
- Modbus device configuration library
- Myenergi.