The Role of Distributed Multi-Vector Energy Assets in Economic Decarbonisation: Early Findings of a UK Demonstrator

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13.1 Introduction

Several market and regulatory forces have brought about the prospect of a new age of small scale, distributed low carbon assets across wide geographical areas working uniformly to provide multiple energy services. Given their geographically distributed nature, the aggregation and optimum management of these distributed assets are increasingly examined with virtual power plant (VPP) describing the overarching nature of such heterogeneous but controllable energy system assets. Several features are forming an axiomatic foundation for these multi-site technologies to be united under a VPP umbrella, first the flow of power and information between stakeholders and energy entities [1], second the existence and exploitation of real (i.e. batteries) or virtual (i.e. building inertia and deferable loads) energy storage, third technologies the can add virtual inertia to the system and/or couple multiple sectors and finally a single or a cascade of cloud-based VPP platforms/controllers that can extract operational features from such active yet distributed energy assets and guide the overall system towards its objectives (minimising cost and carbon, maximising comfort, enhancing demand response (DR) capabilities and/or peer to peer trading, etc.)[2]. In the following five sections and against a backdrop of historical practices, techno-economic considerations for the design of VPP are outlined before greater focus are brought on the specific attributes (and initial learnings) of the case study Smart Local Energy System examined in this chapter.

13.1.1 Status Quo, Challenges and Outlooks

The age of Petroleum experienced its zenith in the 20th century, where a boom in industrialisation and spread of internal combustion engines created vast demands for fossil fuels. Energy systems dominated government infrastructure programmes that were planned centrally and before the 2nd and 3rd generation of nuclear power stations, were mostly reliant on oil and its derivatives [3]. The environmental and safety legacy of the 20th century energy systems is one of the prevailing challenges of the 21st century, where emerging visions of future is dominated by decentralised yet interlinked energy systems enabled by renewable generation and distributed storage that connect multiple sectors (transport, heat, power, etc.). This approach has the benefit of exploiting all user flexibilities to create virtual inertia, facilitate greater use of data to enable predictive controls and notably transfer prosperity from energy giants to local communities [4]. Such “smart energy systems” (SES) will not make legacy utility infrastructures redundant but will utilise them to interlink sectors and regions (even transnationally) and facilitate a shift from single-sector thinking to coherent and integrated systems that achieves greater resilience by exploiting synergies between sub-sectors. Importantly SES are planned, designed and managed with host communities at heart. In addition to their economic and social aspects, full realisation of SES is also heavily reliant on integrated energy management that optimises the dispatch of a number of services while taking heed of carbon, cost and human comfort constraints. Fig. 13.1 utilises 2019 UK energy mix statistics [5] and system architecture to provide a simplified comparison between business as usual and a 2050 SES model.

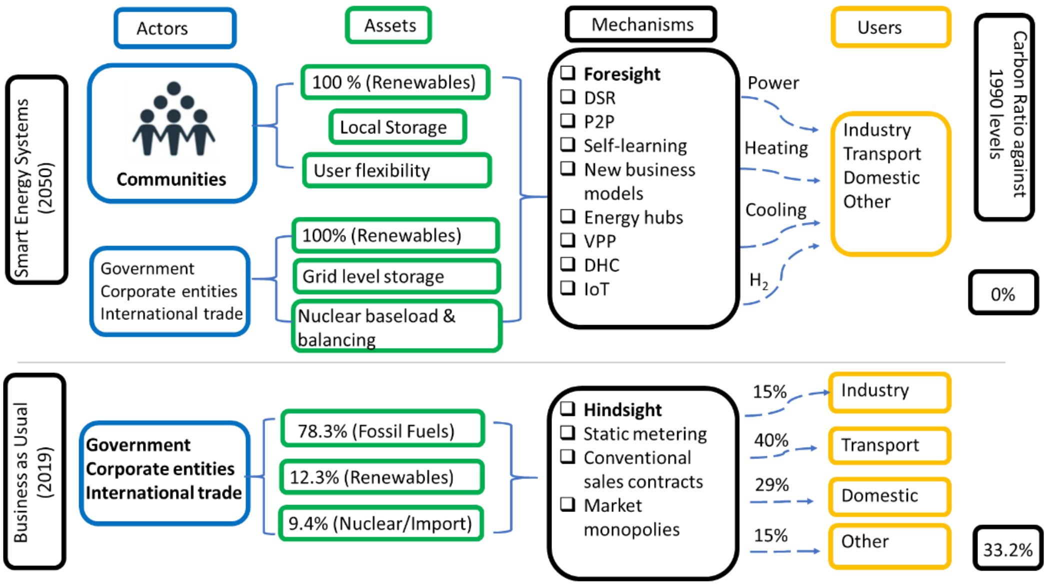

Fig. 13.1: UK energy system outline comparing a 2019 baseline against an envisaged 2050 SES. (VPP: virtual power plant, DHC: district heating and cooling, DSR: demand side response, IoT: Internet of Things)

It should be noted that Fig. 13.1 attempts to simplify an extremely complex landscape with multiple actors engaged over a cascade of interactive layers, however this illustration focuses on the emerging importance of interconnecting sectors and exploiting system level flexibilities to create a new platform for business models, asset sharing and virtual inertia. The baseline (year 2019) involved total UK energy consumption of 197.6 million tonnes of oil equivalent that resulted in 351.5 million tonnes of equivalent CO_2 (which is reported in this figure as a 'carbon ratio' of 33.2% against a 1990 baseline).

13.1.2 Smart Local Energy Systems, Rationale and Potentials

While the definitions of the term SES is evolving, a sharp increase in the use of this term was pointed out by Lund, et al. [4]. As noted, the fundamental feature of SES is a transition from single sector thinking with centralised assets to a more integrated and holistic approach involving distributed assets. The crucial difference between the term “smart energy systems” and other similar terms such as ‘smart grid’ are the holistic and cross-sectoral aspects where multiple services (tri- or quad-generation, i.e., cooling, heating, power, hydrogen) are provided to the hosting community. The transition to distributed local energy systems (involving generation, storage and flexibility of control) provides a greater opportunity for community engagement and the centrality of the host community has led to the term integrated community energy systems (ICESs) gaining traction in literature [6]. “Self-provision” and “system-support” have also been viewed as axiomatic for an ICES which offers the possibility of giving the power of change back to the consumers. Note that system support refers to the ability of ICES to provide services to the wider energy network beyond its own boundary. While technological, socio-economic, environmental and institutional issues act as principal barriers to the wider adaption of ICES, rising electricity prices and falling costs of generation and storage are reported to make grid defection a widespread future reality in Australia and the US, where rich solar resources exists [7, 8]. However, under current market mechanisms, the economics and system reliability of grid-defected ICES was found to be poor in the Netherlands as a result of much larger capital expenditure (CapEx) required for oversized DERs[9]. Being able to market surplus generation to neighbouring communities might improve economic prospects of an off-grid ICES and the importance of existing grids in enabling efficient exchanges of surplus resources between ICESs have been highlighted by several authors [10]. Nationwide and international driving forces behind the ambition to achieve a 100% renewable energy system is examined by Young, J. et al [11] who argue that in addition to favourable national and local green policies, government guarantees are also required to minimise investment risks and to steer energy systems devolution. These clearly point to an evolving technical landscape that will lead to the formation of highly individual SLES platforms as a function of local regulatory regimes, site-specific market mechanisms, availability of RES and forms of demand and level of engagement from the hosting community.

13.1.3 Consumer Attitude Towards Shared Assets and Monetising Flexibility

A study by Richter and Pollitt [12] discusses the findings from a 2015 survey of UK energy consumers about what services are most important to them, and what terms of contracts they would be willing to accept. The authors break down the sample into four main clusters of consumers, sorted by their risk aversion and openness to having their data monitored. Across all four clusters, consumers highly valued technical support and were willing to pay for it. They also find that on average, consumers are willing to pay 34% of the gained energy bill savings from ICES on platform providers that enable the realisation of energy savings. High levels of fixed compensations do not usually entice consumers, rather it is the ongoing energy savings that were the most important factor in their decisions. Richter and Pollitt suggest that platform companies can add fees for technical support and data privacy protection to recoup CapEx and operational costs. The biggest difference in the customer clusters was found to be in the extent of control and monitoring by the energy service/platform companies that customers would welcome at a certain price point. A recent optimisation approach [13] suggested a deterministic/stochastic model for transforming passive consumers with storage and/or PV into active prosumers to participate in the day-ahead market. A two-step process was designed for the aggregator to use clusters of prosumers and predict flexibility capacity to then transform that flexibility into supply and demand bids. This centroid-based clustering approach was found to save on average an additional 20% in energy costs for prosumers, and up to 40% in transaction and trading costs for the aggregator. The model proved centroid-based clustering can limit uncertainty in prediction while maintaining a high quality of energy bids. This predictive modelling can be almost entirely automated to reduce costs further. Gissey et al. [14] use prisoners' dilemma (a scenario used to illustrate a key tenant of game theory, where rational individuals will not cooperate, even though they would be better off in doing so) to support their findings that most domestic PV and storage owners will set up their usage patterns to their own advantage, regardless of system-wide priorities (and despite system-wide efficiency leading to greater overall savings for individuals too). While capital costs for storage are inversely related to size, 'spikier' residential loads offer a larger opportunity for storage to provide efficiencies. This also means that a greater number of players in the residential system are harder to control (as opposed to a few large commercial participants). Authors note that if an aggregator were to leave the control of energy assets entirely up to residential users, the volatility in the system would be on average 2-3% higher, and energy prices would be 4-7% higher than if the assets were centrally controlled. They call for regulators to alter pricing structures and retail tariffs to follow wholesale costs more closely, hence tightening the gap between system and individual priorities. They estimate the total cost to the UK energy system to be £407m per year if the flexibility resources are not centrally controlled. Therefore, a wide range of regulatory and managerial space is left to be occupied by either a new generation of enterprises or/and supportive policy to enable niche technologies, business models and a completely new way of engaging the users. Learning and adaption, reiteration and improvement is also an integral part of the process for SLES as a novel and new approach that can be designed to deliver against a wide range of outcomes, many of which may not be compatible [15].

13.1.4 The Role of District Heating

Even if the Northern European building portfolio can be all built to Passivhaus levels, there is still a very strong case for district heating (DH) within smart energy systems. This is reflected in the UK where a recent publication outlines heat networks as a key part of UK plans to provide low cost and carbon heating [16]. DH's role in SLES is due to their ability to absorb surplus power generation and waste industrial heat to provide domestic hot water (and space heating when needed). Lund, H. et al conducted an EnergyPro modelling examination of a 100% renewable energy system in 2060 to identify the best future heating scenarios [17]. Danish district heating (currently serving 46% of Danish net heat demand) and its expansion to neighbouring areas (to cover 53%, 63% and 70% of net heat demand) was found to be the most cost- and carbon-effective solution, followed by individual air-sourced heat pumps (ASHP), while hydrogen-powered micro CHPs was found to suffer from low overall efficiencies and high costs, and natural gas-powered micro CHPs offer carbon effectiveness in the short run while becoming more expensive than DH in the long run. In order to better plan for consumer integration and expansion of DHs, creating and maintaining municipal heat Atlases has been advocated by Karl and Möller who demonstrated via EnergyPLAN software simulations that DH expansion in 2012 offered little improved efficiency of the overall energy system against a business as usual scenario but will be most cost and carbon efficient for a future scenario where increased power/heat/transport energy exchanges will exist and are complimented by end-user demand reduction [18]. The SLES case-study examined in this chapter involved a $240kW_{th}$

marine-source heat pump that would supply a base thermal demand via a 5th generation ambient temperature DH system to a number of commercial sites. Given the seasonal variations of the heat source (sea water at the south coast of England), the flow temperature was investigated to be between 8°C-15°C. This base thermal energy would then be boosted at site level via water-to-water heat pumps to deliver heating and domestic hot water (DHW) to reflect the requirements of the users at each site.

13.1.5 Hydrogen as a Vector Coupling Solution

Despite low round-trip efficiencies, Hydrogen is unique in facilitating multi-vector energy interchanges and short- and long-term storage capabilities. The power sector can interact successfully with both heating and transport (via CHPs or EVs). But heating and transport (both major primary energy consumers) are less able to share capacity or load except with Hydrogen deployment. Hydrogen is also capable of delivering a power, heat or transport service with zero-emissions at the point of use and have been proposed as a means of creating additional resilience and inertia in future power systems to counteract the potential instabilities that renewables and their associated controls may cause [19]. Even at the single household level, hydrogen has been investigated as a plausible hybrid solution with solar power where the excess output of a 0.5kWp PV array was used to feed a 0.1kW Proton-exchange membrane (PEM) fuel cells to charge a storage tank that contributes to the continuous power demand at domestic level [20]. However, it is at much larger scales that Hydrogen can begin to gain greater economic advantage as both short- and long-term storage mechanism but also a multi-vector element within a SLES. Despite the established nature of fuel cells and electrolysers, it is chiefly the economics of hydrogen and its overall efficiencies that constitute the main barriers to its wider adoption [21]. Additionally most of the hydrogen produced today is heavily reliant on fossil fuels, with a staggering 96% derived from technologies that reform fossil fuel feedstock [22]. This leaves only 4% of hydrogen production that is a product of electrolysis technologies which currently forms the only segment of H_2 production that can be considered low or zero-carbon if wholly produced, processed and stored by renewable technologies.

Current generation efficiencies of Hydrogen range from 1.6% (photosynthesis) [21] to reported values of between 43% to 53%(thermolysis in membrane reactors [23]) with the highest figures reported for steam methane reforming (generally around 85% with a theoretical limit of 93.8% also reported[24]). By the time energy expenditures in the liquification or pressurisation of hydrogen is accounted for and added to efficiency penalties in the final energy conversion mechanisms (i.e., a hydrogen boiler, Fuel Cell, etc.) the overall round trip efficiency of hydrogen as an energy source remains notably low. Despite this, several justifications exist that make hydrogen a convincing candidate in the future energy systems. These include zero emission credentials at point of use, extreme versatility across heat, power, transport, chemical and potentially future aviation sectors [25], facilitating excess renewable diffusion across power and gas [26] and being regarded as the most efficient inter-seasonal energy storage mechanism[27]. Aug 2019 blackout in the UK was noted as a unique stress test that exposed electrical grid fault lines ensuing from excessive penetration of new equipment and controls associated with renewables and smart grid technologies[19]. It is against this challenging background that Hydrogen has emerged as both a unique energy source and a versatile storage mechanism that can bring much greater ‘virtual inertia’ and stability across the entire energy system and enable its phased decarbonisation. The demonstrator concerned in this chapter included a 36kg/hr electrolyser that utilised Proton exchange membrane (PEM) technology and was intended to be deployed close to emergency services to facilitate an initial trial of hydrogen vehicle adaption within public sector service providers.

13.2 The Case-study Demonstrator

Referred to as SmartHubs SLES, this demonstrator was one of four UK energy system demonstrator projects aimed at encouraging innovative low or zero carbon energy solutions that could serve its host community with cheap and clean energy. Additionally, these demonstrators (backed by over £100m of government finance) also aimed to encourage a new wave of entrepreneurial activities that would see greater adoption of niche technologies, greater engagement of end users in energy management and a broader emphasis of creating prosperity at local level through an energy revolution. SmartHubs SLES demonstrator had a wide range of assets that in combined form offered 1.96MW_p of renewable generation, 24MWh_p of household and grid-level electrical storage, 3.87 MW_p of EV charging, 3.49MW$_{th}$ of air and marine source heat pump thermal capacity and 36kg/hr of H_2 production using Proton Exchange Membrane (PEM) technology. The platform for deploying these assets were 250 homes and 40 commercial sites spread across a wide geographical area in the South of England. Fig. 13.2 attempts to offer an outline of the magnitude of assets and their spread across heat, power and transport vectors.

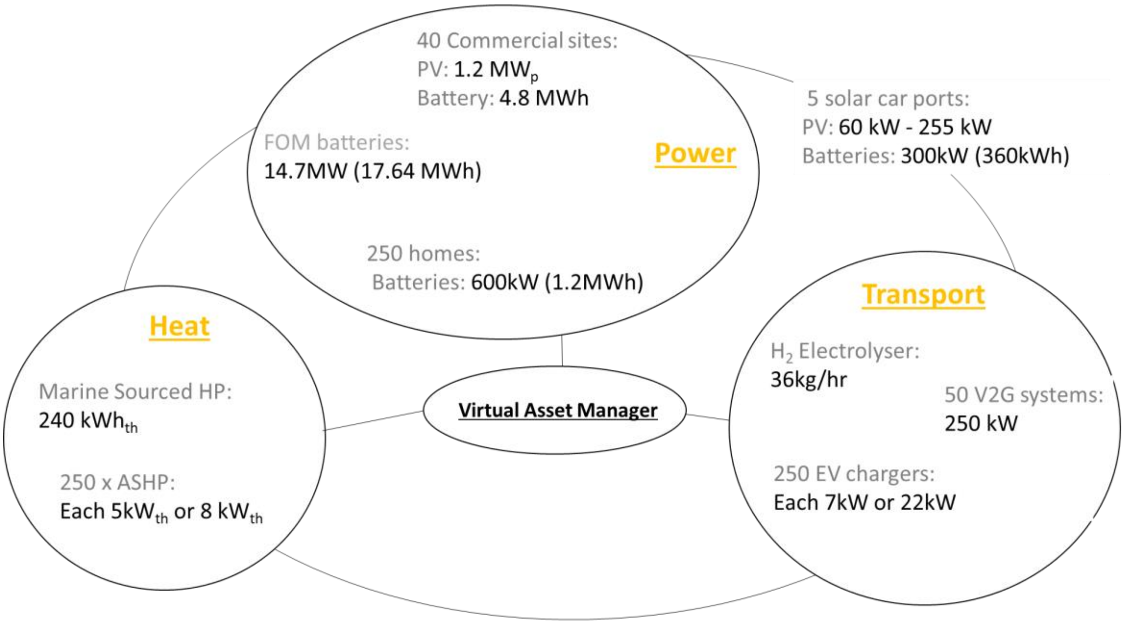

Fig. 13.2: Overview of SmartHubs SLES assets where local and global optimisation of services was pursued through a virtual asset manager (V2G: vehicle to grid, FOM: front of meter).

Within the transport vector, a major global car manufacturer was to install 250 EV chargers, and 50 additional chargers with vehicle to grid (V2G) technology incorporated. A 2MW Proton Exchange Membrane was also intended to produce 36kg/hr of green Hydrogen and stationed close to emergency services to support a first generation of hydrogen vehicles commissioned for ambulance and police service. The electrolyser had the ability to be turned on/off instantly with 5 cycles per hour feasible, therefore it could participate in several ancillary services as outlined in Table 1. Hydrogen would be produced at 20 bar and compressed to pressures of 700-900 bars to support vehicle filling duties.

The heating vector involved the installation of 250 ASHP in domestic properties that depending on the size would be fitted with either a 5kW$_{th}$ or 8 kW$_{th}$ units. These units where all equipped with a Machine Learning algorithm that would extract building thermal response and occupant heating preferences across its initial trial period to then use the natural inertia of buildings to respond to grid signals and provide several demand side response services. A total thermal output of 240$_{th}$ was to be met by one or several modularised marine sourced heat pumps (MSHP) to feed an ambient temperature (8°C-15°C) district heating network supporting commercial sites and schools. The baseload provided by the MSHP/s would then be boosted at site level via water-to-water heat pumps to deliver heating and domestic hot water (DHW). The MSHP unit/s were expected to be able to respond to a grid signal immediately and therefore could engage in a number of auxiliary services with the only constraint being a maximum of 6 starts per hour.

A more diverse range of assets were intended to be deployed on the power vector, with both generation and storage at building and district levels (Fig. 13.2). This included 600kW$_p$ (1.2 MWh) of new Li-Ion batteries deployed behind the meters at 250 homes, and a total of 22.44 MWh of second-life lithium-ion batteries deployed at multiple commercial sites. The VPP would supervise the charging and discharging of these storage assets to fully exploit the project's PV generation (with a peak rate of 1.96MW$_p$ from PV arrays deployed both at 40 commercial sites but also 5 car ports). Clearly in combination, the project contained a diverse portfolio of generation and storage assets across heat, power and transport vectors that could be configured to deliver against a multiplicity of outcomes. Fig. 13.3 outlines how the physical assets, the power/energy flow and data streams had to support a static contractual but dynamic aggregation and market engagement layers. The project data was also to be made available to Newcastle University to pursue two overall research questions. First how the technical optimisation of the VPP could be improved over a long project horizon as increasing high-frequency asset data became available. The second was to quantify (against a business as usual (BaU) scenario) the level of carbon mitigation that all assets in unity can realise, and how VPP could enhance asset portfolio carbon mitigation even further.

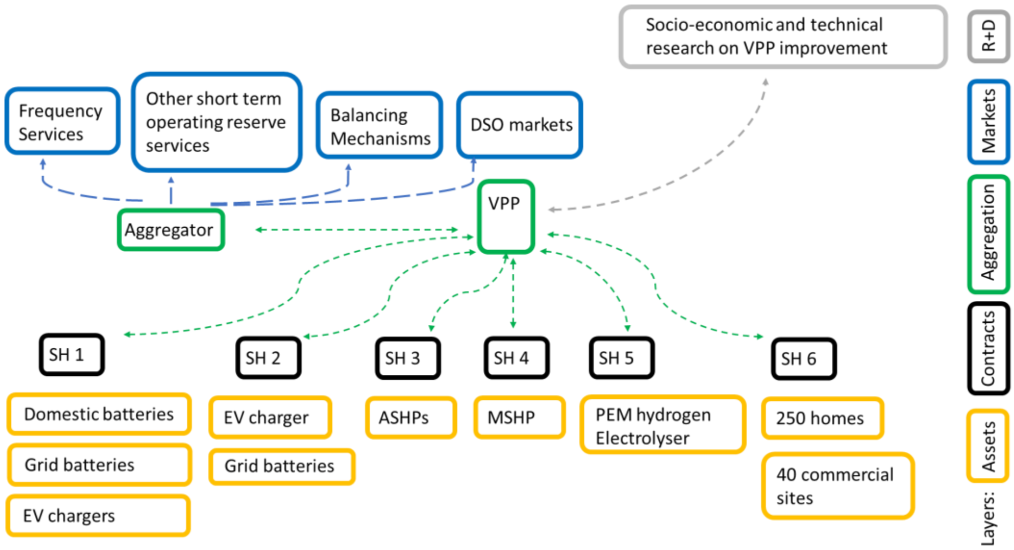

Fig. 13.3: Overview of SLES assets where local and global optimisation of services was pursued through a virtual asset manager performing VPP duties (SH: Stakeholder, DSO: Distribution System Operators).

13.3 Virtual Power Plant: Benefits and Challenges

Quite clearly a portfolio of distributed assets operating in or across interlinked heat, power and transport vectors can be managed to satisfy a variety of different objectives. Initially the funding of four UK demonstrators (of which SmartHubs SLES was one) intended to deliver low cost and carbon energy to hosting communities, showcase ancillary services and demand response from a heterogenous RES asset-base, encourage energy enterprise and green job creation and enhance the level of engagement and interest of the host communities. The broader socio-economic objectives of the project however are beyond the scope of this chapter. VPP architecture is examined under commercial (CVPP) and technical (TVPP) frameworks [28], and this chapter focuses primarily on the TVPP framework of SmartHubs SLES demonstrator. Table 1 outlines the control actions that a TVPP can undertake to execute on each class of assets, and the data required from any asset to enable a revenue-generating or carbon-mitigating flexibility service. In addition to services provided by each individual asset

class, the VPP design seeks to further optimise the overall generation of value from the combined asset portfolio, however the prioritisation of these services could only be finalised in consultation with the 250 domestic property occupants that was an original objective of this demonstrator.
A notable difficulty is that the performance of some asset classes can be optimised locally (e.g., car port PVs can charge local battery or the EV), while others can only be addressed by the VPP (H_2 Electrolyser or front of meter (FOM) batteries). This remained a challenge within the project since a successful TVPP design had to find ways of reconciling onboard control philosophies of each individual asset entity with a system level priority. While multi-objective optimisation and prioritising actions using weight co-efficients are a tried and tested control theory subject, in the case of SmartHubs SLES, control design necessitated a completely fresh approach that wasn't addressed in the conventional global optimum of cost, comfort and Carbon solutions. A specific example of this was the onboard (and hence distributed) machine learning (ML) algorithm that controlled ASHPs by extracting building physics features from operational data to then dictate optimum starts, DR services, avoidance of times of high grid carbon intensity while still delivering occupant comfort. ML-derived control actions of 250 distributed ASHP that each had developed a unique operational regime to reflect property thermal response and occupant heating patterns therefore needed to be united with a centralised TVPP seeking to perform an ancillary service. These aggregated vs local control signals required careful safeguards to avoid control conflicts, excessive plant cycling and occupant discomfort.

	Control Action	Data required	Optimisation	Services	VPP
FOM batteries	Charge / Discharge	AS details BCS	VPP	TA – CM - FR	

BTM batteries	Charge / Discharge	AS details BCS	Local/VPP	TA – CM - FR
Carport PV and Battery	Charge/Discharge battery - Charge EV	AS details BCS EV status Solar irradiation	Local/VPP	TA – CM - PA
Distributed ASHPs [*]	Zone heating On/off	AS details Zone thermal requirement Building thermal response	Local/VPP	CM - TA
MSHP	Zone heating On/off	Thermal demand Thermal system inertia	Local/VPP	CM - TA
H_2 Electrolyser	On/off	Electrolyser status	VPP	CM – TA - PA

Notes:

i. TA Triad Avoidance
ii. CM Constraint Management
iii. FR Frequency Response
iv. PA Price Arbitrage
v. AS Ancillary Services (that includes i to iv above)
vi. BCS Battery charge status
vii. BTM Behind the meter (battery)

[*] ASHPs have a long ramp time of 6 min and therefore not suitable for FR

Table 13.1: A list of local vs. centralised (VPP) optimisation actions that project asset portfolio had the potential to offer.

13.4 Unlocking the Value of Data

Successful management of SmartHubs SLES assets through a VPP require communication, automation, analysis of historical data and dynamic engagement of individual components that inevitably lead into the production of a substantial amount of data. This requires a robust solution for data management and analysis as well as cyber security. As outlined in [29], one of the earliest steps taken within the project was a Smart Energy Platform (SEP) architecture that was designed to conduct data management and analysis for this demonstrator in order to provide optimal planning and technical operation as well as socio-environmental and financial research.

Fig. 13.4 illustrates the data processing structure of the SEP platform which collects, backhauls and stores data and enables near real time as well as retrospective experimental data analysis. The SEP data processing program retrieves recorded operational data and stores it in the database by calling python REST APIs. These include raw power network data, static asset and dynamic weather data, and socio-economic and policy data. Depending on the requirements, different datasets could be selected to feed any specific analysis. For instance, SEP retrieves relevant data to facilitate assessment of balancing energy supply and demand, explores the added value that the flexibility of assets can provide and delivers cost and carbon benefits for stakeholders, including businesses (on commercial sites) and residents of 250 homes as the asset portfolio continues generating data in a low-carbon future. Given that the project asset portfolio was initially planned for installation in 2020, SmartHubs SLES would have been operational from 3rd to beyond 5th UK carbon budgets (CB), where reductions of 8.6% (3rd CB), 23.3% (4th CB), 11.5%(5th CB) are enshrined in UK law as it moves towards a legislated 2050 net zero carbon deadline [30].

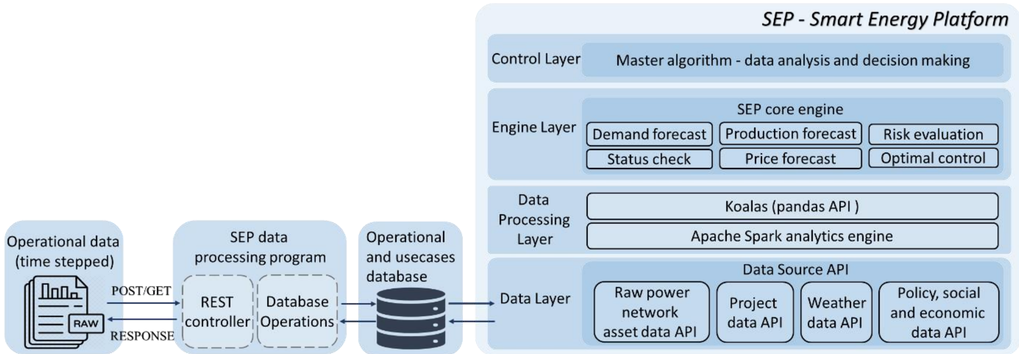

Fig. 13.4: Smart Energy Platform data analysis.

The modularised multiple-layer design of the SEP also makes the interoperability and reuse of existing implementations possible [31]. It can be easily maintained, customised or extended in future for different applications and research purposes.

A greater perspective of data management needed to be taken by the project partners to safeguard the communication infrastructure, VPP management, user identity and information and supply of services against cyber incidents. Initial stages of cyber-security arrangement required encryption of data, firewall protection for devices and authentication of users via secure digital apps. Cyber-security of energy systems however is a new and evolving discipline and against a number of global energy related incidents, additional protection and ongoing learnings are required to adequately protect energy systems integrity and service offering [32].

13.5 Discussion, Challenges and Findings

Over an initial project timespan of 24 months, the team experienced 4 notable challenges, first the procurement process (which remains beyond the scope of this chapter), second design and specification of individual assets and their onboard control, third the design of a TVPP while avoiding control conflict, and finally the challenge of honouring autonomy of choice in particular for residential buildings while retaining full flexibility of the asset portfolio to deliver auxiliary and balancing services. The Covid-19 pandemic presented substantial logistical limitations since 250 homes required energy system retrofits with PV, behind the meter Li-Ion battery and ASHPs. This has meant a temporary halt of project activities however the design stage socio-economic insights of the project team can be summarised as follows.

i. There is little existing guidance on the contractual format and extent of asset control that could maximise consumer adoption of data collection and remote asset management while simultaneously maximising financial returns for VPP platform providers.
ii. The UK has a clear decarbonisation pathway through 5 carbon budgets that are designed to provide forward guidance to businesses and communities. Yet the shape and speed of decarbonisation trajectory (and future cost) of different primary fuels carry substantial uncertainty. For instance, annual rate of decarbonisation of grid electricity or the penetration (and economics) of hydrogen in transport or heating vector (via blending with natural gas) can only be studied across a broad range of plausible scenarios. The wide spread of these scenarios propagates into large uncertainties that can hinder conclusive results. This appear to suggest that TVPP design involving a wide range of assets across multiple energy vectors will have to incorporate an iterative aspect whereby an initial design

aimed at system robustness is improved and adjusted periodically to reflect learnings accumulated through operational data and socio-technical realities that emerge with advancing time.

iii. The UK has attempted to ease the participation in electricity markets via its New Electricity Trading Agreement. This includes [i] future, [ii] day ahead, [iii] reserve and [iv] real time balancing markets. Despite having an aggregate capacity to dispatch services at magnitudes of multiples MWs, SmartHubs SLES asset availability could not be confidently guaranteed at its maximum capacity given the multiplicity of stakeholders, operational regimes and asset types. This limited TVPP participation in mostly intraday, ancillary and real-time balancing markets, which may limit the full realisation of asset profitability and the formation of contracts that are in place prior to asset deployment.

iv. Existing data to benchmark the current carbon intensity of UK power, heating and transport vectors are limited and sporadic. This creates difficulties in establishing a business-as-usual baseline which in turn allows quantifying the amount of carbon saving achieved via the deployment of assets in isolation and finally the added value of VPP. This can underestimate the value of a VPP managing low carbon and DR-ready assets given the large CapEx required to displace legacy alternatives. This is despite future carbon risks, for instance a VPP platform managing a SLES may emerge as more profitable in a future scenario where increasing levels of carbon taxations are levied, which then justifies upfront SLES CapEx.

From a technical perspective, the main project findings and challenges of VPP design and characterisation is as follows.

i. Most thermal conversion energy assets (heat pumps, hybrid boilers, etc.) are under-utilised over their working life. For the existing generation of thermal conversion assets, their lack of adaptability to being remotely controlled via a VPP platform (and yet delivering their duties in a more dynamic manner) presents technical challenges in unlocking their additional value. A case may exist for regulatory interventions to mandate thermal conversion asset designs to support active involvement with power (and energy) systems management to replace existing manufacturing practice of design as siloed entities with static onboard control solutions.

ii. Actual levels of flexibility available to a VPP operator from real-world assets (i.e., marine or air source heat pumps, electrolysers) is still not very well defined by plant manufacturers. For instance, the number of plausible cycling (on/off) that a piece of plant can be subjected to each hour without jeopardising its integrity, and the duration that the plant needs to remain operational after a DR event before the asset is ready to be deployed to perform another DR service is little understood in particular for heating and hydrogen plants.

iii. Modelling the interactions between assets from multiple energy vectors (heat/power/transport/hydrogen) is quite challenging as these energy vectors are represented by different parameters; for instance, voltage, current and frequency (power), mass-flow and temperature (DH and thermal plants), Kg of H_2 production (H_2 electrolyser). This (when combined with the two previous points) reduces the ability to extract combined flexibility of a multi-vector energy system and added value of a VPP at design stage.

iv. Taking heed of uncertainties outlined in [i]-[iii] in the form of a bandwidth poses limitations to VPP design and its global optimum. This is particularly challenging as future VPPs will have to reconcile cost, carbon and comfort optimums with occupant autonomy and energy asset characteristics.

v. Prior to the availability of operational data, existing parametric modelling solutions have a limited scope to extract system features particularly of a multi-vector, multi-site energy system and at low temporal resolutions. This hinders determination of what emergent properties may follow from aggregating the control of all assets. Therefore, the confidence in the design of a VPP for a SLES system that fully exploits dynamic interaction between participants and energy assets remains limited and speculative during SLES design and prior to the availability of operational data.

13.6 Conclusion

This chapter reported on the initial findings of a smart local energy system (SLES) demonstrator part funded by UK government and referred to as SmartHubs SLES. While a solitary low carbon energy asset can deliver carbon savings against comparative conventional technologies, this demonstrator sought to deliver a much broader range of cost and carbon benefits from aggregating heterogeneous RES assets using a VPP platform. These additional services relied on low loss 5th generation district energy, distributed generation and storage, EV charging and hydrogen electrolyser assets to offer ancillary services, increase self-consumption via BTM batteries and VPP signals, increase system virtual inertia through exploiting deferable loads in domestic and commercial buildings, encourage prosumer activity, niche technology deployment and energy entrepreneurship. Except for power system assets, technical knowledge on how to deploy hydrogen and thermal plants for DR events were found to be in early stages. This resulted in a conservative magnitude of services that the demonstrator could offer in response to grid signals, which in turn limited project ability to arrive at conclusive remarks on the economics of a VPP and reduced the confidence of quantifiable revenue streams (from future energy markets).

Most SLES asset entities were manufactured with onboard controls tasked with a local optimum. This local control could be terminated by the VPP in preference for a global optimal service that needed to observe stringent cycling thresholds particularly with thermal and hydrogen assets containing liquid refrigerants and pressurised fluids. While the number of cycles to failure and operational robustness of power system components are well characterised, more manufacturer data is required to allow future VPP design to fully exploit non-power system assets. This is instrumental for SLES design as the load magnitude of heating and transport class of assets are often substantial.

At SLES design stage, arriving at clarity on the combined value of distributed assets is hindered by the order of priority of services and weighting of objectives (cost, comfort, carbon, system integrity), levels of prosumer engagement, full knowledge of asset performance under a DR event together with the location- and case-specific formation of SLES portfolios. This will mean that an optimal design for the governing VPP is more likely to be mapped post inauguration of energy entities and through data-driven approaches that can extract unique system features from actual analytics. Therefore, next generation SLESs need to be commissioned for operational robustness and are only likely to realise their full potential as VPP entities from observed operational flexibilities, asset responsiveness, data-driven machine learning insights and participant activity levels. It is only with advancing time that such SLES portfolios can mature into dynamic agents capable of delivering seasonally and diurnally different outcomes against a changing demand and supply landscape.

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