Programme Area: Energy Storage and Distribution

Project: Community Energy Storage Business Case

Title: Community Energy Storage Business Case – Final Report

Abstract:

The report summarises the work completed during the project to develop and demonstrate business case opportunities for community energy schemes with storage.

Context:

The project is a study by Loughborough University to develop business cases and routes to commercialisation for community energy schemes with storage. This includes consideration of the advantages of community energy schemes utilising storage including security of supply, grid support and the cost of energy vs potential barriers.

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Commercialisation of Community Energy Storage Systems: Final Report

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Executive Summary

This study explores the potential for energy storage to contribute to the delivery of resilient, low carbon and cost effective community-scale energy systems in order to provide insights for a range of stakeholders, including project developers, investors, policy makers and community organisations. The work involves an integrated analysis of a number of candidate community-scale energy business models comprising both electrical and thermal energy storage, and the roles of key stakeholders involved in financing, delivering and operating such projects. It also includes the results of techno-economic modelling carried out for a range of technical platforms comprising embedded energy generation technologies utilised together with electrical and thermal energy storage systems. The insights provided are intended to underpin decision making in policy development, investment planning and project delivery as part of the UK's journey towards a cost-effective low-carbon energy infrastructure.

The aims of the work covered in this study were:

- To identify stakeholders in the community energy storage sector, and consider stakeholder roles, benefits and barriers
- To evaluate potential business models, using relevant recent studies as well as stakeholder input
- To assess storage and related technologies in the near, medium and long terms, and identify candidate energy storage platforms at both device and system levels through a system-of-systems approach
- To examine relevant markets for energy storage, and assess potential value streams applicable to community-scale projects
- To carry out a financial feasibility and risk analysis study for specific community-scale scenarios

The key findings of the work are summarised below.

Business Models

The work included qualitative evaluation of a number of candidate business models in terms of physical, financial and data aspects. Following discussions with a range of private companies, public sector and community organisations, three business model types were characterised in the study, namely:

- Community-owned
- Design-build-operate (DBO) and
- Energy Services Company (ESCO).

Each business model was analysed using schemas that identified the relationships between all stakeholders in the form of Actor Relationship Maps. These showed the material exchange of equipment, finance and information. An example is shown in Fig i for a Community Energy Co-op.

The analysis included key indicators for assessing each model from the perspective of key stakeholders, including asset owners, investors, customers and external added-value partners. This approach provided a basis for evaluating community energy and storage technologies given varying energy generation, demand and storage contexts. The business model analysis identified a number of central aspects to be assessed quantitatively, including:

- Expected rates of return
- Community fuel bills
- Life-cycle carbon emissions
- Additional revenue streams available, such as from ancillary services markets.

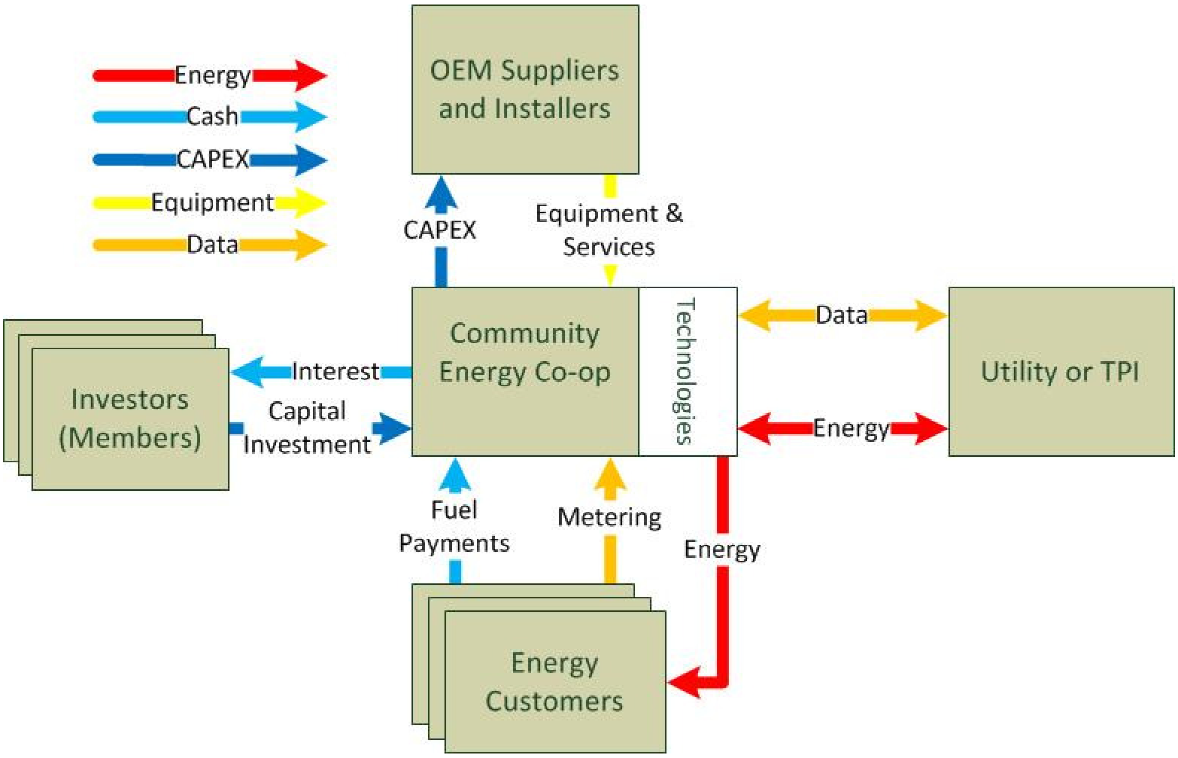


Figure i. Community Energy business model schema

Techno-economic Modelling

In this study, modelling was carried out to analyse the potential for energy storage in community-scale domestic energy scenarios, involving a range of energy demand and supply cases. In summary, the results of the analysis indicate that:

- A ‘whole-system’ approach to the design of such community-scale projects is desirable. Considering ‘demand-side’ fabric efficiency and building configuration and layout aspects together with ‘supply-side’ energy generation and storage plant design can have a significant impact on overall operational efficiencies and economic viability.

- Effectively designed combined heat and power (CHP) systems can utilise thermal storage to reduce heat shedding and gas peaking boiler load factors, and improve project economic viability. However, care must be taken in terms of CHP sizing and storage capacity in order to optimise investment returns.

- To be viable, domestic co-generation projects require both heat and power to be sold locally at retail tariffs. In such domestic contexts, current market regulations will require a householder ‘opt-out’ or ‘opt-in’ arrangement to be in place, which may increase investment risk.

- Our high temporal resolution modelling indicates that viability for domestic-scale electrical storage combined with photovoltaic technology is still some way off in the UK market. However, project viability without subsidies could be attained for domestic energy storage prices of around £250 per kWh or below. Given the current rate of battery cost reductions, in the near term this is more likely to be achieved in community contexts for systems comprising larger-scale storage co-located at the community’s point of network connection, rather than at individual household level. This also offers additional potential advantages in terms of system availability and control when providing network support ancillary services.

- Analysis of ground source heat pump (GSHP)-based community-scale schemes indicates that demand shifting for heating based upon time-of-use tariff price signals could significantly improve investment returns for such projects.

- Ancillary services markets could offer significant opportunities for a wide range of projects. Demand ‘turn-up or down’ services are relevant to both thermal and electrical energy storage, with ‘despatchable’ network balancing and frequency control offered by electrical storage.

- Although not yet financially viable, as electrical battery storage costs continue to fall, this technology could offer a valuable near or medium-term alternative to network reinforcement as battery costs reduce, especially when combined with intelligent demand side management and/or ancillary service provision. This is especially the case where the local network capacities have been reached, and for which network upgrade costs in addition to transformer replacement are especially high. Our modelling has shown that storage capacities as low as 2kWh per dwelling could deliver significant peak demand reductions at the point of connection.

Technical and Market Aspects

Evolving markets, new business models, technological advances and cost reductions in the energy storage sector are resulting in a range of potential new investment opportunities for community-scale energy stakeholders, although not without significant uncertainty and risk at present.

The electrical energy storage technology arena is evolving rapidly. Physical properties such as energy density, response times and durability need to be matched to the specific storage application, particularly the ability to deliver network balancing and capacity services.

For thermal storage, sensible, latent and thermochemical platforms are at various stages of market readiness, with sensible storage currently being the most simple, cheap and widely deployed.

As the energy system has become more distributed with higher penetration of intermittent renewable generation, the requirement for greater flexibility has increased. In response, incremental policy and market reforms are being introduced to incentivise the delivery of flexibility services. With appropriate regulatory refinement (including introducing measures that reflect the value of flexibility offered by energy storage, streamlining of contractual and legal arrangements and re-assessment of current storage asset ownership constraints), community-scale energy storage (either stand-alone or coupled with renewable generation), could benefit from these new markets, thus delivering enhanced value for investors and consumers alike.

Glossary of Terms

ASHP	Air Source Heat Pump
BM	Balancing Mechanism
CES	Community Energy Storage
CHP	Combined Heat and Power
COP	Coefficient of Performance
DBO	Design-build-operate
DECC	Department of Energy and Climate Change (Now DBEIS Department for Business, Energy & Industrial Strategy)
DEM	Distributed Energy Management
DNO	District Network Operator
DSO	Distribution System Operator
DUoS	Distribution use of System
EHR	Enhanced Frequency Response
ERP	Enhanced Reactive Power
ESCO	Energy Services Company
EV	Electric Vehicle
FCA	Financial Conduct Authority
FCDM	Frequency Control by Demand Management
FFR	Fast Frequency Response
FIT	Feed-in Tariff
GSHP	Ground Source Heat Pump
ICT	Information and Communication and Technology
IRR	Internal Rate of Return
L1A	Approved Document L1A Building Regulations: Conservation of Fuel and Power
LCOS	Levelised Cost of Storage
LLP	Limited liability partnership
MCS	Microgeneration Certification Scheme
OFGEM	Office of Gas and Electricity Markets
PCM	Phase Change Materials
PHES	Pumped hydro energy storage
RD&D	Research Development and Deployment
ROI	Return on investment

SO	System Operator
STOR	Short Term Operating Reserve
TPI	Third party intermediary
TSO	Transmission System Operator

1. Introduction

The UK's energy system is undergoing a rapid transition primarily driven by both the imperative to reduce greenhouse gas emissions and the significant recent reductions in costs of renewable energy technologies, including wind energy and solar photovoltaics. With a current combined PV and wind capacity of over 25GW, the variability of this resource presents challenges in terms of electrical system balancing. Energy storage (in conjunction with other technologies such as demand side management and flexible 'despatchable' generation) is increasingly seen as a key means of maintaining power system stability.

In terms of thermal energy, around half of total final UK energy demand is used for heating in buildings and industry, with combined space and water heating accounting for over 75% of this energy. With the majority of this energy derived from fossil fuels, rapid decarbonisation of thermal energy demand is needed to achieve the UK's greenhouse gas emission reduction targets. In some respects, this is an even greater challenge than that facing the electrical energy sector.

Both electrical and thermal energy demand vary significantly over different time scales, and are strongly dependant on factors such as outdoor weather conditions, with large seasonal and daily variations depending on building design, usage and occupancy levels. This variation in energy demand, with generation and load profiles that are predictable to an extent presents opportunities to use energy storage to manage supply requirements to meet specified demands. To this end, new regulatory structures and market instruments (such as variable and cost reflective energy tariffs and electrical ancillary services markets) represent exciting business opportunities for energy storage stakeholders over the coming years.

In this rapidly evolving landscape, there is significant scope for communities to play an important role in the provision of energy services. Community-scale energy storage (CES) is seen as being an increasingly important aspect of an integrated energy strategy for the UK that includes optimised community-based energy services. As the economics and technical maturity of CES (and related technologies such as PV) continue to improve, the potential of CES to realise value across a number of markets is becoming increasingly apparent in terms of delivering desirable outcomes for consumers and service providers alike, including lower energy bills, lower emissions, and improved system reliability and safety.

This report presents the findings of a 12-month project into the potential role that could be played by energy storage within the UK energy system at community scale. The investigation includes an assessment of technical feasibility, as well as evaluation of potential business models and economic analysis as factors that could influence adoption.

Specifically, the objectives of the work are to:

- Identify and evaluate relevant stakeholders in the community energy storage sector, and specify roles, benefits and barriers relevant to each.
- Assess storage and related technologies in order to identify appropriate future technical platforms.
- Identify and define relevant markets from which value may be generated, both now and in the future.
- Evaluate potential business models, and carry out a financial feasibility study for specific market scenarios.

The rest of this report is structured as follows:

Section 2 contains summary key findings of the financial viability analysis for energy storage in community energy contexts based on specific case-study scenarios.

It also includes summary key findings from the techno-economic modelling analysis for thermal and electrical energy storage used in a number of community-scale energy scenarios.

Section 3 evaluates a number of candidate potential community energy service business models and their associated stakeholders that could facilitate commercialisation and deployment of energy storage technologies at a community level, and the framing of likely market environments that could form the basis for future business model development.

Section 4 contains the detailed results of the financial viability analysis for energy storage in community energy contexts, based on specific case-study scenarios. The work has a particular focus on domestic housing, for which various energy supply and building design and layout options are studied.

Section 5 examines near, medium and long term prospects for storage at both local and system levels in order to assess likely technology platforms for integrated community energy storage systems. This includes analyses of storage technologies and their suitability for candidate community energy applications and system integration aspects, including connection, control and related microgeneration technologies such as PV. It also includes an evaluation of current and likely future technology costs.

Section 6 analyses potential value streams relevant to community energy storage, and evaluates their importance in order to inform subsequent assessment of specific business models and financial analysis. It also includes quantification of value streams arising from such mechanisms as reduced consumers' energy bills, energy arbitrage and ancillary service provision, together with as yet immature markets, such as demand side flexibility and peer-to-peer energy.

Section 7 details the main conclusions derived from this work.

2. Key Outcomes of the Techno-economic Study

In this section we present in summary form some key results of the techno-economic modelling analysis presented in more detail in Chapter 4. The analysis examined specific community energy platforms comprising thermal and electrical energy storage of varying capacities for a range of 100-dwelling community energy scenarios. Various building stock typologies with varying thermal fabric efficiencies and building configurations were examined. Parameters such as capital equipment and operation and maintenance costs, fuel purchase and sales tariffs and plant performance characteristics were obtained from a range of industry and recent research sources, as specified in section 4.

The 100-dwelling demand scenarios were modelled using a high resolution time-step method developed by CREST and widely used in previously published research (Richardson et al, 2010; McKenna & Thomson 2016), and reflect a range of hot water and space heating loads representative of:

- Energy efficient new build low carbon apartments
- Retrofitted terraced houses
- New build 'L1A' building regulation detached dwellings (DCLG, 2014).

Financial viability and CO_2 emissions were analysed for several energy supply platforms integrating energy storage were evaluated including:

- CHP with community heat networks and large-scale GSHP, coupled with thermal storage,
- Electrical storage for grid reinforcement mitigation and
- Domestic battery storage with PV.

The modelling approach is presented in greater detail in Section 4. The key outcomes of the modelling work in terms of potentially viable project typologies are summarised below.

2.1. CHP with Thermal Storage

The results for a community CHP platform delivering heat and power locally and sold at retail tariffs demonstrate the potential for appropriately specified and controlled CHP systems with energy storage to be profitable. However, for high per-dwelling energy demands (especially at low housing densities) relatively high heat network capital costs reduce project viability.

For relatively compact buildings with a high thermal load, project viability may be enhanced due primarily to lower heat network capital costs and lower efficiency losses. For example, the 100-dwelling apartment block project modelled in this study demonstrates the greatest increase in IRR for a 30kW CHP system comprising 250kWh of thermal storage.

Table 1 IRR for CHP/Storage with 100 L1A detached dwellings (%)

		CHP Capacity (kW)					
		10	**30**	**50**	**70**	**120**	**200**
Storage Capacity (kWh)	**0**	-0.43	0.22	0.51	0.61	0.23	-1.89
	250	-0.47	0.52	0.99	1.18	0.91	-0.88
	500	-0.52	0.50	1.20	1.45	1.23	-0.38
	1000	-0.62	0.40	1.16	1.53	1.47	-0.04
	2000	-0.82	0.20	0.98	1.39	1.39	-0.03
	3000	-1.01	0.01	0.80	1.21	1.25	-0.14

Table 2 IRR for CHP/Storage connected to 100 Retrofit terraced dwellings

		CHP Capacity (kW)					
		10	**30**	**50**	**70**	**120**	**200**
Storage Capacity (kWh)	**0**	-0.10	0.51	0.19	-0.67	-4.35	-14.65
	250	-0.15	1.01	0.92	0.30	-2.83	-12.75
	500	-0.23	0.97	1.04	0.48	-2.33	-12.11
	1000	-0.38	0.84	0.95	0.43	-2.24	-11.97
	2000	-0.68	0.57	0.70	0.21	-2.33	-12.05

Table 3 IRR for CHP/storage connected to 100 low carbon apartments

		CHP Capacity (kW)					
		10	**30**	**50**	**70**	**120**	**200**
	0	4.70	2.06	-3.24	-10.94	n/a	n/a
	250	4.86	3.63	-0.74	-7.99	n/a	n/a
	500	4.59	3.48	-0.65	-7.79	n/a	n/a
	1000	4.08	3.07	-0.85	-7.92	n/a	n/a
	2000	3.17	2.31	-1.29	-8.25	n/a	n/a

In all these scenarios, the most sensitive input parameters in terms of financial outcomes include gas purchase price, operational system efficiency and energy sale tariffs. This means that an effective project risk management strategy would include careful consideration of the likely eventual values of these key parameters prior to detailed project development.

2.2. Ground Source Heat Pump Using Arbitrage with Time of Use Tariff

Thermal storage can be used with heat pump based electrical heating to take advantage of cheaper night time ‘Economy 7’, or forthcoming ‘smart’ time-of-use tariffs. The modelling results for ground source heat pump (GSHP)-based systems predict that thermal storage, charged during off-peak periods, could increase annual returns significantly. However, the results are very sensitive to heat pump efficiency (coefficient of performance - COP) with variations in operational COP values having a significant impact on returns.

In the table below, the high COP band corresponds to a seasonal efficiency of around 400%, which is attainable for good quality GSHP systems subject to careful monitoring, maintenance and control. If possible, negotiation of an energy performance guarantee is desirable to manage the risk of under-performance. The implications of the impacts of storage on the viability of air-source heat pumps (ASHPs) are similar, provided that a good quality of technology, monitoring and control are maintained.

Table 4 below shows the impact of storage upon predicted returns for GSHP systems, based upon cost and performance parameters specified in section 4.

Table 4 IRR (in %) for GSHP with storage connected to 100 dwellings (L1A detached, retrofit terraces, low carbon apartments)

		L1A detached			**Retrofit terraces**			**Low carbon apartments**		
		COP band			**COP band**			**COP band**		
		High	**Medium**	**Low**	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**
Storage Capacity (kWh)	0	3.9	1.4	-5.5	3.6	1.1	-6.0	2.5	0.0	-7.4
	250	4.0	1.7	-4.8	3.9	1.6	-4.7	3.0	0.9	-4.8
	500	4.2	1.9	-4.1	4.1	2.0	-3.6	3.5	1.7	-2.9
	1000	4.4	2.3	-3.0	4.5	2.6	-2.0	4.0	2.5	-0.9
	2000	4.8	3.0	-1.4	4.9	3.4	-0.2	3.9	2.7	0.0
	3000	5.0	3.4	-0.4	5.0	3.7	0.6	3.5	2.3	-0.4

2.3. Ground Source Heat Pump with Storage for Ancillary Services

Participation in electrical ancillary services mediated by an aggregator partner can in theory raise significant additional revenue for projects with flexible demand and generation capabilities, which can be enhanced by energy storage. In this example, storage provides ‘head’ and ‘foot’ room allowing the GSHP to turn demand up or down without compromising the supply of energy to local households. Based on our 100-dwelling community, the modelling indicates that this enhanced system flexibility enabled by the addition of energy storage helps deliver added revenue of up to £400 per dwelling in the case of the largest GSHP installations for L1A detached homes. IRR is predicted to increase as storage capacity increases, and the viability of heat pumps operating at relatively low COPs is improved. More efficient GSHP-based systems are projected to make higher returns (IIR up to 10%) (Table 5).

Table 5 IRR (in %) for GSHP with storage and FFR ancillary services connected to 100 dwellings (L1A detached, retrofit terraces, low carbon apartments)

		L1A detached			**Retrofit terraces**			**Low carbon apartments**		
		COP band			**COP band**			**COP band**		
		High	**Medium**	**Low**	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**
Storage Capacity (kWh)	0	3.9	1.4	-5.5	3.6	1.1	-6.0	2.5	0.0	-7.4
	250	5.4	3.2	-2.3	6.1	4.0	-1.0	7.1	5.4	1.4
	500	6.6	4.6	-0.2	7.9	6.1	2.1	8.8	7.3	4.1
	1000	8.4	6.7	2.8	9.4	7.9	4.5	9.0	7.6	4.6
	2000	9.7	8.2	4.9	9.7	8.2	5.1	8.4	7.1	4.1
	3000	9.9	8.4	5.3	9.3	7.9	4.9	7.8	6.5	3.7

2.4. Electrical Storage for Grid Reinforcement Avoidance

It has been shown previously that electrical energy storage has the potential to act as an alternative to traditional network reinforcement (Poudineh & Jamasb, 2014). To explore this, a high time resolution power demand analysis for the same 100 dwelling community scenario was carried out. The peak demand management capabilities of battery storage, as well as the size of battery capacity needed to cope with the most extreme periods in terms of aggregate community power load were analysed.

Table 6 below shows battery storage capacities needed to limit load flow (in kW/min) at the point of connection to limits of 40, 60, 80 and 100kW respectively. For comparison, a 60kW load constraint equates to around a 55% reduction in maximum total community aggregate load of around 140kW.

Table 6 Battery sizes required for given connection constraints

Constraint	**Battery size needed to deal with demand above constraint (kWh)**	**Charge battery whenever demand is less than constraint?**	**Charge battery during lowest time of use tariff times (12pm-7am)?**
100kW	21	Possible	Possible
80kW	90	Possible	Possible
60kW	245	Possible	Not Possible
40kW	520	Not Possible	Not Possible

The results indicate that a relatively low battery capacity is required to operate within a 100kW connection constraint, representing approximately 0.21kWh per dwelling to achieve a peak load reduction of around 30%). To operate within a 60kW limit (a peak load reduction of 57%), the analysis indicates a storage capacity of around 2.4kWh per dwelling is needed. To operate within a higher peak load limit would require additional on-site demand management, as the modelling indicates that it is not possible to achieve the required battery state-of-charge for subsequent peak load management using the available time window from grid supplied energy whilst remaining within load constraint limits. The financial case for this approach for peak load management is explored further in section 4, and it should be noted that this approach to peak load mitigation is not at present adopted widely in the UK, especially for community-scale developments, although. However, large scale dedicated network installations are becoming more prevalent, especially when co-located with large ground arrays.

2.5. Battery Storage with Household PV

The potential for domestic scale PV with battery systems in the UK was analysed in the study, assuming data for Li-Ion battery costs from market projections for the year 2020, which has been cited as the earliest point at which break-even for PV/battery storage systems may be approached (Reid et al. 2015). The analysis utilised 1-minute time-series simulations based on the aforementioned CREST demand and PV model, together with financial parameters and round-trip battery efficiency and degradation data used in previous research (BEIS 2016; Hoppmann et al, 2014).

Two scenarios are used in the analysis (Table 7), representative of relatively high and low inflation contexts respectively. Each scenario comprises a 20-year investment term, an additional discount rate of 5% and a Li-ion cost estimate for the near (2-5 year) term likely to be relevant for larger community-scale 200-1,200 kWh Li-ion installations co-located at the point of network connection.

Table 7 Scenario parameters used in analysis

Scenarios	**Export tariff** £/kWh	**Import Tariff** £/kWh	**Inflation**	**Battery Price** £/kWh
1	0.05	0.15	2%	250
2	0.03	0.20	4%	250

PV array sizes of 2kWp and 4kWp per dwelling were evaluated, representative of the lower and upper bounds of current UK domestic PV installation systems respectively.

The results (table 8 below) indicate that although scenario 1 (a relatively low inflation case) does not show financial viability across all configurations comprising larger PV systems and battery capacities per dwelling, break-even is indicated for small PV systems combined with relatively small specific battery capacity (2kWp/2kWh). The results for scenario 2 (a relatively high inflation case) indicate economic viability is achieved across all cases except for a relatively large battery size of 12kWh per dwelling. However, note that this extra capacity may be useful where household time-of-use energy arbitrage is utilised, or for the provision of network ancillary services.

Table 8 NPV outcomes for PV with battery storage

2kWp PV			
Scenario & NPV (£)	2kWh	4kWh	6kWh
1	92	-337	-808
2	765	467	129

4kWp PV					
Scenario & NPV	4kWh	6kWh	8kWh	10kWh	12kWh
1	-105	-447	-890	-1401	-1912
2	980	858	566	107	-352

The analysis shows that the potential exists for viable combined PV/battery system deployment without the need for subsidies in the near future in the UK, although risks in terms of achieving viability related to wider economic factors are significant. The analysis also shows that careful consideration of technical aspects is required in terms of appropriate matching of PV and battery capacities, together with consideration of relative import/export tariff structures. Potentially, investment risk could be mitigated *via* energy arbitrage together with the provision of ancillary services, subject to the development of the appropriate technical, market and regulatory landscape.

3. Business Models for Community Energy Storage

3.1. Defining business models

When trying to define relevant business models for new sectors such as distributed community-scale energy, barriers related to both the organisational and structural nature of the market must be considered. This is especially the case where a disparate number of stakeholders engage in order to create non-traditional models in a fluid regulatory, technical or economic landscape.

Box 1 Components of the Business Model

The conceptual tool developed by Osterwalder et al (Osterwalder, Pigneur and Tucci, 2005) comprises four key business model components (or pillars), and nine related building blocks. This has been further developed as a basis for business model design which has gained widespread use (Osterwalder and Pigneur, 2013).

Pillar	Business Model Building Block
Product	Value Proposition
Customer Interface	Target Customer
	Distribution Channel
	Customer Relationships
Infrastructure Management	Value Configuration
	Core Capabilities and Competencies
	Partner Network
Financial Aspects	Cost Structure
	Revenue Model

Burlinson and Giulietti (2014) identify actors, value, consumers, and ownership as key elements. Particularly within innovative business models with collaborative actors, ownership of the assets and value generated become less obvious and therefore need to be clearly defined.

As a starting point, it is useful to place the key actors at the heart of the business model (Boscán and Poudineh, 2016), and consider the capabilities and competences required for success. For example, when targeting and nurturing customers they must relate to the value proposition, and there must be adequate research in to consumer behaviour (including temporal aspects of energy demand) to ensure this matches their (sometimes changing) expectations over time (Magretta, 2002), with a strong and competent organisational structure to deliver the value proposition in accordance with clients' expectations.

A useful device to help understand a specific business model from the actors' perspectives is a schema of the detailed relationships between all stakeholders in the form of an Actor Relationship Map delineated by the material exchange of equipment, finance and information. Figure 1 shows an example of a relatively complex arrangement of actors between which flow energy in the form of heat and electrical energy, as well as finance, data and equipment which together enable the required business transactions and the exchange of value.

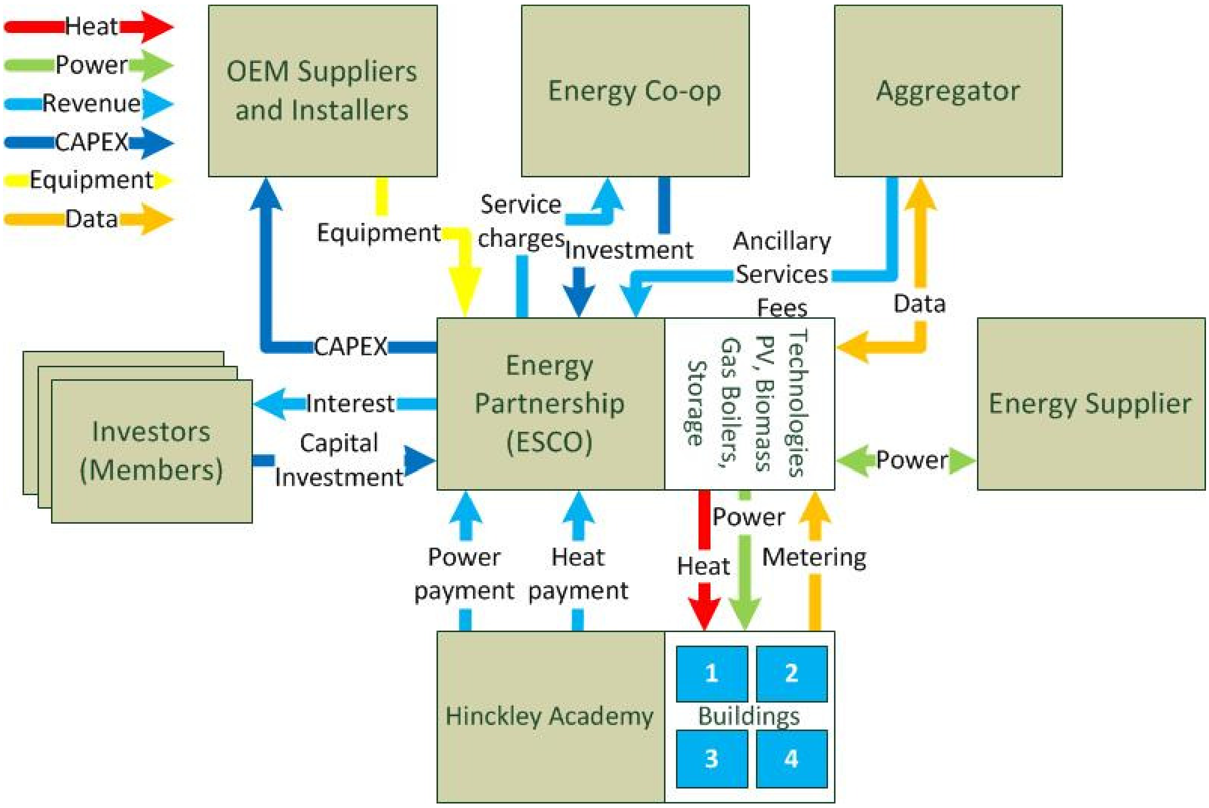


Figure 1 A diagram of a business model represented by the material exchange of equipment, finance and information.

The model shown in Figure 1 represents the breadth of actors – energy producers and consumers, investors, equipment suppliers and installers, aggregation services, and links to the wider energy system. At the core is a complex management structure in the form of a partnership which capitalises and provides energy services, and includes both the main consumer (i.e. a 'prosumer'), and an arm's length management services organisation.

A key requirement for any business model is the capitalisation of the venture. The total cost of capital can be represented by payments to investors (equity financing), the cost of loan repayments (debt financing), or a mixture of the two. In the above example, investors who have purchased shares expect interest payments (see below).

The model shows several value streams, and, these may be stacked in order to generate enough income to provide a greater return on investment or to render a marginal project viable. For example, appropriate energy storage may reduce the net cost of energy generation by enabling demand side management to manage the cost of more expensive peak loads, and by participating in ancillary markets such as frequency response or STOR.

For this example, there are numerous configurations of key stakeholders, some of whom may adopt multiple roles (such as the prosumer role increasingly relevant to embedded generation), each of whom should benefit from a positive value proposition in order to consider it worthwhile to participate in a community energy scheme. It is the alignment of multiple benefits for disparate stakeholders which remains a significant barrier.

Three principal types of community-scale energy with storage business models are described below which are subsequently used as a basis for the modelling in this study. These business models are:

- Community-owned
- Design-build-operate (DBO) and
- Energy Services Company (ESCO)

Other models can also be analysed if the relationships between actors are characterised appropriately (Figure 1).

3.2. Business Model Characterisation

In this section, each of the selected candidate business models are qualitatively analysed in terms of physical, financial and data aspects. This acts as a basis for subsequent quantitative modelling in Section 6.

3.2.1.Community-Owned

Community-owned energy generation and storage schemes are regarded here as social enterprises characterised by local ownership, participation and benefit-sharing. They may be formally established as a co-operative or community benefit society regulated by the FCA, and they seek to raise capital using community shares offers from, as far as possible, the local community instead of from private investors (Brown, 2011).

The purpose of such social enterprises is not primarily to maximise profits for investors, but to deliver additional socio-economic or environmental objectives, especially within the local community. Surpluses are commonly re-invested in the community, and as a form of quasi-equity, community shares are not able to be sold other than back to the social enterprise for their original price. Although relatively modest returns on investment are often realised, research suggests that recent schemes are yielding returns as high as 7% (Burlinson and Giulietti, 2014). Additional collective benefits for the community (including reduced bills, revenue generation, investment opportunity and community regeneration) are important drivers (Smart Energy Special Interest Group, 2013). Thus, although risks are still present for investors, the lower expected yields ensure that the cost of capital can be quite low for such community schemes, thus in theory giving them a competitive advantage.

A relatively simple community energy model is shown below in Figure 2. Here, a co-operative enterprise, which raises finance from community investors, is able to sell heat and electrical energy to customers. Excess electrical generation is exported to the grid, whist imports make up shortfalls in meeting demand. Typical projects might include Solar PV, and even community scale hydro technologies (ukcec.org, 2017).

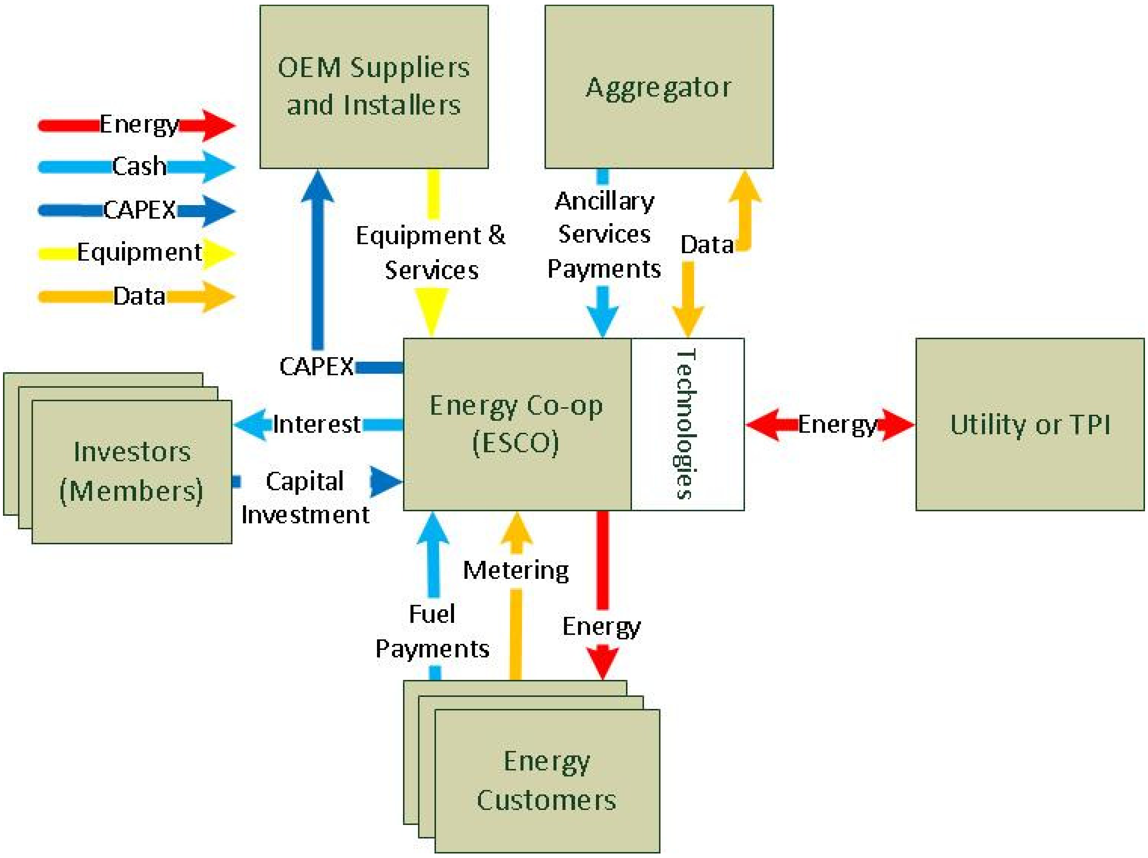


Figure 2 Community Energy business model map

3.2.2.Design-Build-Operate

Design-build-operate (DBO) is a relatively common method of project financing, especially for public sector district heating schemes. In this case, the main contract-giver is a local authority, the key requirements of which are to provide heat at a market-competitive tariff and to make carbon savings as part of decarbonisation targets. The DBO company may establish a special purpose vehicle (SPV) to deliver and manage the project. For a typical district heating scheme, capital investment risk can be mitigated by including a minimum contractual heat demand which means that the local authority must ensure that its building stock remains connected or is substituted by replacement loads if buildings are sold and disconnected. A core of energy demands, such as local authority offices, and other buildings such as hospitals or shopping centres represent a base (or anchor) load. Additional buildings including local authority social housing stock may also be connected with a view to delivering social impacts such as fuel poverty alleviation.

If raised by the delivery partner, the current cost of project capital for such DBO projects can be somewhat greater than if raised directly by the local authority partner, whilst if financed from company equity the opportunity cost of the investment may result in discount rates in excess of 10%. This can significantly impact the apparent viability of candidate projects at the planning stage.

As the principal contract-giver, a local authority requires evidence of an attractive value proposition; for example, savings in excess of 10% on existing energy bills may be required. A typical business model network is shown in Figure 3. Note here that some or all equipment may be supplied by a separate equipment provider, which may have a close relationship with the DBO company.

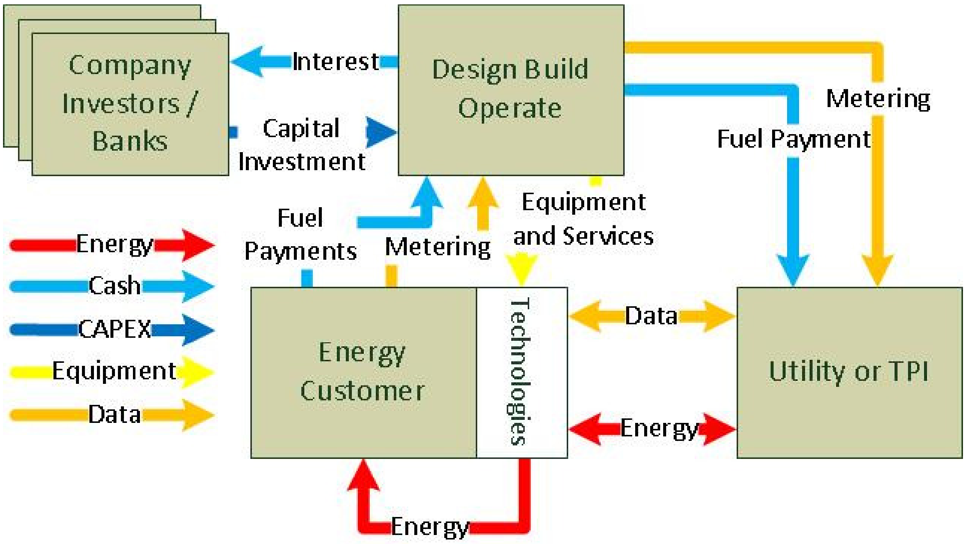


Figure 3 Design-build-operate business model

3.2.3.ESCO with Aggregator

The third candidate business model illustrated here comprises an energy services company (ESCO), in this case involving an aggregation partner (Figure 4). This allows the energy generation and storage asset owner to participate in the grid balancing services market managed by the TSO (national grid), and thereby leverage additional revenue streams. An aggregator is useful in this case, because for a typical community scale energy scheme the, barriers for accessing these services are relatively high. Furthermore, an individual ESCO scheme may not satisfy the TSOs delivery requirements, such as minimum capacity and availability requirements.

The aggregator receives payments from the TSO for ancillary services delivered, and passes these on to the asset owner, less a service charge of between 10 and 30%. This model requires a close partnership between the aggregator and the energy system operator acting on behalf of local energy users, and it is essential that provision of an ancillary service does not interfere with day-to-day energy supply obligations. Whilst the aggregator can remotely control the local energy system, an aggregator will provision an opt-out of a grid balancing service during specific periods in deferment to local energy requirements (Flexitricity, 2017).

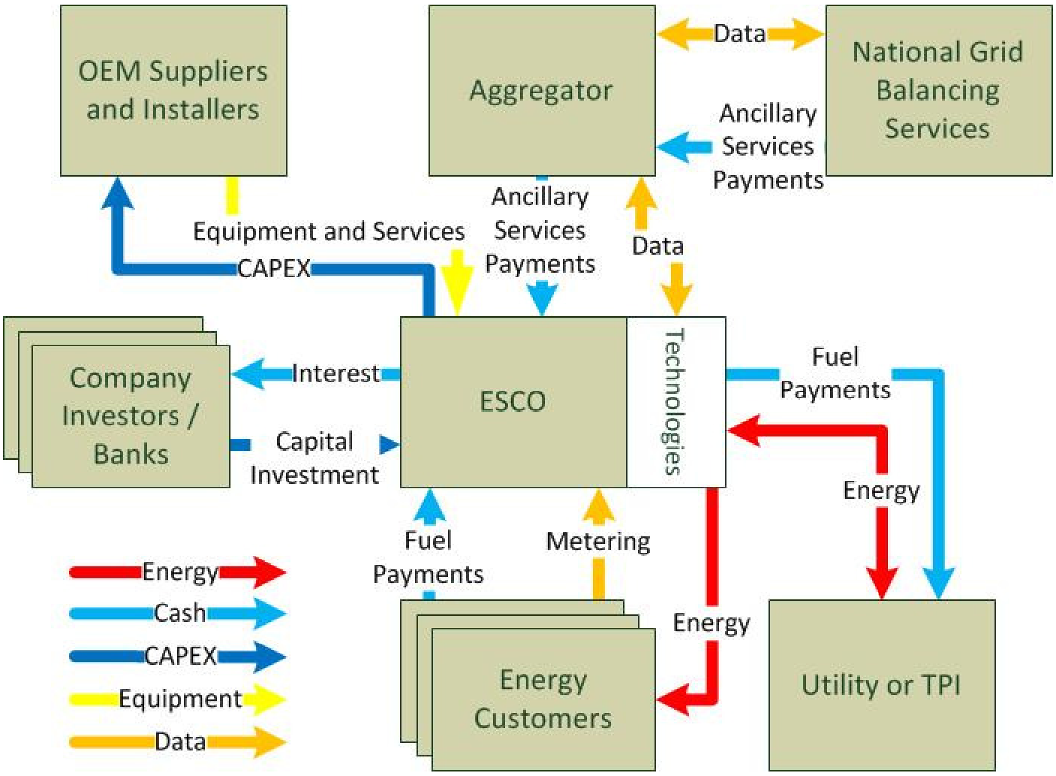


Figure 4 ESCO with Aggregator business model

3.2.4. Business Model Viability Indicators

A candidate business model should where possible be validated on the basis of its economic value in order to test its viability (Boscán and Poudineh, 2016). Ideally, this should comprise more than a simple cash flow (NPV) evaluation, but should also include analysis of project uncertainties and risks and demonstrate value-for-money for consumers commensurate with economic value for stakeholders (Magretta 2002). Thus once CAPEX payments have been accounted for, and annual revenues projected, it is important to assess business model viability from the perspective of the key stakeholders shown in the above network diagrams such as:

- Can different shareholders, investors or loan providers receive their expected individual rates of return?
- Is cash flow sufficient to finance ongoing OPEX given the calculated probabilities of unexpected operation and maintenance costs?
- By how much and for how long can customer fuel bills be kept competitive in comparison with conventional utility energy suppliers in order to provide an attractive customer value proposition, especially given future uncertainties in external factors such as fuel supply costs, tax rates or carbon emission tariffs?
- What are the projected long-term carbon emissions, and in the case of domestic dwellings, what are household fuel bills in order to evaluate both environmental and social impacts?
- What is the likely long term value of additional revenue streams from sources such as aggregation services, capacity market and/or demand side management enabled by energy storage technologies.

3.3. Summary

In this section, a number of business model structures have has been characterised in terms of networks of project actors and stakeholders and their relevant relationships. The analysis includes five indicators for assessing these business models from the perspective of key stakeholders, including asset owners, investors, customers and external added-value partners.

In the next section, an analytical approach is taken to evaluating community energy and storage technologies given varying energy generation, demand and storage contexts.

4. Modelling Community Energy System Scenarios

4.1. Introduction

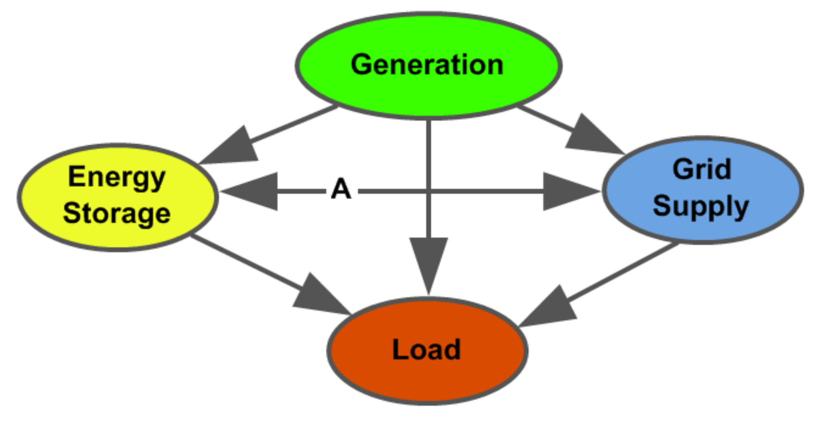
In section 3, a summary of the key outcomes of the study's modelling work was described. Here in section 4, this work is presented in more detail for several community scale energy system scenarios. The work is set within a framework informed by our initial stakeholder workshop held in April 2016 along with research on generation and storage technology platforms together with candidate ownership and business models applicable to community energy with storage as described in section 3.

To quantify aggregated value streams, a modelling tool developed by CREST was used. This enables integrated time-resolved simulations to be carried out in order to evaluate energy flows between embedded generation, energy storage, loads, and the wider energy system. By defining parameters, such as equipment costs, energy sale tariffs and fuel purchase prices, the model enables discounted cash flow analysis of candidate community energy scenarios, both with, and without thermal or electrical storage.

In all instances, except where indicated otherwise, a notional community of 100 dwellings was used as the basis of the analysis. Simulation of energy demand was carried out for of varying dwelling layout and thermal efficiencies, together with a core set of energy generation platforms, including natural gas co-generation (CHP) and electric-only technologies. Subsequently, the impact of electrical and thermal energy storage technologies on the viability of community energy with storage scenarios was evaluated.

Box 2 Energy flows of a grid connected generation technology storage and a load

The CREST model simulates energy generation in discrete time steps (1 or ½ hour, or 1s for solar PV. Energy generation is distributed to a load, to the grid (in the case of electricity), or used to charge an energy storage technology. The load may also receive power from the grid or by discharge from the storage.



Both simple thermal and electrical storage can be modelled, and the supply grid can be the gas network (e.g. the case of CHP), or the distribution network. In the gas of electricity there may also be two-way flow of energy between the grid and energy storage (connector **A**).

Realistic heat or power load profiles, and generation profiles (time series) for a whole year are generally used. The cost of energy imports and value of energy services are aggregated over a whole year and using appropriate CAPEX and OPEX, techno-economic indicators are calculated which are used to evaluate business models.

4.2. Defining Scenarios - Energy Demand and Building Stock

Space heating demand profiles are determined primarily by building configuration/density, fabric thermal efficiency and occupancy and usage patterns. Thus, our 100 notional dwellings comprise three primary configurations, each with three different dwelling fabric thermal performance levels. The configurations are:

- A single 100-dwelling apartment block;
- A 10 x 10 row terrace townhouse arrangement; and
- 100 detached properties.

In terms of thermal fabric efficiency, analysis was carried out for buildings conforming to the following performance levels:

- Current part L1A building regulations (‘standard L1A’)
- An intermediate fabric performance corresponding to a building retrofit energy efficiency interventions such as external solid wall insulation (‘retrofit’) and

- High thermal efficiency approaching Passivhaus standard (‘low carbon’)

Table 9 shows a matrix of these characteristics along with the average annual thermal demand per dwelling. The results presented here focus on the configurations and efficiencies shaded in the table to represent a broad range of heat loads representative of UK building stock as shown in Figure 5.

Table 9 Average annual thermal loads for building stock configurations and fabric thermal efficiency (kWh/year)

		Building configuration		
		Detached	Rows	Block
Fabric thermal efficiency	High “low carbon”	7,975	5,485	4,953
	Mid “retrofit”	12,353	10,283	8,048
	Standard “L1A”	18,065	14,533	11,514

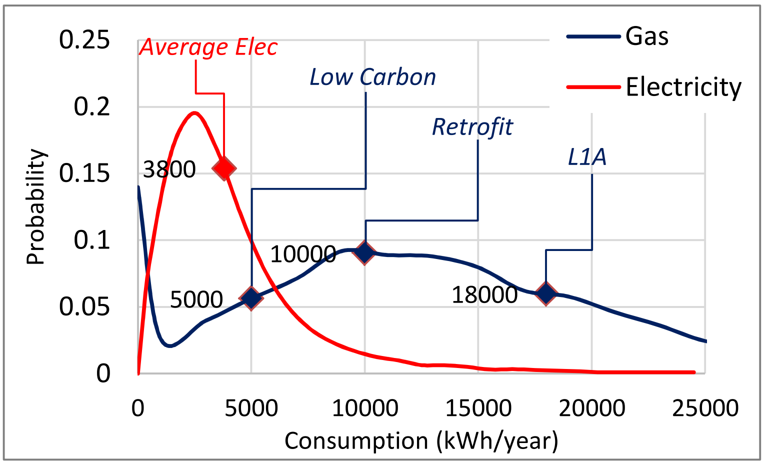


Figure 5 Frequency distributions for gas and electricity consumption for the UK housing stock, taken from the NEED Framework. The lozenge markers show the points for energy demand modelled in this work.

Electrical and thermal energy demand for each dwelling was simulated using a stochastic demand model, based on active occupancy and daily household activity profiles, and upon appliance, lighting and heating use (Richardson et al, 2010). This generated classical ‘spikey’ demand profiles for showing appliance usage the cycling of appliances such as refrigerators which closely matched empirical load profiles. Separate electricity demand data time series were then aggregated to represent the total power demand of an entire community of 100 dwellings.

4.2.1.Modelling Energy Supply and Storage Technologies

Two energy supply technology platforms encompassing both gas network-connected and all-electric contexts were evaluated in the study, namely:

- Gas-fired cogeneration (CHP) with peaking gas boiler
- Electric-only ground source heat pump

The impact of electrical and thermal storage at the community scale was evaluated for specific supply platforms and building characteristics described above. This included technology scenarios for both off-gas and on-gas cases and these were compared with realistic counterfactual or baseline energy systems. Typical model input parameters are shown below in Table 10 and include fuel/energy tariffs, inflation estimates and capital and O&M costs.

Table 10 Input parameters used in the study

Parameter	**Base case value**	**Note**
Cost of Gas	3.2p/kWh	DECC, 2015B
On-site electricity sale price	12p/kWh	DECC, 2015 [1]
On-site heat sale price	6p/kWh	DECC, 2015 [1]
Electricity import price	11p/kWh*	CIBSE, 2012 [2]
CHP Export tariff	6p/kWh	CIBSE, 2012 [2]
Boiler efficiency	80%	Fragaki and Anderson, 2011
Heat Network Capital Cost	£400-600/meter	AECOM, 2015
CO_2 emissions (grid)	458g /kWh	Defra, 2013
CO_2 emissions (natural gas)	184 g/kWh	Defra, 2013
Storage capital cost	£843/m^3	AECOM, 2015
Energy price inflation rate	2.5%	Estimated
Project period	20 years	n/a
[1] Revised down following consultation with stakeholders [2] Revised up following consultation with stakeholders * Where fixed, otherwise ToU Tariff.		

Given the potential future introduction of various new tariff structures, including flexible time-of-use (ToU) and ‘wind tariffs’, these have been analysed to assess the value of storage for energy arbitrage. Estimates of potential value derived from ancillary services markets, determined by the generating capacity and energy headroom offered by storage was also included. Figure 6 illustrates a summary of the modelling approach taken in the work.

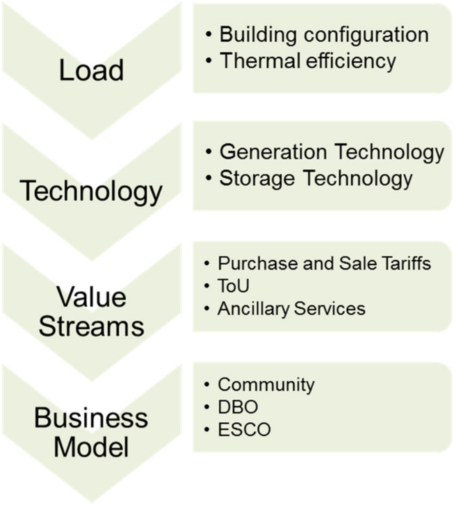


Figure 6 Scenario schematic for community energy modelling approach

Results for specific community energy scenarios are presented in the next section.

4.2.2.CHP with Thermal Storage

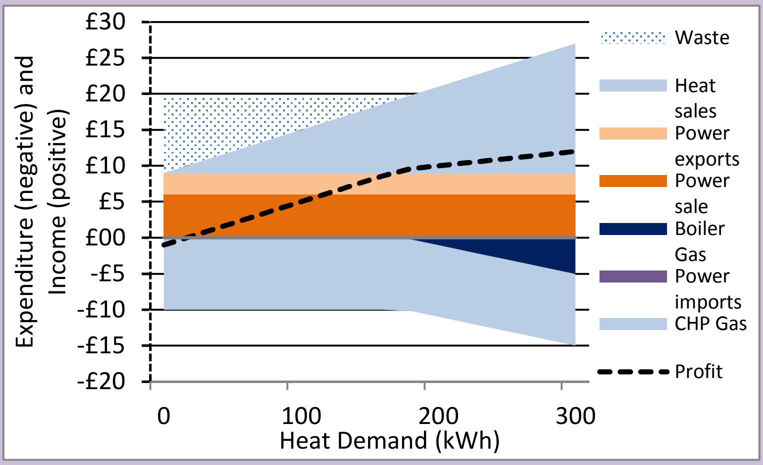
CHP systems are frequently deployed in large building complexes (such as hospitals) or connected to heat networks to distribute heat via a network of insulated pipes to commercial or domestic buildings. They commonly adopt a heat demand-led operating strategy, but may also follow electrical power demand.

Thermal loads are diurnal and seasonal in nature. Because of the high “ramp-up” costs for CHP they are often sized to satisfy the base load so that they can run continuously at maximum power output. Peak demand is met with the additional thermal capacity provided by an auxiliary, gas fired ‘peaking’ boiler.

The economics of CHP mean that, whilst an income stream is obtained for all the power generated, this is only economically viable when there is sufficient demand for cogenerated heat. The key factor in the profitability of CHP is the efficient use of both electrical and thermal outputs by minimising the rejection of excess heat. ***Box 3*** shows how profit varies as heat demand rises, with a constant output of thermal and electrical power. Waste heat and the use of the peaking boiler also reduce profitability. Furthermore, profitability is enhanced if power is sold at the higher price obtained from direct sales to customers, currently only possible with a private wire arrangement, as opposed to exported to the grid and sold to a utility or TPI.

Box 3

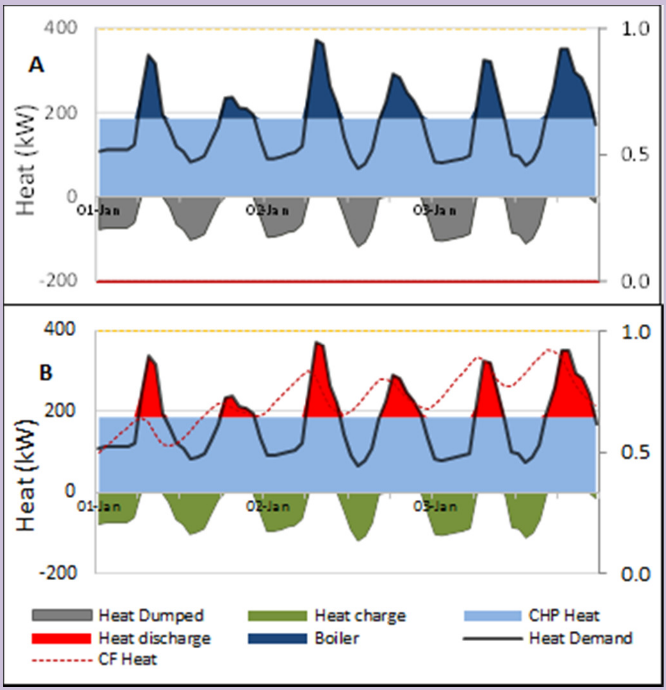
If a 100 kW CHP system runs continuously for an hour it generates 100kWh of power and 175kWh of heat. This chart shows the profit or loss as a function of the heat demand during the hour, and the contributions to the expenditure and income streams (it is assumed half the power output is exported to the grid, and half is sold directly to customers). At low heat demand, a large proportion of the heat is wasted (hashed area), at higher heat demand heat sales increase, but past 175kWh, the peaking boiler has to be switched on which generates less profits than the CHP.



Thermal storage can play a valuable role in reducing waste (rejected heat), balancing the diurnal demand, thus allowing the system to remain on full power, even during periods of lower demand. ***Box 4*** demonstrates a CHP system sized above the base load. Thermal storage can drastically minimise wasted heat, and reduce the use of a peaking boiler. Keeping the engine going and maximising heat and power usage also maximises carbon savings and makes maximum use of the generation asset.

Box 4 **CHP Storage and Demand Side Management**

A CHP system sized above the base load running continuously can generate a lot of income for power, but excess heat is rejected (chart A)



Storage can be used instead of rejecting heat, and this can be used later to satisfy peak demand. In chart B the storage provides enough capacity, shown by the capacity factor (CF) curve, so there has been no need for the peaking boiler, thus increasing the profitability of system.

Simulation of our notional 100-dwelling community's aggregated 1-minute time step loads shows that the optimum size of the community CHP platform increases with space heating load, from 30kW$_{e}$ for a 'low carbon' thermally efficient apartment block, to 70kW$_{e}$ for the 'mid efficiency' retrofit terrace, and 120 kW$_{e}$ for 'standard' L1A detached dwellings. This outcome reflects the higher heat revenues achieved. It also includes electricity sold to the community at retail tariffs via a 'private wire' arrangement, with a proportion exported to the grid via a commercial power purchase agreement (PPA). As will be discussed later, there are at present regulatory barriers to such an arrangement.

Results of the IRR analysis for this scenario are shown in Figure 7. The analysis illustrates the sensitivity of the financial outcomes to capital costs, especially for very high storage capacities which can account for a significant proportion of project capital costs. It should be noted however that large thermal stores with electric heating could be justified if sufficient added value is obtained from ancillary markets such as demand turn up services.

For lower storage volumes, a significant increase in IRR is evident for total storage capacities of around 300-400kWh (3-4kWh per dwelling). For example, in the case of the low carbon apartment configuration, IRR increases by up to 7.5%. Note that proportional increases in IRR due to the addition of thermal storage are not as significant for the minimum standard L1A configuration.

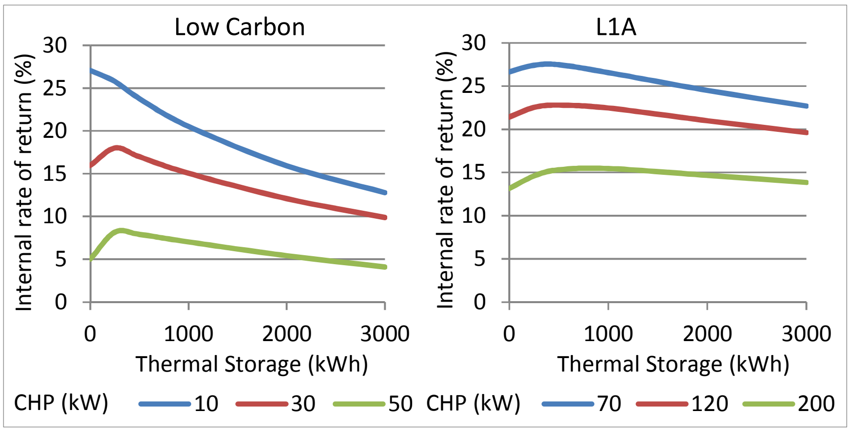
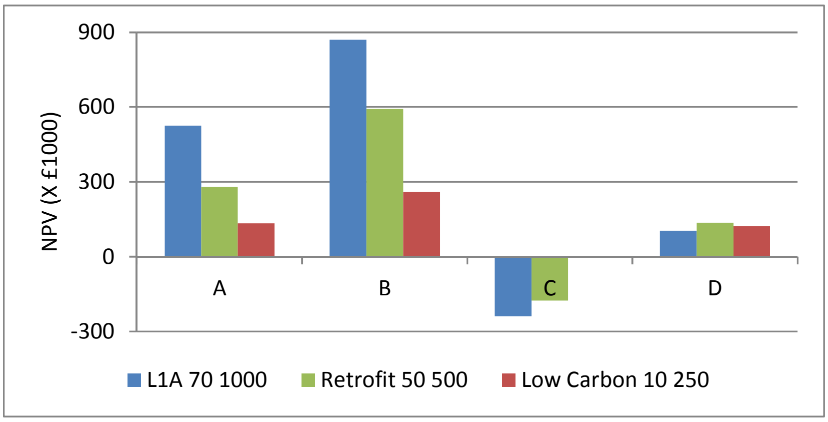


Figure 7 IRR for CHP systems as a function of storage capacity for low carbon and L1A buildings. Storage costs can be up to 40% of the capital cost

In absolute terms, IRR also depends on a number of additional capital costs, especially those for heat distribution infrastructure. This is particularly evident in the case of relatively low density detached dwellings in comparison to higher density apartment block scenarios.

Note also that profitability is also influenced by the magnitude of revenue accruing from community electricity sales. Although currently feasible in commercial or industrial supply contexts, at present regulatory barriers exist for retail CHP electricity sales in domestic settings, and this will need to be addressed to realise the full value of direct electricity to community customers. One option is to utilise an ‘opt-in’ or ‘opt-out’ mechanism in order to provide the required levels of consumer protection. Alternatively, the prospective advent of ‘peer-to-peer’ markets that include equitable cost-reflective use-of-system costs offers an alternative route to improved project viability.



Scenario	With heat network costs	Sale to grid or community
A	No	Grid
B	No	Community
C	Yes	Grid
D	Yes	Community

Figure 8 NPV for CHP and thermal storage scenarios

Figure 8 shows the impact on project viability of inclusion of heat network capital costs and whether private-wire retail sales of co-generated electricity are possible.

As well as generating extra revenue by reducing the use of a peaking boiler, the carbon savings made by the use of storage ranges from 4 to 6% (see Figure 9). This is primarily the result of reduced peaking boiler load factors, enhanced system flexibility in terms of demand matching and improved operational efficiency.

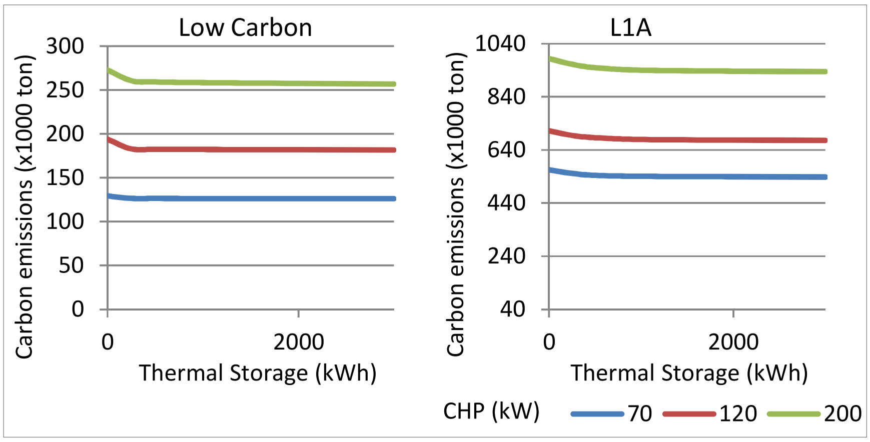


Figure 9 CO$_2$ emission savings for CHP systems as a function of storage capacity for low carbon and L1A buildings

In terms of annual profit resulting from the above factors along with reductions in rejected heat), thermal storage provides a financial advantage for the low carbon apartment block (£2100/15%) and standard L1A detached dwelling (£6300/12%) cases respectively. Thermal stores above about 400kWh for the low carbon apartments provide little further financial benefit in terms of annual profit, whereas for the L1A detached dwellings this rises to about 1000kWh.

Figure 10 shows annual profits from the sale of heat and power at two levels of annual load (high thermal efficiency apartment and L1A detached houses).

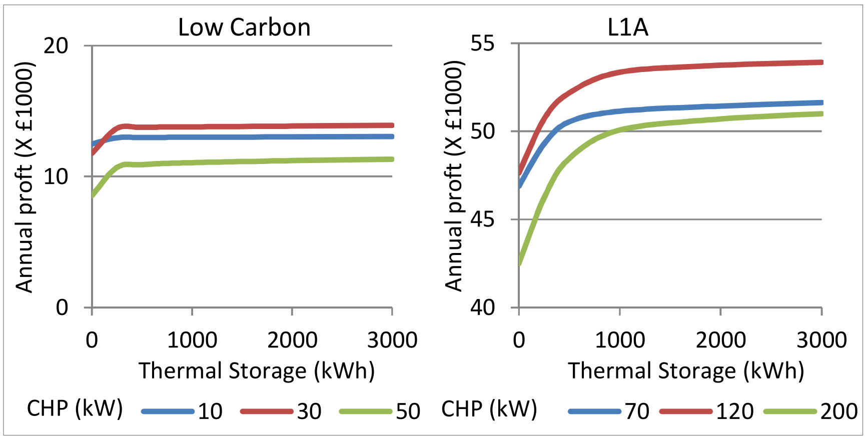


Figure 10 Annual profit for CHP systems as a function of storage capacity for low carbon and L1A buildings

4.2.3.CHP with Thermal Storage: Sensitivity and Monte Carlo Analysis

Figure 11 shows a sensitivity analysis carried out for an apartment block configuration of CHP with thermal storage and with (a) 'standard' L1A and (b) 'low carbon' fabric efficiencies respectively. For both cases, the greatest sensitivities with regards investment returns lie with gas cost, electricity and heat sale tariffs. A gas price increase of 50% results in a negative NPV in both cases. For the standard L1A case, decreases in both heat and power sale prices are also sensitive parameters, with around a 40% decrease in both resulting in a projected negative NPV. For the 'low carbon' case (a) the lower relative contribution of heat sales to project income, means that a given electricity sale tariff reduction has a significantly greater impact on profitability. This is due to the lower space heating demand (and thus lower proportional heat sales) resulting from a more efficient thermal fabric in case (b). Note also that both CHP and boiler efficiencies are more sensitive parameters for the 'standard' L1A case, suggesting an increased risk that the impacts on profitability of non-ideal plant operation (such as rapid cycling) could be significant in this case. Finally, it should be noted that for both cases, variations in baseline capital costs do not represent the key risk in such projects. Rather, it is variations in variable costs (especially feedstock fuel and energy sale tariffs) and plant efficiency that are critical. Note that sensitivities with regards IRR are similar to those seen for NPV in fig. 12.

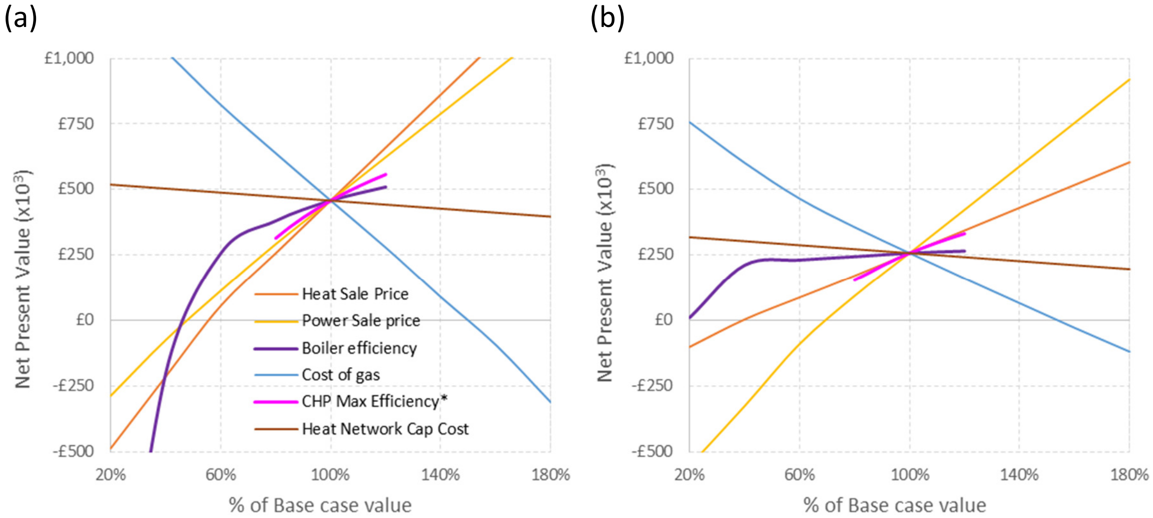
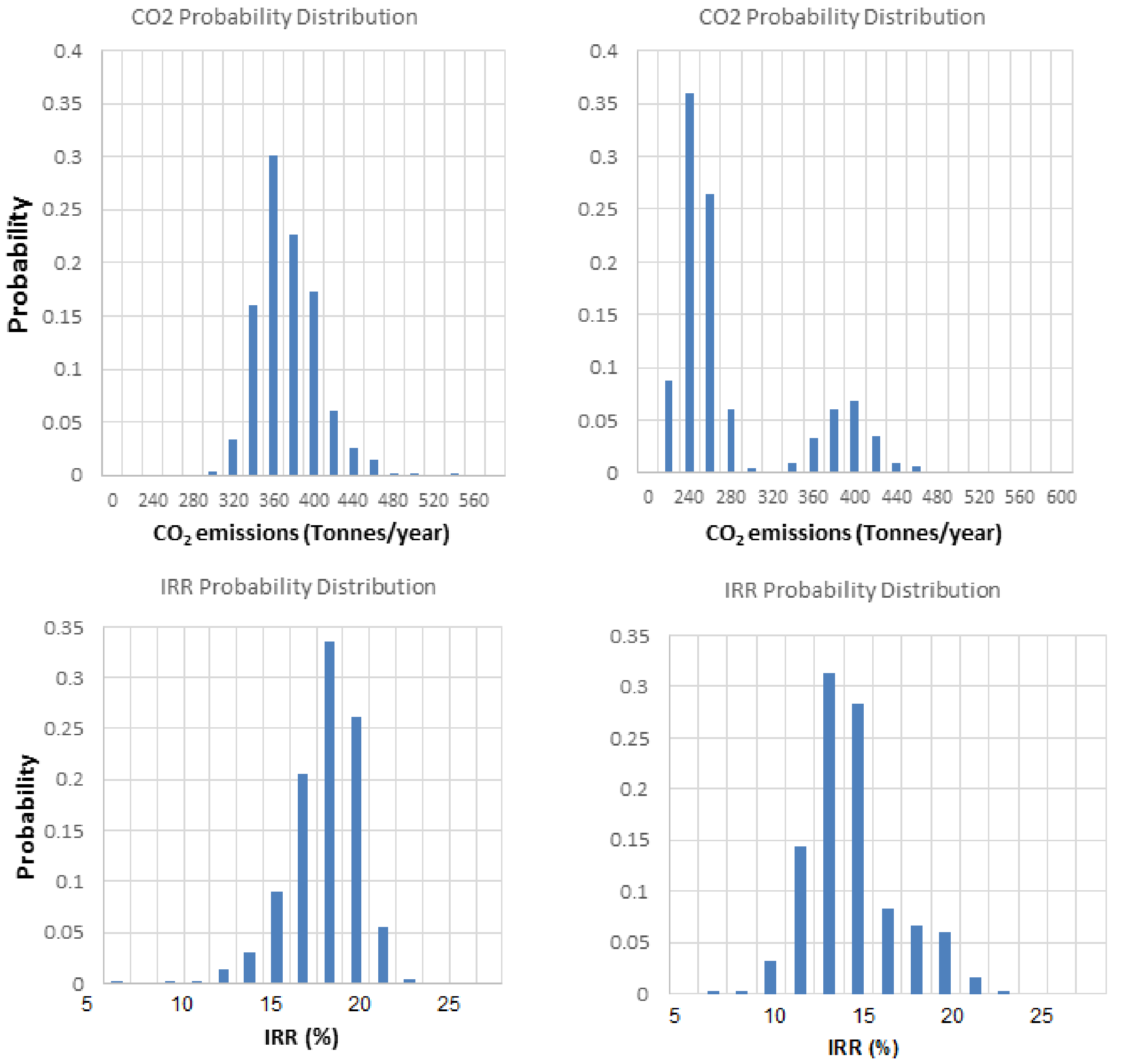


Figure 11 Sensitivity analysis for an apartment block configuration of CHP with thermal storage with (a) ‘standard’ L1A and (b) ‘low carbon’ fabric efficiencies.

Monte Carlo methods are commonly used in project financial analysis where uncertainties of specific input variables is high and the risk associated with this uncertainty needs to be described quantitatively to assess feasibility. Figure 12 shows the results of applying probability distribution functions (PDFs) to two key input variables to represent their real-life operational characteristics. Based on empirical studies, a mean boiler efficiency of around 80%,% is assumed, with variations in boiler efficiency are described by a Weibull function which includes the risk of sub-optimal boiler design, installation and/or control (Rowley et al. 2015). CHP performance is modelled using a non-linear load efficiency curve, and a normal distribution is used to represent the potential deviation in efficiency from the standard manufacturers’ lab-tested efficiency. For this example, Figure 12 shows a 10,000 iteration Monte Carlo- analysis for CO_2 emission and IRR outcomes respectively, given these CHP part-load and gas boiler cycling-related efficiency variations for both small-scale CHP and peaking boiler plant.

The results illustrate the uncertainty of project outcomes in the form of probability distributions, and reflect the empirically based ranges of plant operational characteristics described above, rather than manufacturers’ performance benchmarks, which often tend to be overly optimistic. Note that the results enable the level of confidence in the results obtained under specific uncertainty to be expressed. For example, for the ‘standard’ L1A fabric case, a mean IRR of 16.5% is predicted with a standard deviation of ±1.9%. Alternatively, this result means that there is a 68% probability of the investment achieving an IRR of between 14.5% and 18.5%. In these cases, given that maximum returns relate to the most efficient operation of the CHP plant, reduction of peaking boiler load factors and imported electricity volumes, there is a correlation between increased investment return and CO_2 reductions. This correlation would be increased if the value of carbon reductions arising from system operation is monetised (BEIS, 2017).


CO2 Probability Distribution

CO2 Probability Distribution

IRR Probability Distribution

IRR Probability Distribution

Figure 12 Monte Carlo outputs for (a) 200kW CHP - L1A Building fabric – 300kWh Thermal Store; (b) 30kW CHP – Low Carbon – 300kWh Thermal Store

4.2.4. Ground Source Heat Pump with Thermal Storage

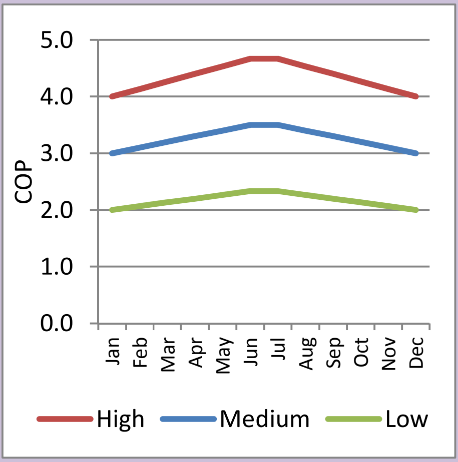
Ground source heat pumps represent a relatively high capital outlay for community heating with a typical costs ranging from £1200 to £2000 per kW thermal output capacity (Energyagency.org.uk, 2017). However, as an electrically driven heat generation technology they offer a number of potential advantages:

- Heat pumps can be implemented in communities without access to the gas network
- Electrical to thermal conversion efficiencies in excess of 400% are possible for well designed and installed systems

- They are consistent with the selective electrification of domestic heat (DECC, 2013)[1], and potentially can deliver significant future greenhouse gas emission reductions as the carbon intensity of grid supplied electricity reduces.

Box 5 **Heat Pump Efficiencies**

An efficient heat pump requires a high capacity high temperature source for the thermal collector. Bore holes and trenches can provide an input delivery temperature of 11 degrees, and some stakeholders are utilising high temperature water such as provided by sewerage systems, or flooded disused mine works.



Three nominal COP value ranges have been used to represent low and high quality ground based thermal collector, since they are ground sourced they do not exhibit strong diurnal temperature variations, but do show a season variation due to warmer summer ground temperatures and therefore higher COP values (Naiker and Rees, 2011).

Ordinarily, the heat pump would be configured to meet the heat demand supported by thermal buffer technology to minimise inefficient cycling of compressors. Thus there is no immediate value in larger scale thermal storage unless electricity price signals permit the realisation of load shifting (***Box 6***).

However, in cases where time of use tariffs apply (and dependant on the thermal load and CoP), thermal storage can make a considerable contribution to the profit margin for GSHP technology with increasing revenue realised as storage capacity increase (Figure 13). In the case of low carbon buildings, the profit margin levels off at large aggregated thermal storage capacities above 3000kWh, but for relatively high thermal demand standard L1A detached houses storage continues to yield increasing revenues above 3000kWh of community-based storage.

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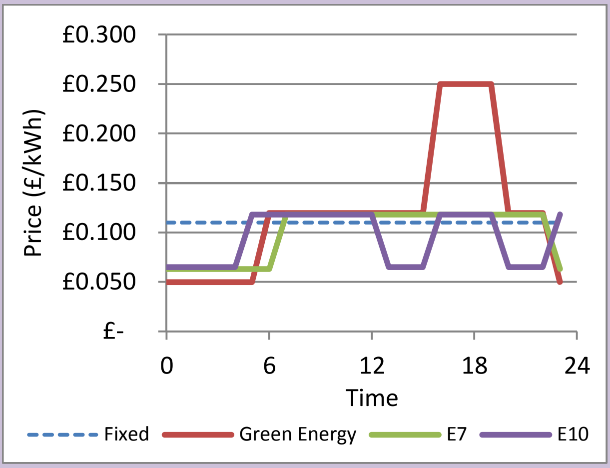
[1] The policy was developed under the previous Conservative-LibDem coalition under Ed Davey but is still displayed on the Government Website.

Box 6 Price signals for electric heat

For consumers price signals in the form of time-of-use tariffs incentivise a shift in demand. These price signals allow the evaluation of the value stream created by storage in conjunction with electric heating technologies.



Several tariffs have been evaluated; here we show results using Economy-7, which, although a domestic tariff, is similar to some commercial offerings which are coming in to the market place. The use of such price signals requires the development of control algorithms to charge the storage during cheap rates, and discharge during expensive rates.

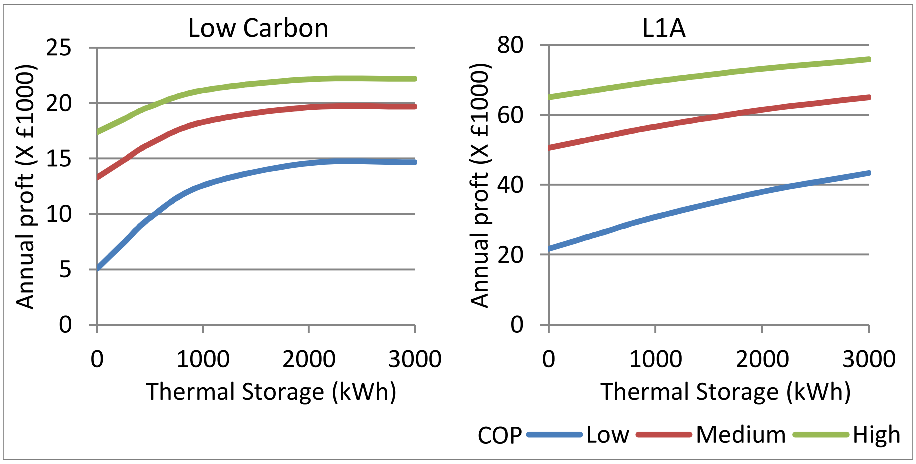


Figure 13 Annual profit for GSHP systems as a function of storage capacity for low carbon and L1A buildings

The IRR indicator shows increasing rates of return as storage capacity increases (Figure 14), levelling off for all COP levels at about 1500kWh for low carbon dwellings.

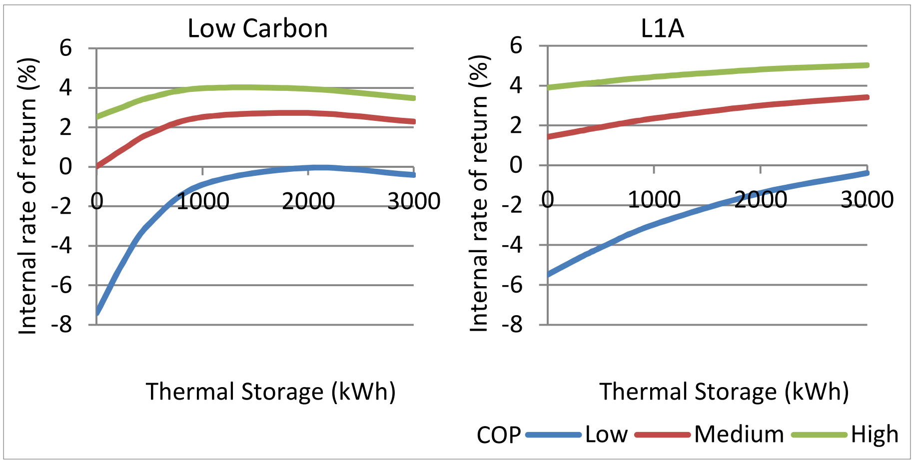


Figure 14 IRR for GSHP systems as a function of storage capacity for low carbon and L1A buildings.

4.3. Energy Storage and Ancillary Services

The range of ancillary services currently available is detailed in Section 6.2.1 (Page 68) where aggregators are introduced as a route to enabling community scale generating assets and flexible loads to access these services. It is worth illustrating here their potential for achieving additional revenue and this is demonstrated in this section with the most valuable service, Firm Frequency Response (FFR) (***Box 7***).

In order for a heating technology to maximise income from FFR availability, control algorithms are required to optimise thermal store charge state to provide headroom for increasing the load over and above the thermal demand, and stored energy to be able to reduce the load whilst still able to meet the thermal demand.

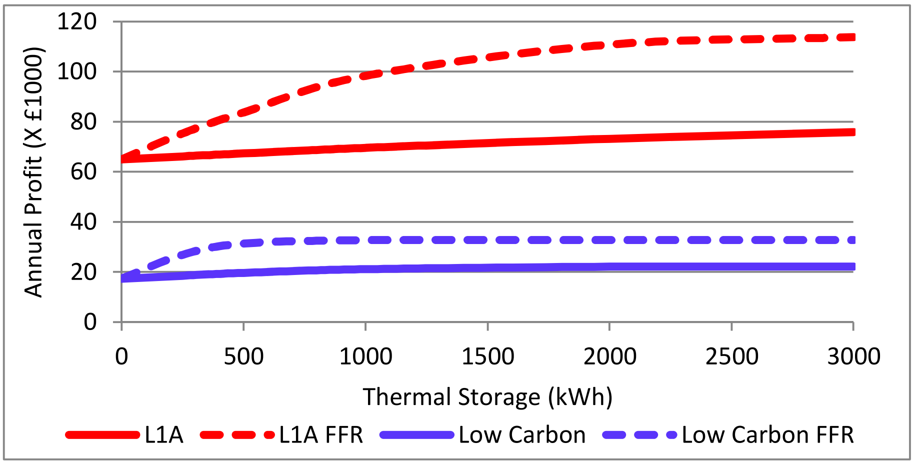


Figure 15 Annual profits with and without FFR participation

Figure 15 shows the extra value delivered by FFR participation as storage capacity increases. Using capacity duration curves for low and high availability (see ***Box 7***) this has been calculated for GSHP technology at the high COP rating (see Section 4.2.4) providing heat for Low Carbon flats and L1A detached dwellings. This includes an estimated 15% share in the ancillary market service fees retained by the aggregator.

For well performing systems, additional revenue streams approaching £380 per dwelling for the L1A detached dwellings and £120 per dwelling for low carbon flats are predicted with high COP heat pumps. This includes a reduction in the benefit of ToU tariff utilisation, lost due to greater emphasis on FFR availability. These represent an increase in predicted annual profits by as much as 60% for a high COP system. It should be noted however, that these results are sensitive to operational factors (such as sub-optimal control or user intervention) that could significantly reduce financial outcomes. Such an increase in predicted annual profits has a significant impact on the IRR. Without FFR due to the high CAPEX for GSHP IRR is generally below 4% whereas with FFR an IRR of 9 or 10% can potentially be realised (Figure 16)

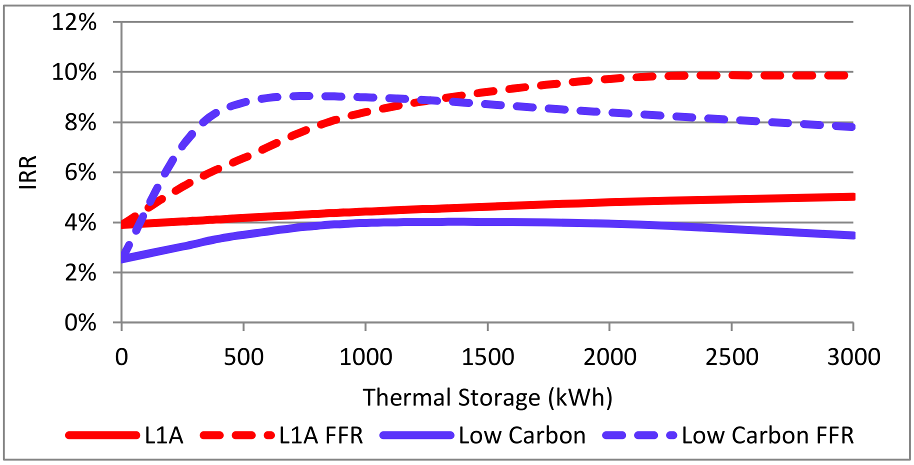
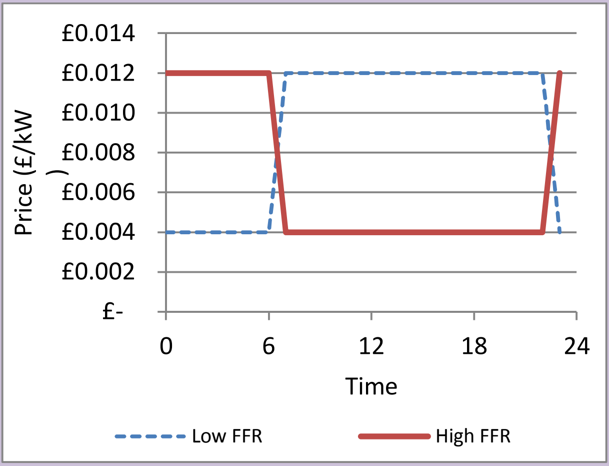


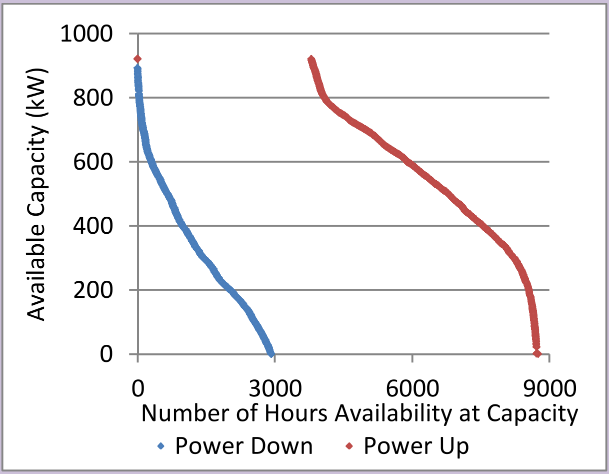
Figure 16 IRR with and without FFR participation for the L1A and Low Carbon thermal load scenarios

Box 7 FFR rates

An aggregator may, for example, offer £12 and £4 per MW/hour for load reduction/increased generation and load increase/decreased generation respectively during the day (7:00 to 23:00). During the night these prices become £4 and £12 respectively.



Availability for low (demand reduction) and high (load upturn) FFR services are facilitated by storage; a charged store permits low availability and storage and heat generating headroom permits high availability. This is demonstrated using a capacity duration curve to show how many hours at or above a particular capacity are available.



The aggregator needs direct remote access to the GSHP sub-control system in order to operate individual compressors directly; such innovations are already operating in the market.

4.4. Electrical Storage for Grid Reinforcement Avoidance

Across the UK, there are an increasing number of areas where distribution networks are becoming constrained with regards the possibility for new connections without grid reinforcement. This can potentially result in high connection and/or network reinforcement costs. In this section, battery storage technology is analysed as a potential alternative to traditional network reinforcement. Specifically, the analysis utilises the aggregated power demand at 1 minute time steps for our case study community of 100 detached dwellings, using the same simulation methodology as applied in previous sections. The peak demand management capabilities of battery storage of varying capacities are evaluated, together with the techno-economic characteristics of battery storage as a mitigation for network reinforcement, using industry benchmark capital and variable cost data.

In terms of peak load management, battery storage will need to cope with the most extreme periods in terms of community power load; this period was identified from simulated data and used to calculate the battery size needed at different levels of connection constraint.

Figure 17 shows simulated 1-minute time step load profiles for maximum, hourly average and median demand days during December, based on the appliance usage and occupancy diversity characteristics described above in section 4.2, page 26. The data shows the value of relatively high resolution (1 minute) time step simulation in contrast to using hourly average data in terms of identifying power spikes.

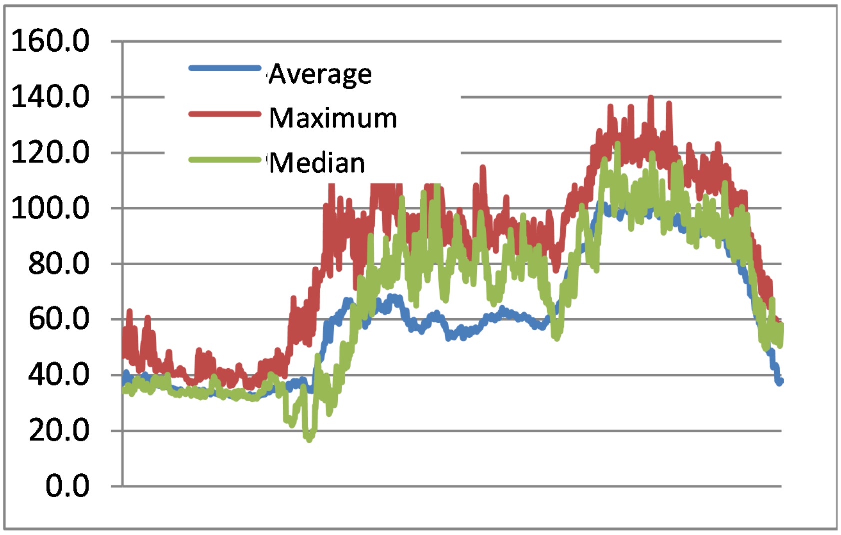


Figure 17 Maximum, median and average electrical demand profiles for 100 dwellings during December.

Table 11 below shows the required battery storage capacities needed to limit load flow (in kW/min) on the highest peak demand day. The maximum network load flow limits at the point of connection were 40, 60, 80 and 100kW respectively, compared with a baseline aggregate evening demand peak of just over 140kW (fig. 18). It should be noted that this analysis does not take into account increases in future demand that may arise from increasing ownership of electric vehicles or for communities that include a high proportion of electric space and/or domestic hot water heating. Such cases would imply that even with an optimal community-scale demand management approach, higher capacities of energy storage would probably be required in order to attain a given aggregate maximum load at the transformer.

Table 11 Battery sizes required for given connection constraints.

Constraint	Battery size needed to deal with demand above constraint (kWh)	Charge whenever demand is less than constraint	Charge during lowest time of use tariff times (12pm-7am)
100kW	21	Possible	Possible
80kW	90	Possible	Possible
60kW	245	Possible	Not Possible
40kW	520	Not Possible	Not Possible

The relatively low battery capacity needed to operate within a 100kW total connection constraint is notable, representing approximately 0.21kWh per dwelling. The results also indicate that to operate within a total 40kW load limit, a battery capacity of around 5.2kWh per dwelling is required. This is comparable with currently available domestic scale battery storage units which typically range from 2.5-8kWh. This does not suggest that distributed dwelling-based storage is optimal for this scenario; rather, centralised storage co-located at the point of connection is probably optimal given economies of scale and ease of control. It should also be noted that to operate within a peak load constraint limit below 80kW, some form of additional on-site demand-side management approach would be required, as it is not possible to achieve the required battery state-of-charge for subsequent peak load management using grid supplied energy.

In terms of the financial viability of battery-mitigated grid reinforcement, a base case involving traditional grid reinforcement based on a DNO 500kW 11kv/400v substation costing methodology was used (Scottish Power Networks, 2008). Table 12 shows the results for a battery charging at night using the lowest time of use tariff and then discharging for sale to the community at a higher rate. This outcome assumes that the local distribution network feeder has sufficient capacity to upgrade the transformer at the point of connection. However, given projected increases in penetration of technologies such as heat pumps and electric vehicles, it may increasingly be the case that suburban medium and low voltage feeders themselves (rather than individual transformers) reach their load capacity (Navarro-Espinosa & Mancarella), which suggests another potential advantage for battery-based network upgrade management. Finally, it should be noted that these results do not include potential income derived from providing additional ancillary services, which as previously discussed, could help deliver financial viability for projects which otherwise would not be profitable solely on the basis of grid reinforcement mitigation considerations.

Table 12 Economics of battery storage for mitigation of grid reinforcement

	Demand only				
Constraint	Amount of charge needed (kWh)	Import cost (£)	Energy sale revenue (£)	Profit over 1 year	20 years Net Present Value (£)
100kW	26.24	£794.74	£1,436.28	£641.54	-£669.28
80kW	197.95	£5,996.90	£10,837.76	£4,840.87	-£3182.66
Import rate (00:00 to 07:00)		£0.083 per kWh			
Sale tariff to the community		£0.015 per kWh			
Cost for Li-ion batteries		£500 per kWh			

4.5. Battery Storage with PV

The potential for domestic scale PV technology with battery systems in the UK was analysed in this study, assuming data for Li-Ion battery costs from market projections for the year 2020, which has been cited as a point at which break-even for PV/battery storage may be approached where aggregated (rather than individual household) storage is installed (Reid et al. 2015). However, the best PV/storage configuration for community-scale projects is related to a number of project-specific conditions, including demand profiles and housing design and layout, as described in more detail in section 5.3.

If the primary focus is on PV energy time-shift (also referred to as PV self-consumption), previous research has shown that transformer co-location (or at least aggregation of storage to supply groups of dwellings) offers advantages in terms of economies of scale, control, balance of plant and maintenance (Parra et al, 2015; Parra et al, 2017). On the other hand, in the absence of formalised community energy supply and/or ownership agreement, installing a battery in a single dwelling is relatively straightforward in terms of the transaction with the individual household consumer. For a battery installed next to a transformer, DSO perspectives and objectives also need to be considered, and currently there is significant regulatory uncertainty with regards aggregated community storage. In Germany for example, taxes and levies need to be paid on electricity feeding in to the national grid by CES systems since it assumed that the consumer is playing the role of a distributor/utility.

For the present study, the analysis utilised 1-minute time-series simulations based on the aforementioned CREST demand and PV generation model, together with financial parameters and round-trip battery efficiency and degradation data used in previous research (BEIS 2016; Hoppmann et al, 2014). Two scenarios are used in the analysis (Table 713), representative of relatively high and low inflation contexts respectively.

Table 13 Battery storage scenarios

Scenarios	Export tariff	Import Tariff	Inflation	Battery Price
1	0.05 £/kWh	0.15 £/kWh	2%	250 £/kWh
2	0.03 £/kWh	0.20 £/kWh	4%	250 £/kWh

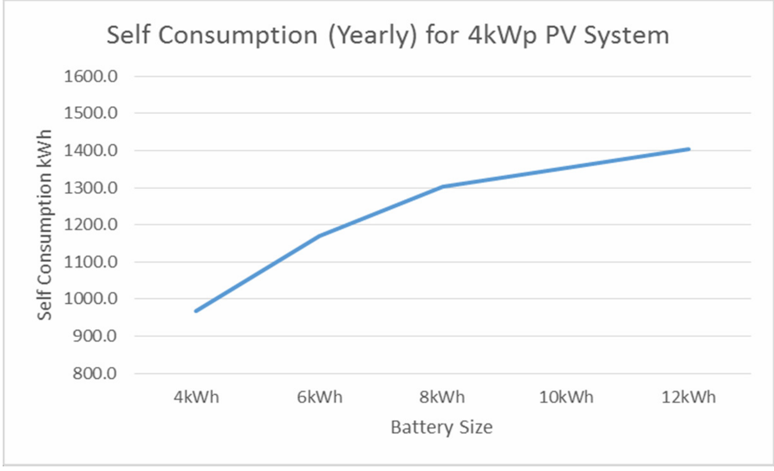


Figure 18: Self Consumption with varying battery sizes for 4 kWp PV system

The analysis uses a baseline PV-only scenario, and measured increases in the level of PV self-consumption, which results in money saved due to (a) reduced export of PV energy at a low export tariff and (b) energy provided by the battery that otherwise would be imported from the grid if the battery were not present. Note that for clarity the analysis does not include household energy arbitrage, whereby the battery is used to store energy during cheaper tariff periods for use later during high tariff times. PV array sizes of 2kWp and 4kWp were evaluated, representative of the lower and upper bounds of current UK domestic PV installations respectively. Figure 18 shows results obtained from high time resolution modelling of self-consumption values assuming a 4kWp PV array and varying battery sizes, showing proportionally lower self-consumption ratios in proportion to battery capacity as battery size increases. The results in Table 14 indicate that scenario 1 (a relatively low inflation case) does not show financial viability across all system configurations. The results for scenario 2 (a relatively high inflation case) indicate economic viability is achieved across all cases except for a relatively large battery size of 12kWh. However, note that this extra capacity may be useful where household time-of-use energy arbitrage is utilised, or for the provision of network ancillary services.

Table 14 Scenario parameters used in analysis

2kWp PV			
Scenario	2kWh	4kWh	6kWh
1	92	-337	-808
2	765	467	129

4kWp PV					
Scenario	4kWh	6kWh	8kWh	10kWh	12kWh
1	-105	-447	-890	-1401	-1912
2	980	858	566	107	-352

For both PV system sizes evaluated here, a ratio of battery energy capacity to PV rated output of around 1kWh/kWp is indicated.

5. The Energy Storage Sector: Technology Review

In this section a technology review of the energy storage sector is presented, with a focus on systems and architectures that are relevant to community-scale applications. Both electrical and thermal storage technologies are explored in terms of operational characteristics and costs, and prospects for storage cost reductions are discussed. Technologies that are complementary to community-scale storage are described, including ICT platforms designed to facilitate advanced control and transactional functions, and the relevance of increased penetration of electric vehicles is briefly explored.

5.1. Electricity Storage

Currently available electrical storage technologies are summarised here in terms of (a) their ability to supply power and energy to one or more buildings and (b) their capacity to provide services to specific markets such as network ancillary services. It should be noted that storage performance characteristics (including round-trip efficiency, costs, lifetimes and degradation) should be assessed in the context of the target markets for which the asset is intended to operate. For example, a storage technology selected primarily to perform a daily cycling energy arbitrage function at ½ hourly intervals may differ from one selected primarily to provide a service to the FFR market, which may require rapid sub-second response and high power/low energy characteristics. In this context, the nature of various storage technologies is described in Table 15.

Table 15 Technical and economic characteristics of various energy storage technologies (source ECOFYS, 2014).

Technology	Maturity	Installed Cost ($/kW)	Installed Cost ($/kWh)	Efficiency	Cycle Limit	Response Time
Lead Acid Batteries	Demo to Mature	950-5,800	350-2,800	75-90%	2,200->100,000	Milliseconds
Lithium-ion Batteries	Demo to Mature	1,085-4,100	600-4,200	87-94%	4,500->100,000	Milliseconds
Flow Batteries (Vanadium Redox)	Develop to Demo	3,000-3,700	620-830	65-75%	>10,000	Milliseconds
Flow Batteries (Zinc Bromide)	Demo to Deploy	1,450-2,420	290-1,350	60-65%	>10,000	Milliseconds
Sodium Sulfur (NAS)	Demo to Deploy	3,100-4,000	445-555	75%	4,500	Milliseconds
Power to Gas	Demo	1,370-2,740	NA	30-45%	No	10 Minutes
Capacitor	Develop to Demo	-	-	90-94%	No	Milliseconds
SMES (Superconducting Magnetic Energy Storage)	Develop to demo	-	-	95%	No	Instantaneous
Flywheels	Deployed to Mature	1,950-2,200	390-430	85-87%	>100,000	Instantaneous
Compressed Air (Above-ground)	Demo to Deploy	1,950-2,150	390-430	60-70%	No	Seconds to Minutes
High Temperature Thermal Storage	Demo to Deploy	NA	NA	-30%	No	Storing: Seconds Generating: Minutes
Pumped Hydro	Mature	1,500-2,700	138-338	80–82%	No	Seconds to Minutes
Compressed Air (Underground)	Demo to Mature	960-1,250	60-150	60-70%	No	Seconds to Minutes

Energy storage and power density considerations can be of significant relevance in specific contexts, for example, where space constraints apply, or where there is an electric vehicle charging or grid support requirement. With average floor area values for modern UK dwellings below 100m^2 (and in higher density contexts as low as 50m^{2}-per dwelling), bulky storage units could represent an issue relating to the proportion of dwelling space occupied by the storage technology. Indeed, this applies to both electrical and domestic scale thermal storage. Heavy storage modules (such as lead-acid technologies) may be constraining in some retrofit contexts, for example where the preferred storage location is in a loft void, and thus could require structural reinforcement. Careful selection of storage technologies, together with consideration of storage capacity in relation to desired service provision, as well as the location of its integration within specific building contexts is a requirement in these contexts. Figure 19 shows weight and volume energy densities for various storage technologies, and indicates potential candidates for single dwellings, space-constrained or high power and/or energy requirement contexts vs. aggregated whole-community-scale contexts with lesser space constraint issues (for example, a dedicated energy centre at the point of grid connection in a less dense urban context).

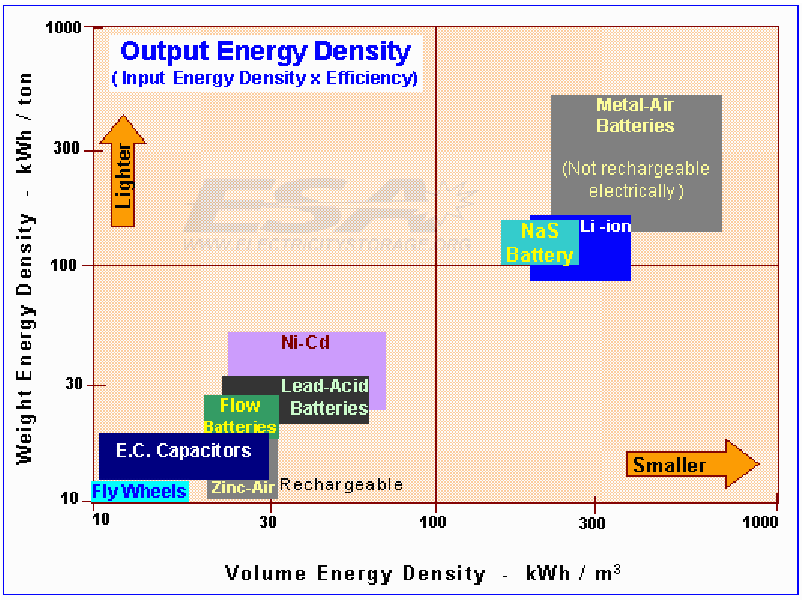


Figure 19 Weight and energy densities of some storage technologies (ECOFYS, 2014))

Similarly, Figure 20 shows rated power outputs, maximum energy content and discharge times of various storage technologies. This indicates that although Li Ion battery storage may represent the majority of the building-sector storage market globally at the present time, this does not preclude the application of alternative technology platforms in future as markets such as fast response or capacity services becomes accessible, and corresponding storage requirements for rapid discharge, high power and high energy performance become clearer. For example, flow batteries may represent a suitable technology for mid and long term community energy applications because of their specific technology characteristics. Hydrogen is also considered promising because of its high specific energy and volumetric densities, together with the potential to decouple power and energy ratings. Hybrid systems may offer advantages for energy and power flow management within a community in terms of both peak power requirement (kW) over a few minutes, as well as having sufficient energy (kWh) to supply the community for a number of hours (Parra et al. 2017).

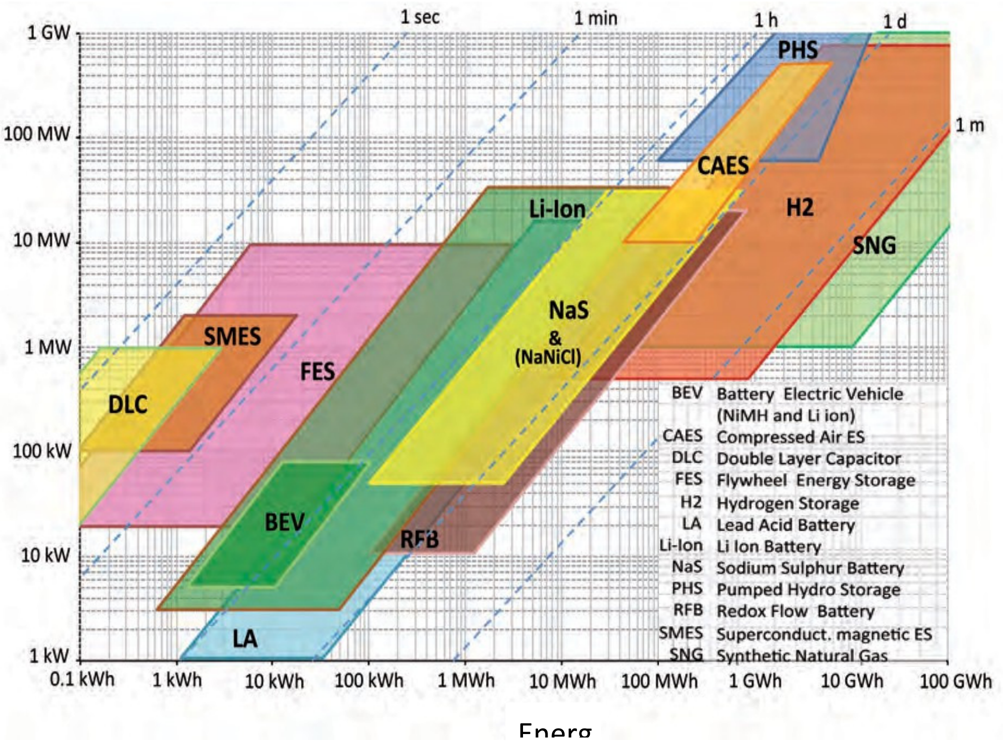


Figure 20 Rated power, energy content and discharge time of various Electrical Energy Storage technologies (from IEC, 2011).

5.2. Electricity Network Coupling Aspects

Given the potentially enhanced value that electrical storage can generate when they are highly utilized and multiple services are ‘stacked’ (RMI, 2015), the impact of various ‘balance of system’ aspects is worthy of consideration (See 6.1). For example, with regards to the coupling of electrical storage systems to the wider distribution network, there are a number of potential advantages associated with AC (as opposed to DC) coupled storage systems. These include ease of installation (especially in retrofit contexts), and the reduced impact on existing MCS certification or FIT revenues. AC systems can also potentially deliver greater consumer payback and flexibility using for example arbitrage or accessing ancillary services (see Section 6.2, page 67). Table 16 below summarises benefits and drawbacks for both AC and DC coupling approaches.

Table 16 Domestic Energy Storage System Installation Options

AC Coupled System **Energy Storage system is connected to the AC / mains side, typically by the consumer unit**	**DC Coupled System** **Energy Storage is connected to DC side of system, typically between Solar PV panels and the inverter**
Benefits	
• Easy add---on to new or existing solar independent of legacy system • Solar and Mains chargeable – access cheap night and smart tariffs or grid services benefits • Significantly better payback • Electrician skill only to install • UPS/Backup option (AC , DC loops) • Install Location choices	• New install or PV expert/MCS install check if suitable on existing • Typically cheaper as just batteries or DC switch apparatus • Potential off---grid or back---up use (but at loss of FIT payments) • DNO G83/59 process unlikely to be needed on retrofit install unless inverter change
Drawbacks	
• Slightly higher cost as includes extra inverter / power controls • Process – filing of G83 post install or G83/G59 pre if multiple or large • Typically needs current clamp or connection to meter, so located near consumer unit	• Battery efficiency losses reduce metered FITs • Unknown impact to existing MCS status or FIT risk • May invalidate inverter warranty or need bespoke inverter (Tesla) • No benefit from night or smart tariffs as no mains charge • Grid services availability highly dependent on PV yield so seasonally variable. • Not suitable for micro---inverters • Location restrictions – e.g. next to inverter, clamps or meters needed

5.3. Community-scale Storage System Architectures

This analysis has indicated the considerable range of value streams relevant to CES. However, successfully accessing these value streams depends to a considerable extent upon the location of the storage assets, ranging from highly distributed, ‘behind the meter’ storage to more centralised storage at transmission or distribution transformer levels respectively. Figure 21 shows these value streams from the perspectives of end-users, utilities and TSOs/DNOs respectively, and illustrates that distributed community scale storage can in theory offer the widest range of benefits, provided specific regulatory, technical, market and other barriers can be addressed. These benefits are discussed in greater detail in Section 6.2.

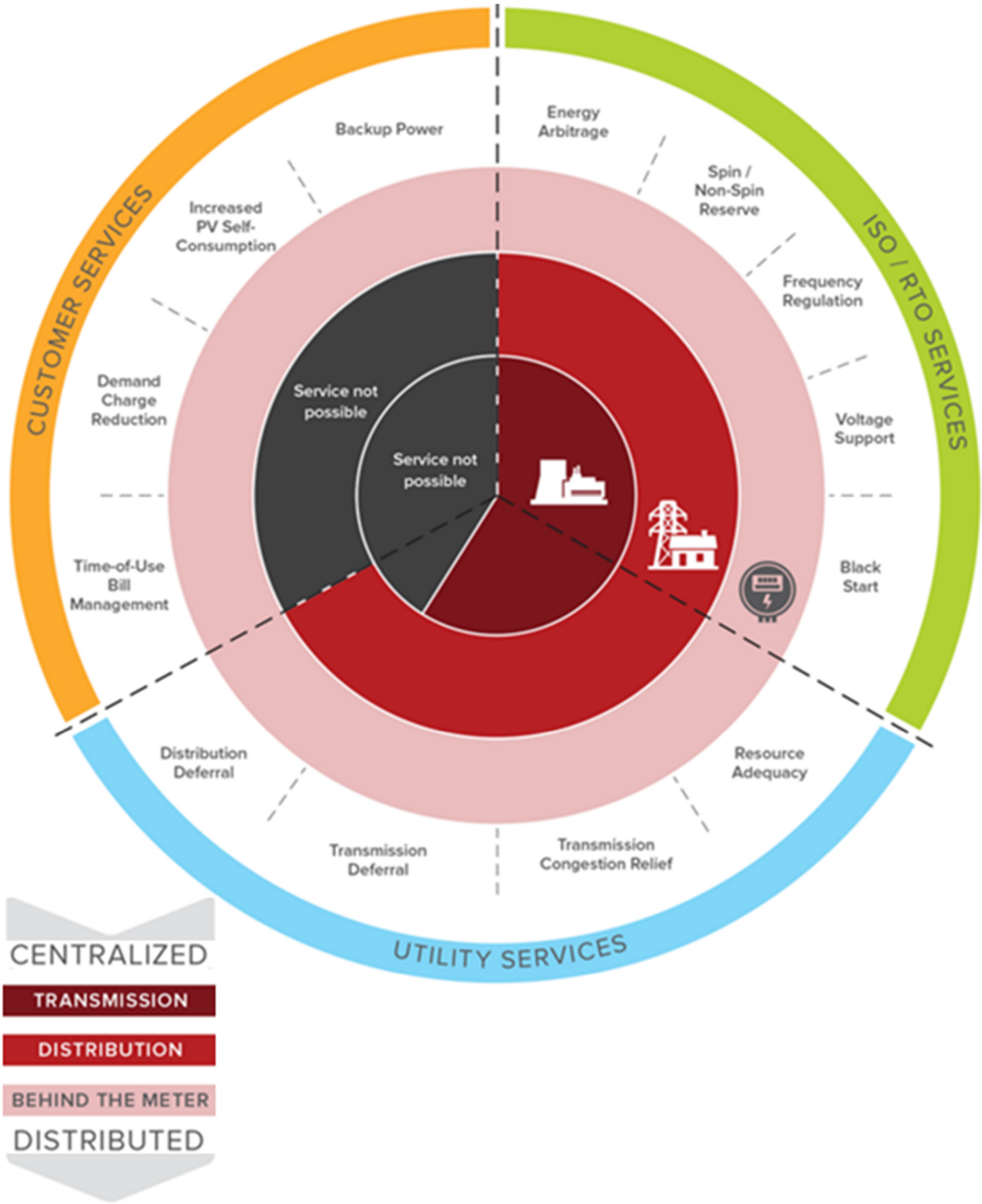


Figure 21 Potential value streams in relation to location of storage assets [RMI]

A community scale architecture, based on research studies and commercial offers available in more mature markets than the UK such as the USA (S&C, 2016; Arghandeh et al, 2014), can comprise a distributed energy management (DEM) system located in (or near) the community substation or control room. Performing a “master controller” function of one or more community energy storage (CES) units, the DEM constantly monitors the status of each CES unit and communicates regular condition reports to the control agent. In this way, the DEM can control groups or fleets of CES units, allowing their operation to be coordinated to facilitate higher-level services such as CES charge/discharge, peak shaving/load levelling, system-level ancillary services and renewable energy time shifting. Figure 22 illustrates the architecture of such a system. This architecture, with PV (if present) installed on individual household rooftops, but with storage aggregated at multi-household level or at the point of network connection, offers an alternative to individual household-based storage. Advantages of this approach include the leveraging of demand diversity across multiple households to improve battery utilisation and reduced complexity with regards aggregator control of the storage assets when providing service to the ancillary markets.

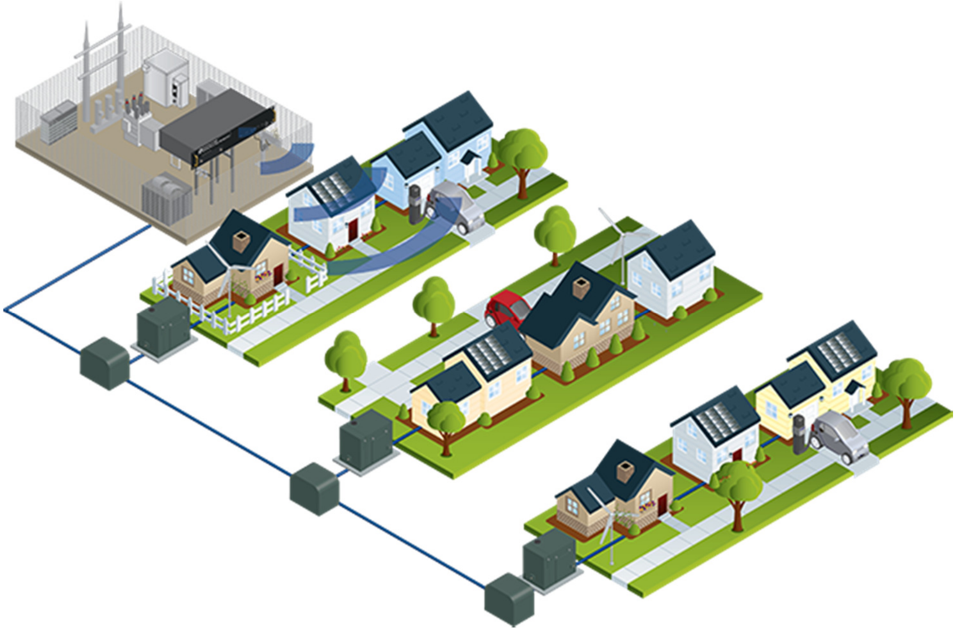


Figure 22 Candidate CES system architecture

5.4. ICT and Extended Platforms

Such CES architectures can also be integrated as part of an automated building energy management and efficiency strategy. These systems, which can be implemented for both individual or groups of buildings at community scale, include plant and appliance monitoring and control of specific loads, together with integral energy management of the storage systems themselves.

A number of system aggregators provide automatic control in order to optimise a large number of flexible generation and storage systems (including electric vehicles) to fulfil their ancillary service contracts with the TSO. Open source platforms are appearing in the UK market and ICT developers are able to develop algorithms to optimise revenue streams whilst still fulfilling local energy requirements. These can use machine learning or AI techniques to combining learnt consumption patterns, weather forecast prediction of loads and generation and occupancy data for example.

Accessing and optimising additional revenue streams can ensure that a community energy project may become more economically viable when coupled with storage.

5.5. Electric Vehicles & CES

The role of electric vehicles and associated infrastructure within the CES context is currently a focus of considerable research and development. The community action behind many community energy schemes, and the business models utilised, often align with the motivators and opportunities for the integration of electric vehicles, for example in related community transport schemes. There is also the potential for reducing the space and cost requirements for stationary storage by utilising EV-based storage to provide building energy and grid support services where possible, using V2G technology. The potential for such systems in terms of current EV & V2G platforms has been the focus of a recent collaborative project between CREST and CENEX. This indicated the potential future viability of such V2G approaches for ‘pool’ vehicle fleets, provided care is taken in the targeting of appropriate ancillary and related electricity markets (Gough et al. 2017).

5.6. Thermal Energy Storage

For community energy applications, three distinct forms of thermal energy storage are relevant namely sensible, latent and thermochemical technologies. Each of these has a different physical storage mechanism, described in Table 17.

Table 17 The three Forms of Thermal Energy Storage

Type	Description
Sensible	The storage (extraction) of thermal energy in (from) the thermal store results in a temperature increase (decrease) of the material; no other physical properties change apart from a possible accompanying volume change due to thermal expansion or contraction of the material. An example would be the heating of bricks in a night storage heater.
Latent	Latent heat, when stored in a material, results in no temperature change but instead changes the phase of the material e.g. solid to liquid; the energy is given back up when the reverse change occurs. An example would be the melting of ice or paraffin wax.
Thermochemical	Thermochemical storage occurs as the result of a chemical change involving the breaking of chemical bonds and the subsequent separation of components. An example of this would be storage of energy to dehydrate hydrated salts such as calcium hydroxide. The energy is recovered on the subsequent rehydration of the salt.

Sensible thermal energy storage has a long history in the UK energy system. 13.7m UK households are equipped with an average of 6kWh of thermal energy stores in the form of domestic hot water cylinders (EHS, 2010). A steady decline in the number of hot water cylinders has occurred as the number of dwellings with combination boilers, which deliver instantaneous hot water on demand requiring no storage, has increased to 37% in 2007 from just over 1% in 1991 (BRE, 2007). The space they formerly occupied has been lost in renovation work such as bathroom or bedroom refurbishments thus presenting a potential barrier to future deployment of storage (ERP, 2011).

Heated brick thermal storage forms the basis of the primary heating system of 7% of the UK building stock mainly flats. These are electrically heated primarily on the night-time Economy 7 tariff, demanding 23% of the GBs domestic electricity consumption (DECC, 2010). Less common is building design that intentionally uses the thermal mass of buildings themselves as thermal storage. Appropriate selection of context-specific energy technologies in combination with advanced building control approaches can facilitate demand response without impacting upon the internal conditions by utilizing the buildings' thermal mass. Recent research (Cabrol & Rowley, 2012) has shown that such an approach can enable effective utilization of Economy 7 or Economy 10 tariffs by air source heat pump units in domestic settings, especially when combined with floor-embedded phase change-based storage.

At the community scale, CHP plants which power district heating networks (DHN), can take advantage of large scale sensible heat stores to provide a short term balancing mediate the temporal mismatch between thermal and electrical power demand by time shifting heat for periods of a few hours (CityWest Homes, 2012). The oldest UK DHN in Pimlico, London, has been furnished with a 2300m^3 thermal store able to retain water heated to just below boiling point. The use of such thermal storage has the potential to reduce the dumping of heat or avoiding of curtailment (switching off) thus improving fuel efficiency, reducing carbon emissions and increasing revenues from electricity sales (Martin and Thornley, 2012). Currently only 7% of operational UK DHNs are equipped with a thermal store compared with virtually all networks in Denmark.

In contrast, inter-seasonal storage can make a significant contribution to winter heat loads using heat stored months earlier. These are generally lower temperature, using tanks, boreholes or aquifers in conjunction with heat pump technology, raising the delivery temperatures and the coefficient of performance (COP) (Eames et al, 2014). A solar thermal inter-seasonal storage system in Friedrichshafen, Germany, which supplies heat to 390 flats, achieved an annual solar fraction of 33% (Mangold, 2007).

Latent heat storage using phase change materials (PCM) is a rapidly emerging technology (Cunha and Eames, 2016). These operate at temperatures which may find practical application in domestic and non-domestic buildings for heating and cooling applications in the UK. Heat exchange technologies were also considered which integrate with water or air space heating applications. Whilst PCM can store higher energy densities over smaller temperature ranges when compared to sensible storage, poor thermal diffusion can seriously impair discharge rates. The technical advantage of PCM over sensible heat storage is that the charging and discharging temperature is set by the constant temperature of the phase change. Furthermore this can be tuned for particular applications using binary mixtures of organic materials (Liston et al, 2016).

Thermochemical storage can offer even higher energy densities delivering more compact systems and the spatial separation of chemical reagents ensures little energy losses during storage, and permits the possibility of long distance transport of stored thermal energy (Abedin and Rosen, 2011).

5.7. Comparison of Thermal Energy Storage Technologies

The three types of thermal energy storage (sensible, latent and thermochemical) require quite different technological approaches to implement them at scale, operating at different temperatures and using materials of very different thermal and chemical properties. Mature, durable technologies for sensible storage already are routinely deployed and recent advancements in thermal insulation have led to improved performance (IRENA-ETSAP, 2013). In the community-scale context, water-based sensible heat stores are by far the most commonly deployed technology, despite the relatively large volumes commonly required, which can present problems in space-constrained settings (Eames et al, 2015). Latent storage technologies are less mature with some commercial systems available for encapsulated building materials. Thermochemical materials and technologies are still very much at the research and development technical readiness level with some pilot installations in place (Eames et al, 2014). In contrast to sensible storage, the latter two technologies can suffer degradation after many cycles of use.

Table 18 summarises the technical status of these three forms of thermal storage, with the advantages of sensible storage approaches outweighing the drawbacks for almost all community energy settings.

Table 18 Comparison of Different Types of TES Based on Various Performance Factors (After Abedin and Rosen, 2011)

Type of Thermal Energy Storage			
Performance Parameter	Sensible TES	Latent TES	Chemical TES (Sorption and Thermochemical)
Temperature range	Up to: 110 °C (water tanks) 50 °C (aquifers and ground storage) 400 °C (concrete)	20-40 °C (paraffins) 30-80 °C (salt hydrates)	20-200 °C
Storage density	Low (with high temperature interval): 0.2 GJ/m3 (for typical water tanks)	Moderate (with low temperature interval): 0.3-0.5 GJ/m3	Normally high: 0.5-3 GJ/m 3
Lifetime	Long	Often limited due to storage material cycling	Depends on reactant degradation and side reactions
Technology status	Available commercially	Available commercially for some temperatures and materials	Generally not available, but undergoing research and pilot project tests
Advantages	• Low cost • Reliable • Simple application with available materials	• Medium storage density • Small volumes • Short distance transport possibility	• High storage density • Low heat losses (storage at ambient temperatures) • Long storage period • Long distance transport possibility • Highly compact energy storage
Disadvantages	• Significant heat loss over time depending on level of insulation • Large volume needed	• Low heat conductivity • Corrosivity of materials • Significant heat losses (depending on insulation)	• High capital costs • Technically complex

Further technical data is provided in Table 19 which shows the relative Marketing/R&D focus for specific technology applications.

Table 19 Maturity, Market Barriers and R&D Priorities for various TES Technologies (From IRENA-ETSAP, 2013)

Technology	Status (%) Market/R&D	Barriers	Main R&D topics
Sensible Thermal Energy Storage			
Hot water tanks (buffers)	95/5		Super insulation
Large water tanks (seasonal)	25/75	System integration	Material tank, stratification
Underground Thermal Energy Storage	25/75	Regulation, high cost, low capacity	System integration
High temp. solids	10/90	Cost, low capacity	High temp materials
High temp. liquids	50/50	Cost, temp<400C	Materials
Phase Change Materials			
Cold storage (ice)	90/10	Low temp.	Ice production
Cold storage (other)	75/25	High cost	Materials (slurries)
Passive cooling (buildings)	75/25	High cost, performance	Materials (encapsulation)
High temp. PCM (waste heat)	0/100	High cost, Material stability	Materials (PCM containers)
Thermochemical Storage			
ALL Types	5/95	High cost, complexity	Materials, and reactor design

5.8. Technology Costs

A key uncertainty when carrying out techno-economic modelling of CES systems is the likely trajectory of costs of storage technologies in the near and medium terms. For example, although capital costs for Li-ion batteries are expected to come down by around 50% over the next five years, at all scales thanks to largely modular designs (largely as a result of increased renewables generation and the expansion of the EV market), there is significant uncertainty moving forward with regards to parameters such as raw material availability, scaling up of global manufacturing capacity, and storage efficiency and lifetime metrics.

For the CES sector specifically, given current capital and ongoing costs, in most cases economic viability presently requires capitalising upon multiple value streams as described in Section 6.2.6 (page 78). A recent study on 20 dwellings by Ausnet in Melbourne, Australia found that for although household community storage is not competitive when used for maximising PV self-consumption and tariff shifting, the trial was successful in proving the technical performance of residential energy storage, and was sufficient to further work aimed at realising the benefits of storage and managing customer uptake (Ausnet, 2016). However, it should be noted that this study comprised dwelling-based Li-ion storage, rather than an aggregated community-scale system co-located at the transformer, and did not include evaluation of the financial impacts of the stacking of multiple revenue streams.

Lazard’s comprehensive study of the economics of storage (Lazard, 2015) perhaps offers the most realistic snapshot of the global storage market. Their Levelised Cost of Storage Analysis (“LCOS”) addressed topics including:

- Adoption of a range of defined use cases for energy storage,
- Decomposition of the levelised cost of storage for various use case and technology, combinations by total capital cost, operations and maintenance expense, charging cost and tax, as applicable,
- Assumptions for the various use case and technology combinations examined.

Figure 23 shows LCOS comparisons for various storage use cases. Key conclusions from this study were:

- Certain “in front of the meter” technology and use case combinations in the UK could soon be cost-competitive with their dominant or “base case” conventional alternatives under some scenarios (such as higher cost fossil fuelled platforms including diesel generators), even without the benefit of subsidies or additional, non-optimized streams of revenue. Such combinations include Li-ion or flow battery installations delivering balancing, frequency response and PV support services.
- While no “behind the meter” technology and use case combination is strictly viable from a cost perspective as compared to an illustrative conventional alternative, a number of combinations are within “striking distance” and, when paired with certain value streams (such as fast response system balancing services) may currently be economic for certain scenarios.

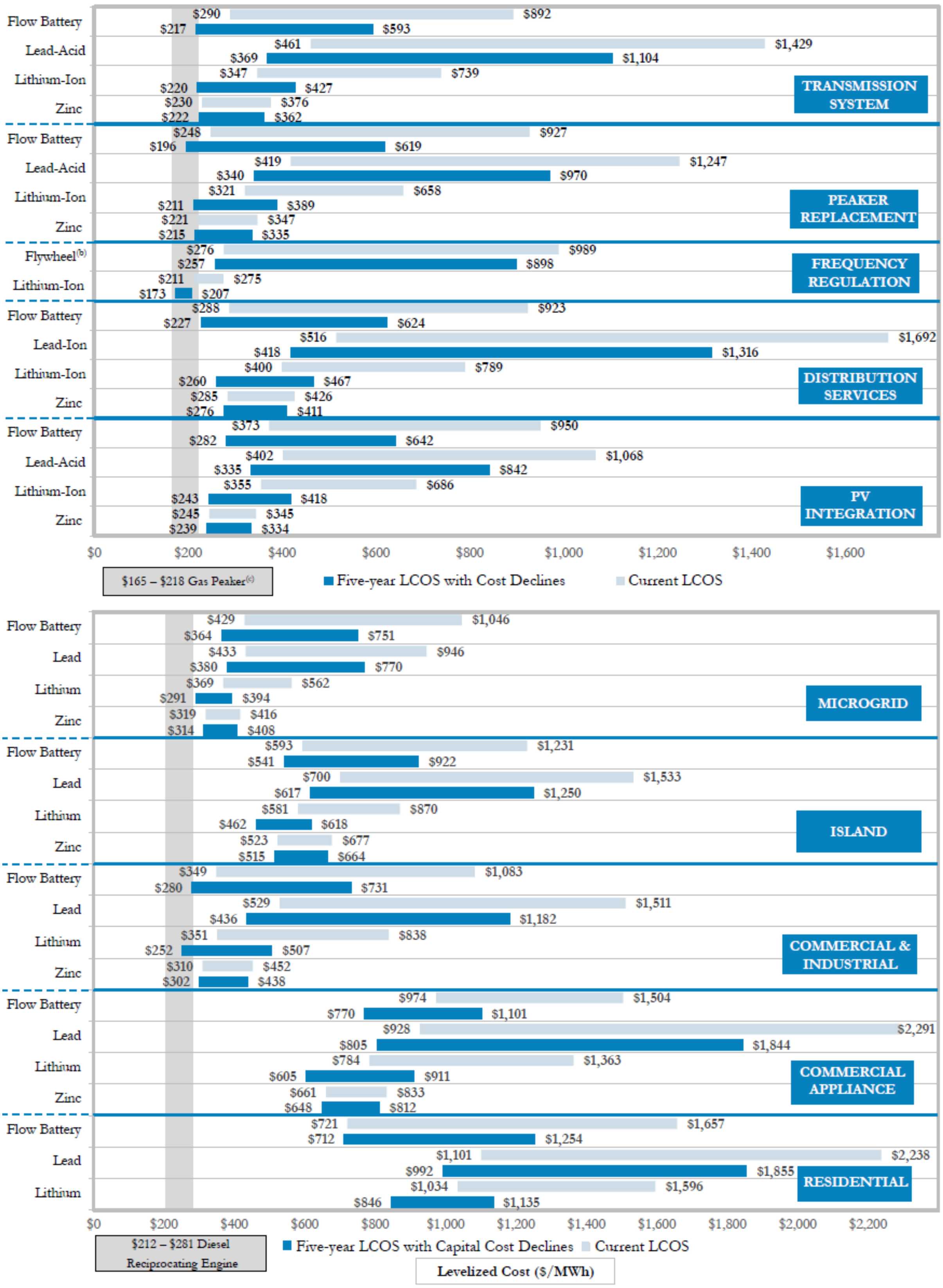


Figure 23 Lazard's 2015 and 2020 forecast LCOS comparison for various use cases. Note change in scale on lower graph.

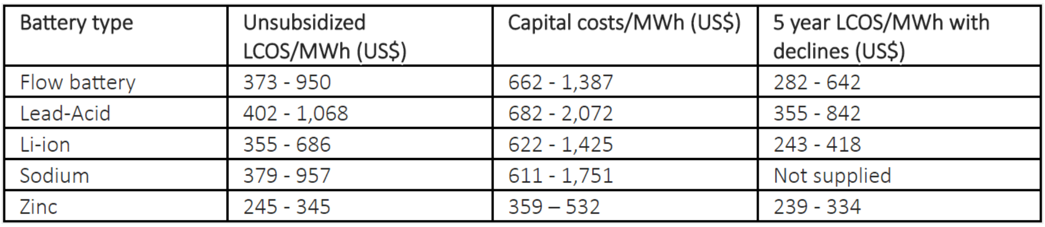
Whilst the analysis suggests considerable potential for storage in the short to medium term, is apparent that significant change in the prevailing regulatory and market environment is needed for storage to compete effectively with incumbent fossil fuel-based technologies. It should also be noted that this analysis does not take into account the externalities associated with energy storage, such as the social costs of demand charge shaving, and the environmental benefits associated with avoided gas peaking plant investment, which are also beyond the scope of the current study.

In the medium term, forecast cost reductions are projected to be functions of the magnitude of total capital cost decreases expected, as well as the relative weight of DC capital costs vs. balance of system and other costs according to Lazard.

Overall, industry participants in the study, which numbered around 50, expect lithium battery prices to fall by roughly 50% over the next five years, while flow battery costs are projected to decline by approximately 40% and lead batteries by around 25%.

Table 20 below shows the unsubsidised LCOS, and capital costs, relevant to large-scale solar PV integration, per MWh. Commercial & industrial scenarios analysed in the study show costs slightly above those of large-scale applications. However, residential energy storage costs for equivalent technologies are significantly higher at present, although they are projected to reduce rapidly over the coming 5 years.

Table 20 Present and projected costs for a range of storage technologies, From Lazard, 2015.



Battery type	Unsubsidized LCOS/MWh (US$)	Capital costs/MWh (US$)	5 year LCOS/MWh with declines (US$)
Flow battery	373 - 950	662 - 1,387	282 - 642
Lead-Acid	402 - 1,068	682 - 2,072	355 - 842
Li-ion	355 - 686	622 - 1,425	243 - 418
Sodium	379 - 957	611 - 1,751	Not supplied
Zinc	245 - 345	359 – 532	239 - 334

The results of this and related studies suggest that electrical storage combined with utility-scale solar and wind technologies can already be a cost-effective complement to conventional generation even in a low natural gas environment, whilst smaller, community-scale applications could be on the cusp of viability given a favourable market and regulatory environment. Indeed, storage may be on a trajectory similar to renewables (especially PV) over the past five to seven years, and increased demand for storage should also boost further cost reductions in renewables and, in turn, increase their uptake, representing a potential symbiotic ‘virtuous circle’ with regard these technologies.

For CES in the UK, it is useful to compare cost breakdowns for specific use-cases in terms of decision-making around system layout and architecture. Figure 254 below shows the effect of such factors as economies of scale for some larger transmission and distribution services, in comparison with smaller domestic scale applications. In contexts where the objective is to obtain maximum value for community stakeholders (including for residents via private wire arrangements), this further supports the case for having aggregated CES storage assets located at or near the community’s point of connection where a range of system support as well as local services can be delivered most effectively, rather than at the individual household level. In such contexts, it is by no means clear which electrical energy storage technology will prove to be most viable, despite the current pre-eminence of Li-ion technology in this sector.

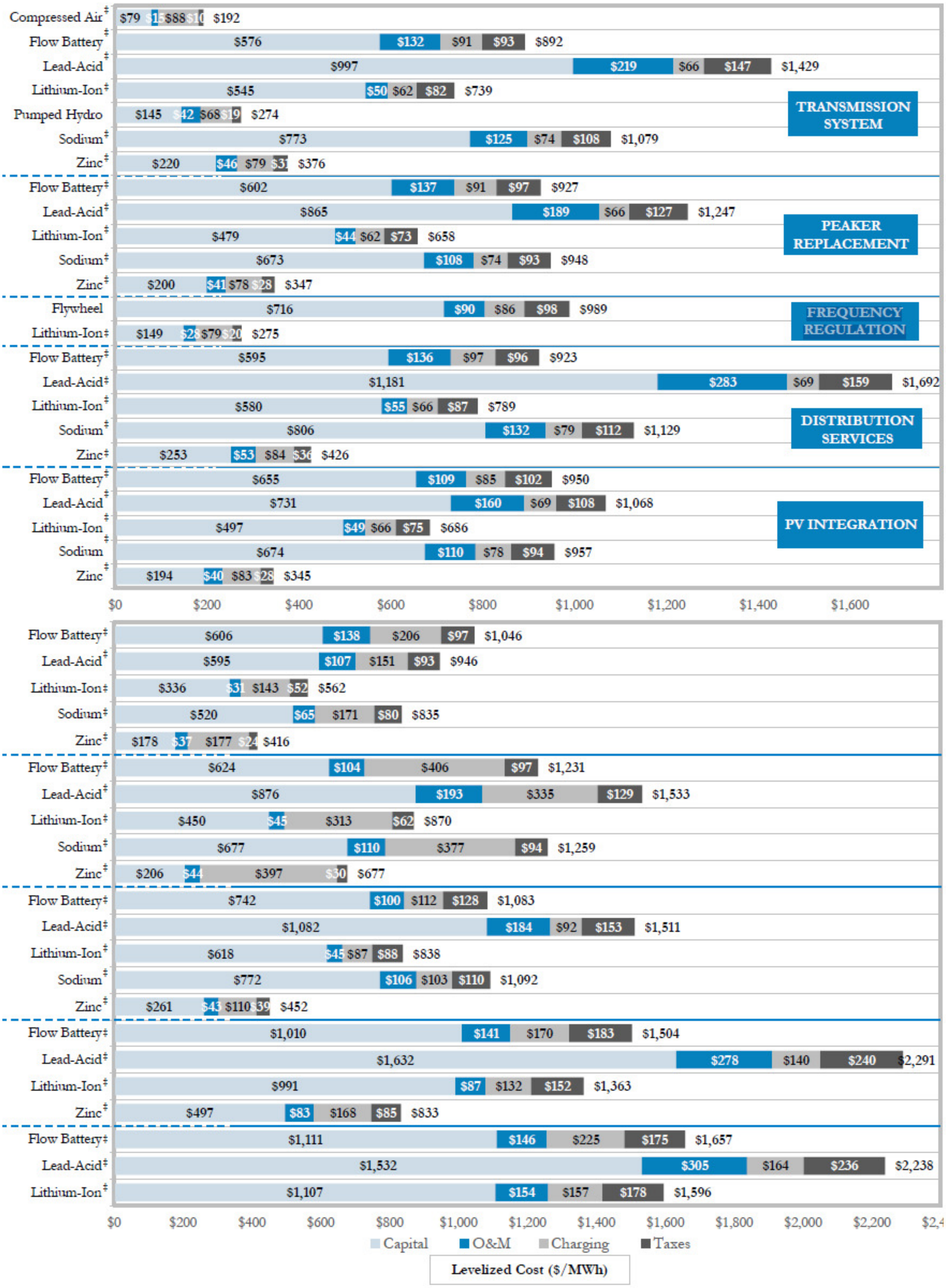


Figure 24 Disaggregated costs for a range of storage use-cases (Lazard, 2015). Note change in scale on lower graph.

The costs for inter-seasonal (lower temperature) thermal energy storage are difficult to ascertain in the UK context due to a limited experience for the technology. Figure 25 shows the cost for a number of mainland European demonstration plants (mainly in Germany) at

2012 prices (Schmidt and Miedaner, 2012). The cost per m^3 comes down steeply for larger projects, with a lower range of 300 Euros/m^3 for 300m^3 storage plant dropping to 25 Euros/m^3 for a 120,000 m^3 plant.

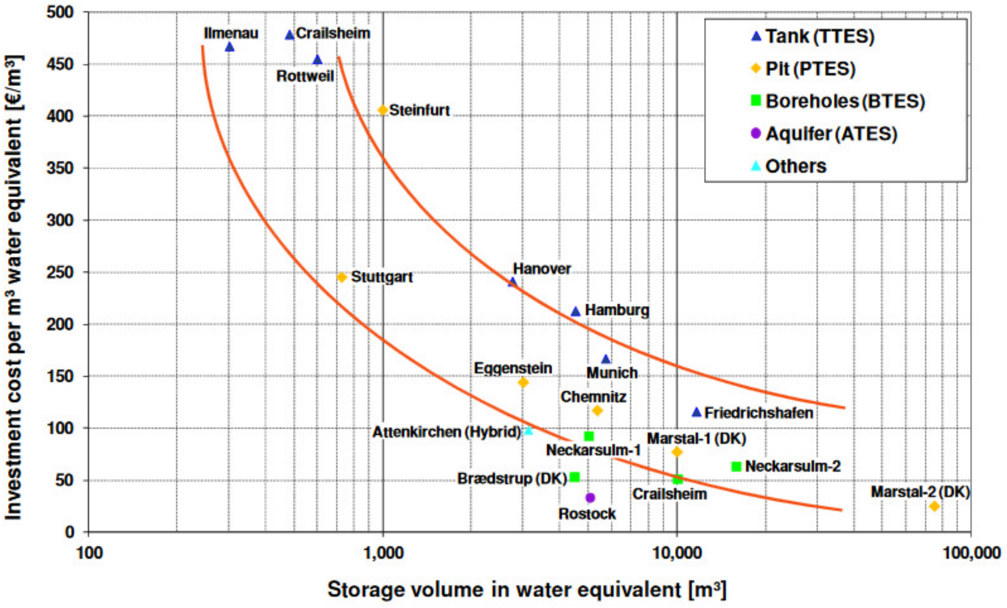


Figure 25 Specific storage costs of demonstration plants (ex-VAT), plants without a country code are located in Germany. From Schmidt and Miedaner, 2012

Costs of CHP higher temperature thermal stores as might be integrated with a heat network are also difficult to quantify due to a lack of data. DECC's (2015) report on the costs of UK heat networks suggested a figure of £1,080/m^3 for bulk[2] schemes and £843/m^3 for non-bulk schemes (expressed as 2013/14 prices). However these were based on single unit sample sizes. For reference, the Pimlico scheme uses a 2,300m^3 store serving 3256 homes, 50 businesses and three schools.

Currently, the cost of latent heat and thermochemical shortage technologies, which are not in general at deployment-ready levels, are prohibitively high for community-scale energy applications. Also, the relatively low rate of new build in the UK acts as a major constraint for deployment, since retrofit is costly (IRENA-ETAP, 2013).

In near term community-scale contexts, these factors imply that commercially viable storage applications will comprise 'sensible' (typically water-based) thermal storage systems

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[2] Bulk heat networks are defined as those where the main scheme operators deliver heat in bulk to major distribution points, but who do not have responsibility for final delivery to the end customers. Non-Bulk schemes are those where the operator or manager of the scheme is responsible for final delivery to the individual customer (each dwelling or flat).

and (in most cases) Li-ion electrical storage platforms, with perhaps a niche role for low-cost lead acid where relevant.

6. Markets for Energy Storage

6.1. Market Assessment

In this study, current and potential future value propositions for CES have been evaluated. Although this is carried out primarily in light of UK opportunities and constraints, a wider international perspective is also taken in order to inform near-term UK policy development. The work also forms the basis for the financial modelling described in sections 2 and 4.

Energy storage can provide a broad array of grid-operator, end-user and societal benefits that represent either reduced or avoided costs, and/or increased revenue. These benefits are set within a rapidly changing energy market and technology landscape, meaning that the analysis of the financial value of storage-based assets is subject to a high degree of uncertainty. Therefore, any evaluation of long-term project viability needs to manage this inherent uncertainty via appropriate modelling approaches.

The values of individual benefits that comprise a specific CES value proposition are context specific, and are defined by a number of temporal, spatial and technical factors, such as:

- Location
- Year, season, time of day
- Utility generation technology (equipment and fuel)
- Characteristics of T&D (Transmission and Distribution) systems
- Types and numbers of end-users and end-use equipment being served

In this section potential revenue streams for both electricity and thermal storage are briefly described and assessed.

6.2. Electrical Storage Value Streams

In this analysis, benefits are grouped into six broad application/use categories (Table 21). These benefits are not all solely deliverable by energy storage, but apply to a number of flexibility options that will ease the transition to a low carbon energy system as the share of variable non-dispatchable renewable generation increases (Zucker et al, 2013).

Table 21 Categories of Value Streams for Electrical Storage

Category	Value Stream
Ancillary Services	Reserve or backup power Temporal reconciliation of supply and demand Voltage and frequency support Storage can perform better than generation due to better ramp rates, and less prone to start-and-stop wear and tear
Electricity supply	Arbitrage (Buy low–sell high transactions) Capacity Services (delivering peak demand and therefore can also deliver other benefits at off peak times).
Electrical grid infrastructure	Improve effectiveness, efficiency, and cost of T&D equipment. Often used at hot spots to improve the capacity of extant or proposed equipment thus deferring capital expenditure.
End-user Benefits	Using storage to avoid end users' cost to purchase electricity during high price tariff periods.
Renewables integration	Temporal mismatch between supply and demand (balancing services) Alleviating power quality issues arising from output variability from renewable sources particularly wind and solar PV Mitigating undesirable grid impacts ("electrical effects")
Incidental (and other)	Often diffuse benefits with multiple stakeholders Societal value proposition - Reduction in fuel use Environmental benefits Increased GT&D asset utilisation

6.2.1. Ancillary services

Due to the increasing levels of variable renewable energy generation connected to the grid, (and the commensurate greater probability of temporal mismatch between supply and demand), the volume of grid balancing services required is ever greater (Chang, Madjarov, Fox-Penner, and Hanser, 2011). In order to fulfil the terms of its transmission licence, the UK TSO (National Grid Plc.) is required to procure a range of third-party services in order to maintain a safe and secure electricity supply according to electricity supply regulations (National Grid, 2016). Such 'grid balancing' services are procured from either electricity suppliers (generators and storage asset owners) via power and energy despatch, or from energy consumers via demand control means.

The wider UK ancillary services market was estimated to be worth £560M in 2014-15 (Figure 26). This is projected to increase as the energy system's reliance on variable renewable generation increases and reserve margins thin due to decommissioning of old thermal generation plant (Thinkinggrids.com, 2017). A key question is - to what degree can storage take advantage of the ancillary services market?

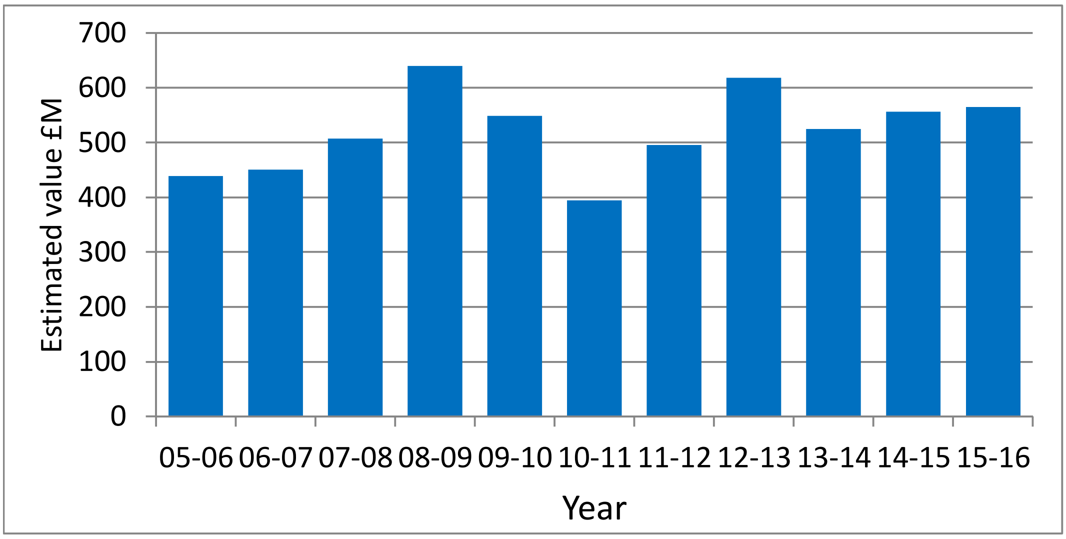

Figure 26 Ancillary service market 2005 to 2015 (NAO, 2014)

Currently, there is a significant volume of UK system-level energy storage in the form of pumped hydro together with biomass, gas and coal fuels. With the continued decarbonisation of the electricity system, these reserves will reduce rapidly (Ultilitywise, 2017), creating a requirement for alternative forms of both long and short-term storage.

Beyond the 1.8GW pumped-hydro resource in Dinorwig, Wales, and several smaller units, there are limited rapid response commercial storage solutions in the UK. Therefore grid balancing services must be procured from standby generators or the demand side balancing reserve. Such measures help deliver within-day flexibility for the electricity market, to balance the energy system (Pöyry, 2014). In the UK, energy storage has been identified as an important contributor to this required flexibility (Infrastructure Review, 2016) and a significant enabler of the development of a low carbon energy supply.

A portfolio of balancing contractual mechanisms, each with its own set of technical requirements, has been made available by National Grid. Participation in the market to deliver these services is subject to conditions defined in Energy Acts and statutory instruments. Contracts for some services are awarded following a reverse auction, other limited tender processes or through the establishment of bilateral arrangements.

Table 22 lists the key named services for balancing the grid offered by National Grid within this portfolio. There is a co-evolutionary development of storage and ancillary services thus the storage market is encouraged to develop and services are developed to provide a specific role for the storage market, for example the Enhanced Frequency Response service. (Taylor et al, 2012).

Table 22 Balancing Ancillary Services Procured by the National Grid

Frequency Response Services	System frequency is a continuously changing variable that is determined and controlled by the second-by-second (real time) balance between system demand and total generation.
Mandatory Frequency Response	Generators connected to the grid must be able to provide mandatory frequency response capability to maintain the frequency within statutory (49.5-50.5Hz) and operational limits (49.6-50.2Hz). One of three services, Primary, Secondary and High frequency response services are used
Firm Frequency Response (FFR)	FFR is the delivery of a minimum of 10MW (demand or generation) of frequency response services and is open to non-BMU[3] providers. Storage can deliver this directionally using grid scale technology, or an aggregator.
Frequency Control by Demand Management (FCDM)	FCDM service is provided by customers who can interrupt their demand for up to 30 minutes, to mitigate the frequency deviation caused by the loss of a large generator. Providers must be able to deliver a minimum of 3MW which may be achieved by aggregating a number of loads.
FFR Bridging Contract	Similar to FFR but aimed at providers under 10MW to grow their portfolio thus allowing access to market for smaller service providers. They can deliver demand side reserve by either reducing or shifting demand. Reduction may be achieved by operating behind-the-meter standby generation for example using diesel generators or storage technology.
Enhanced Frequency Response (EFR)	This is a new service aimed at storage assets which can provide a response on a 1s timescale (not sure about the capacity required though but seems to be at least 1MB)
Reserve Services	Extra power to deal with unforeseen demand increase, generation unavailability, or utilise excess zero-marginal cost generation
Fast Reserve	Fast Reserve provides the rapid and reliable delivery of active power through an increased output from generation or a reduction in consumption from demand sources, following receipt of an electronic despatch instruction from National Grid. Fast reserve is typically served by UK's two pumped storage generators.
Demand Turn Up	Demand Turn Up, sometimes known as 'Footroom', is a service to encourage large energy users and embedded generators to either increase demand (through shifting) or reduce generation when there is excess energy on the system – typically overnight and weekend afternoons. The purpose of the relatively new service to avoid the curtailment of renewable energies during periods of high generation and low demand.
Short Term Operating Reserve (STOR)	STOR is a service for the provision of additional active power from generation and/or demand reduction.
STOR Runway	STOR Runway is a contracting opportunity for Demand Side Providers to support the growth of new volume in to the STOR market.
Enhanced Optional STOR	This service is where National Grid has a requirement for provision of a volume of an Enhanced Optional STOR Service from non-BM Providers on a trial basis for this winter
BM Start Up	The BM Start-up Service gives National Grid on-the-day access to additional generation BMUs that would not otherwise have run, and which could not be made available in Balancing Mechanism timescales.
Enhanced Reactive Power	ERP is the provision of reactive power capability from any plant or apparatus which can generate or absorb Reactive Power that isn't required to provide the Obligatory Reactive Power Service.

Both reserve and frequency response services are pertinent to storage. There is also potential value to be realised from participation in the enhanced reactive power (ERP) service (Papadopoulos et al, 2016). The relevant services are listed in Table 23.

The most relevant reserve service currently is STOR since, as mentioned above, Fast Reserve is presently provided for predominantly by pumped-hydro resources and flexible fossil fuel assets such as gas turbine-based peaking plant. It is not yet clear as to the extent that electrical storage may in future compete for these service contracts. STOR providers can be paid for availability and again for delivered energy. Two types of contract are available: Committed STOR where the service provider makes the service available for all required availability windows and Flexible Service STOR which offers the provider greater freedom to choose the duration and when the service is offered. STOR was worth £62m in 2014/15, serviced by a number of generators and demand service providers.

Table 23 Breakdown of commercial opportunities by ancillary service

Service	Market Share	Market value (£m)	Specific Annual Revenue (/£MW)	Minimum Capacity (MW)	Gen	Load
Demand Turn-up	1%	8	15-35	N/A	x	x
Mandatory FR	9%	48	Varies	100	x	
STOR	11%	62	25-46	3	x	x
Reactive Power	13%	72	Varies	50	x	
Enhanced Reactive Power	n/a	n/a	n/a	n/a		
Commercial Frequency Response (FCDM and FFR)	23%	126	50-55	10 (FFR) 3 (FCDM)	x	x
Fast Reserve	23%	130	40-50	50	x	x
Others:	20%	109				
Total	100%	555				

Demand Turn-up, or Footroom, enables payments to business energy users which can flexibly ramp up their consumption during periods of high renewable generation at low loads (for example during the night, weekends and bank holidays with concomitant high wind or irradiance event) at the request of the SO. System aggregators can also participate in the market, thus providing an opportunity for smaller consumers to participate in the market. Aggregators such as Flexitricity suggest that the best sites have storage or inertia in their systems, including cold storage, and water pumping. Footroom was worth £8M in 2014/15, which is 1% of all balancing costs procured by National Grid. The revenue ranges from £15K to £35K per MW/year. The required response time is typically within 30 minutes, and mediation by aggregators permits generators of any size and loads though Flexitricity prefers loads of over 250 kW.

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[3] Balancing Mechanism Unit

The frequency response services, FCDM, and FFR had a market value of £126M, the largest proportion of the balancing market budget, in 2014/15. Per MW it is also the largest value stream, delivering between £50K and £55K per MW. FFR requires a minimum capacity of 10MW, whereas for FCDM, assets above 3MW can provide the service. However aggregation could facilitate the participation of smaller storage assets in these markets.

There is little in the body of literature of the provision of the enhanced reactive power service by energy storage asset owners, and the market value is uncertain. However, recent research conducted by the Smarter Energy Storage Project[4] has shown that battery storage has the potential to offer SO services for reactive power management (Papadopoulos, Laguna-Estopier and Cooper, 2016).

In a significant recent development in August 2016, 8 companies utilising battery storage assets won National Grid Plc's enhanced frequency-response tender for installation during 2018. 61 of the 64 sites with storage units that bid were batteries, making this the first time National Grid will use the technology at that scale. It is projected that these contracts will save £200M over four years. Significantly, at the time of writing, this tender is likely to be the energy storage industry's biggest contract globally during 2016 in a market expected to install £4Bn worldwide in 2020, according to Bloomberg New Energy Finance. In terms of the scale of the UK market moving forward, National Grid plans to add 30% more such units by 2020 in order to deal with expanding flows of clean energy in the U.K. However, battery storage will compete in this market with traditional generators, including plants fired by natural gas and coal.

The electrification of heat, coupled with thermal storage, as demonstrated in Section 4.3 (page 39) also provides the opportunity for participation, using community scale heating assets, in ancillary services provision. By using thermal storage head room and foot room capacity, a down-turn or up-turn in local demand can be used to deliver demand flexibility for the services in Table 23 whilst still meeting the local thermal load.

6.2.2. Distribution Network Services

DNOs have the requirement to ensure that the network has the required capacity to meet demand, in particular peak demand. Furthermore, with the increase in variable generators requiring the grid to both deliver and receive electrical energy from distributed renewable energy generators, there is an increasing need to reinforce the grid in order to

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[4] The Smarter Network Storage (SNS) project, funded through Ofgem's Low Carbon Network Fund, is carrying out a range of technical and commercial trials using energy storage to tackle the challenges of transitioning to a low-carbon electricity sector. Through demonstrating the UK first multi-purpose application of the installed 6MW/10MWh energy storage device at Leighton Buzzard primary substation, the project is exploring methods for accessing multiple 'stacked' benefits, maximising value from alternative revenue streams for storage, while also deferring traditional network reinforcement at the site.

accommodate a high penetration of variable renewables, which can cause the quality of the supply to overstep regulatory requirements for voltage and frequency harmonics on the low voltage network.

Electrical energy storage, either behind or in front of the consumer meter, can mitigate or defer the cost of grid reinforcements required to accommodate peak loads or high volumes of variable renewable energy generation. Thus avoided capex facilitated by storage could in theory realise a revenue stream for storage asset holders. UK Power Network's 'Smarter Network Storage' LCNF project (Greenwood et al, 2015) provides an example of this, albeit at a somewhat large scale than CES.

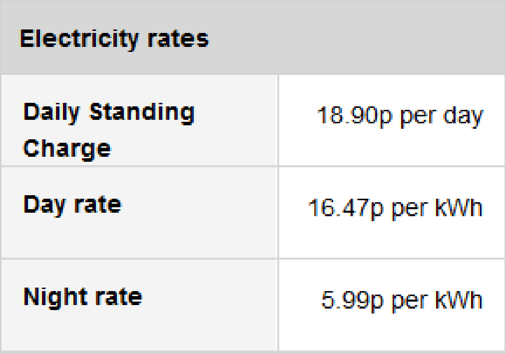
Note that storage is currently designated as a generation activity which creates considerable uncertainty adopters (Pöyry, 2016). Since, due to EU and UK regulatory requirements for the unbundling of generation and distribution in the electricity market, DNO licence holders are not permitted to generate electricity (Taylor et al, 2012). *At the current time, the case for DNOs to operate storage assets is still under review as a current priority for the energy regulator, OFGEM (2013).*

6.2.3. Energy Arbitrage

Energy suppliers and DNOs have provided a number of price signals to encourage behavioural change towards demand side shifting and in particular peak shaving. This can benefit the system by mitigating the need for peak capacity investments and the operation of more expensive spinning reserve.

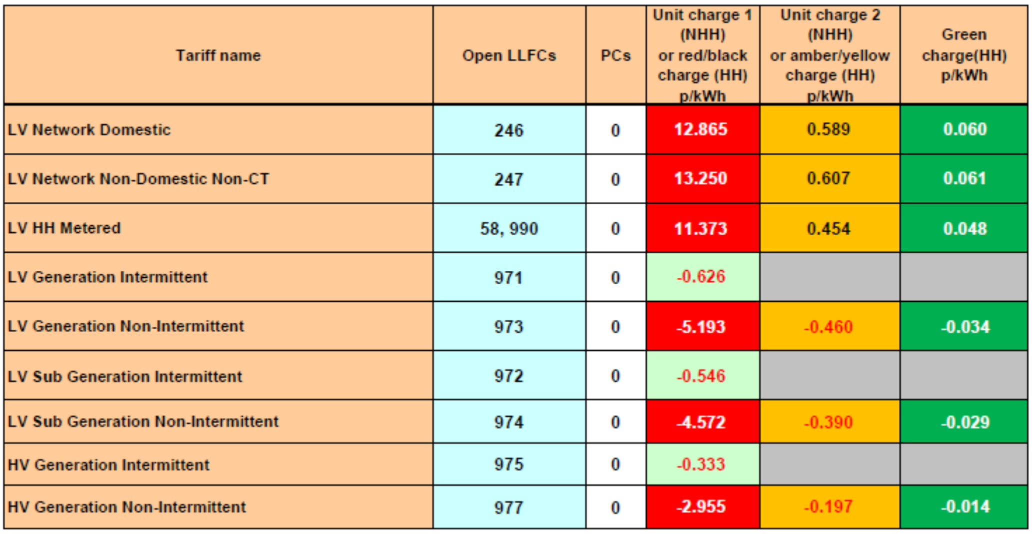
Electrical storage technologies can take advantage of time-of-use tariff differentials by charging during periods when electricity is cheap, and discharged when it is more expensive, a market activity known as arbitrage. For example, storage asset owners connected to domestic meters can charge using night time Economy 7 rates, and discharge during the day time when electricity is priced at a higher rate. The price difference may be as high as £0.105 for domestic consumers (Table 24). Whilst Economy 7 tariffs are not generally marketed anymore, such time of use tariffs for both domestic and commercial consumers are likely to proliferate following the smart meter rollout, with one big-6 energy supplier already trialling a new tariff (British Gas, 2016).

Table 24 Standard (Variable) tariff unit rates in East Midlands with EDF Energy (EDF Energy, 2016)



Electricity rates	
Daily Standing Charge	18.90p per day
Day rate	16.47p per kWh
Night rate	5.99p per kWh

To incentivise peak shaving the DNOs also embed price signals in the 'distribution use of system' (DUoS) costs, incurred by generators for the use of the distribution network (Pöyry, 2016). The key objective is to mitigate the infrastructure costs required for the few hours of peak demand. Typical DUoS rates (Figure 27) show significantly higher charges for the red-time band, typically between 16:00 and 19:00 (Figure 28), for both consumption and generation by assets which feed energy into the grid. Thus a storage asset can earn a revenue stream by charging when DUoS costs are amber or green, and discharging (exporting) when the DUoS costs are red, earning 5.2p/kWh. Depending on the metering system used, mitigation of DUoS costs for community-sale projects could be achieved by reducing aggregate load at peak times, optimising available capacity levels and cross-checking DUoS charges against published rates in order to identify over-payments. To this end, new technology platforms are now being developed by third parties to optimise the way electricity is consumed during peak tariff hours to avoid excess charges (Origami Energy, 2017).

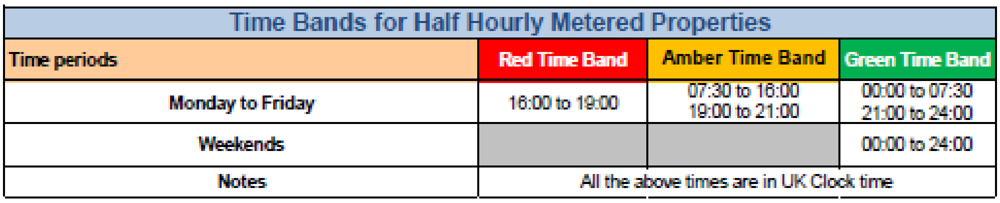


Tariff name	Open LLFCs	PCs	Unit charge 1 (NHH) or red/black charge (HH) p/kWh	Unit charge 2 (NHH) or amber/yellow charge (HH) p/kWh	Green charge(HH) p/kWh
LV Network Domestic	246	0	12.865	0.589	0.060
LV Network Non-Domestic Non-CT	247	0	13.250	0.607	0.061
LV HH Metered	58, 990	0	11.373	0.454	0.048
LV Generation Intermittent	971	0	-0.626		
LV Generation Non-Intermittent	973	0	-5.193	-0.460	-0.034
LV Sub Generation Intermittent	972	0	-0.546		
LV Sub Generation Non-Intermittent	974	0	-4.572	-0.390	-0.029
HV Generation Intermittent	975	0	-0.333		
HV Generation Non-Intermittent	977	0	-2.955	-0.197	-0.014

Figure 27: DUoS costs for red, amber and green time bands in the East Midlands DNO region (WPD, 2015)

6.2.4.End User Benefits

End-user value streams relate to storage asset holders and consumers who are able to manage their local supply arrangements to avoid the import of electricity particularly when it is expensive, and taking advantage of electricity when it is cheap using load shifting. In terms of present opportunities for load shifting, Figure 28 shows time bands that currently apply in the East Midlands. In terms of storage assets installed ‘behind the meter’ (whether at single household or whole community points-of-connection), the opportunities for energy storage to facilitate arbitrage and realise the additional value facilitated by ToU tariffs (especially if used in conjunction with demand management) have been demonstrated. This is explored in 4.2.4 for the case of ground source heat pumps used in conjunction with thermal storage. For domestic consumers, these opportunities presently relate primarily to households using ‘Economy 7 or 10’ tariffs. However, given the rapidly changing landscape in terms of more refined time-of-use tariff structures, it seems clear that the opportunities related to the flexibility offered by CES assets will be clarified in the near future.



Time Bands for Half Hourly Metered Properties			
Time periods	Red Time Band	Amber Time Band	Green Time Band
Monday to Friday	16:00 to 19:00	07:30 to 16:00 19:00 to 21:00	00:00 to 07:30 21:00 to 24:00
Weekends			00:00 to 24:00
Notes	All the above times are in UK Clock time		

Figure 28 Time Bands for half-hourly metered properties in the East Midlands DNO operator, Western Power (after WPD, 2015)

End users with renewable energy technologies integrated with storage can also benefit directly by increasing their self-consumption of renewable energy generation, particularly where marginal costs of generation are close to zero (as is the case with PV). For example, Figure 29 illustrates the variability of direct self-consumption for domestic consumers with on-site PV installed. With mean PV self-consumption in the UK below 40% (and significantly lower for a large number of households) this shows that there is still significant head-room for storage to increase the level of self-consumption in the community context.

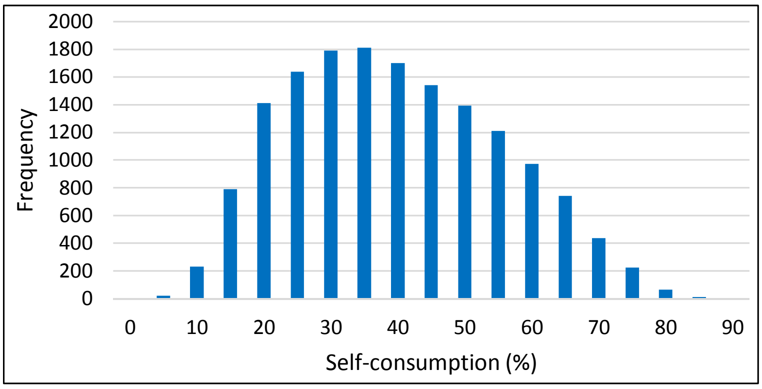


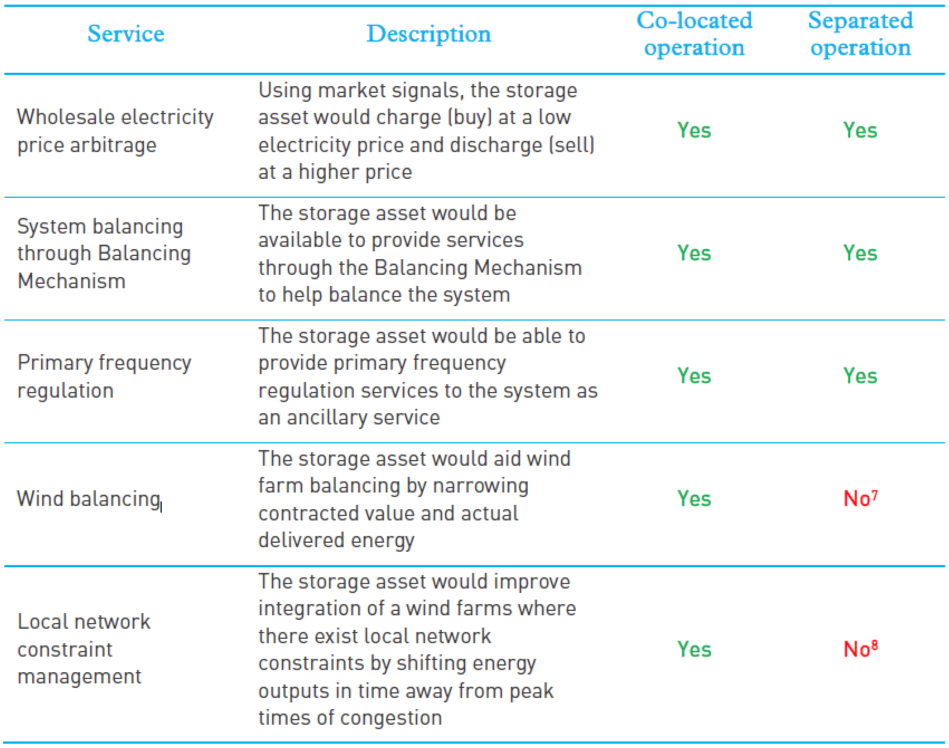
Figure 29 Frequency plot showing number of households with domestic PV which achieve the given levels of self-consumption obtained using a simulated sample size 20,000 calibrated to empirical electricity consumption (Leicester et al, 2016)

This analysis shows there are significant potential additional benefits arising from increased self-consumption using electrical storage and reduced household electricity purchase costs. This is explored in the context of CES in this study in sections 2 and 4. Note that such benefits are likely to be greater during periods at which grid-supply tariffs are higher (as is the case with time of use tariffs) and are related to household occupancy and electricity consumption patterns (Leicester et al, 2016).

6.2.5. Renewables Integration

Electrical energy storage can be assessed in a stand-alone context, operated separately from any generation technology, or it can be integrated with a renewable energy generation installation. This can enhance the business case for a renewable energy project. Coupling the above ancillary services with variable renewable generation could lever extra value for the generation asset by balancing the renewable generation thus narrowing the contracted and actual delivered energy, or where local network constraints exist by shifting energy outputs away from times of peak congestion (Carbon Trust, 2016). Thus a more viable business model for wind generation at the community scale (such as Hockerton Housing Project (Seyfang, 2010) can be constructed by stacking several value streams for co-located generation and storage (Figure 30). However there remain market barriers to stacking revenue streams (see Section 6.5).

Figure 30 Services that could be provided by a storage asset, either co-located with wind generation, or separated



Service	Description	Co-located operation	Separated operation
Wholesale electricity price arbitrage	Using market signals, the storage asset would charge (buy) at a low electricity price and discharge (sell) at a higher price	Yes	Yes
System balancing through Balancing Mechanism	The storage asset would be available to provide services through the Balancing Mechanism to help balance the system	Yes	Yes
Primary frequency regulation	The storage asset would be able to provide primary frequency regulation services to the system as an ancillary service	Yes	Yes
Wind balancing	The storage asset would aid wind farm balancing by narrowing contracted value and actual delivered energy	Yes	No[7]
Local network constraint management	The storage asset would improve integration of a wind farms where there exist local network constraints by shifting energy outputs in time away from peak times of congestion	Yes	No[8]

Similarly, ongoing reductions in costs of distributed storage with solar PV have the potential to improve the economics for domestic solar PV in the near term (Reid et al, 2015). As well as household bill reduction through increased self-consumption and energy arbitrage, storage devices could in theory also participate in ancillary services markets. In future, third parties could aggregate the services provided by a large number of separate domestic installations, simplifying market participation for smaller community and household PV-with-storage asset owners. For this to occur, suppliers will need to innovate in terms of their customer propositions and business models. In this context, UK technology developer Moixa is currently offering payments of £75 p.a. to residential customers (DeltaEE, 2017), and the potential exists to extend models such as this to community-scale settings, especially in light of ongoing capital cost reductions.

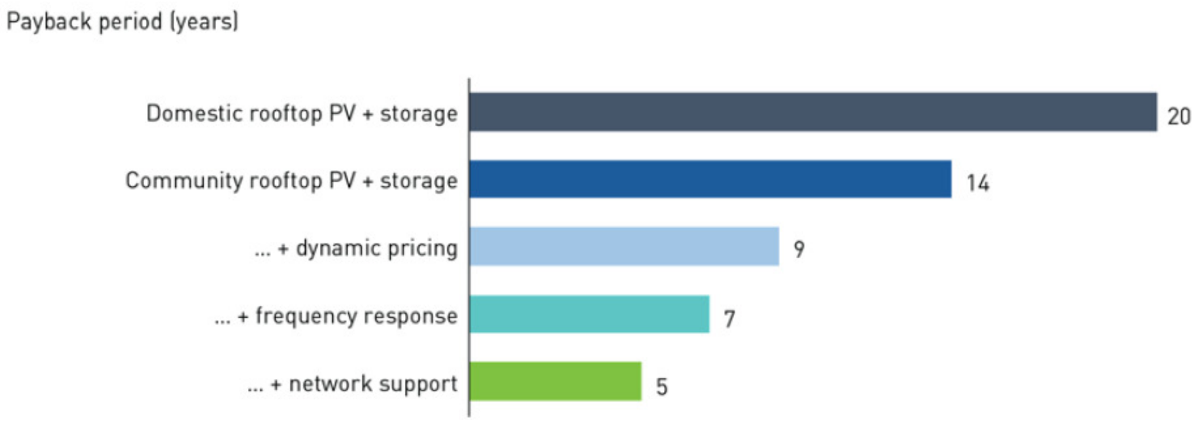
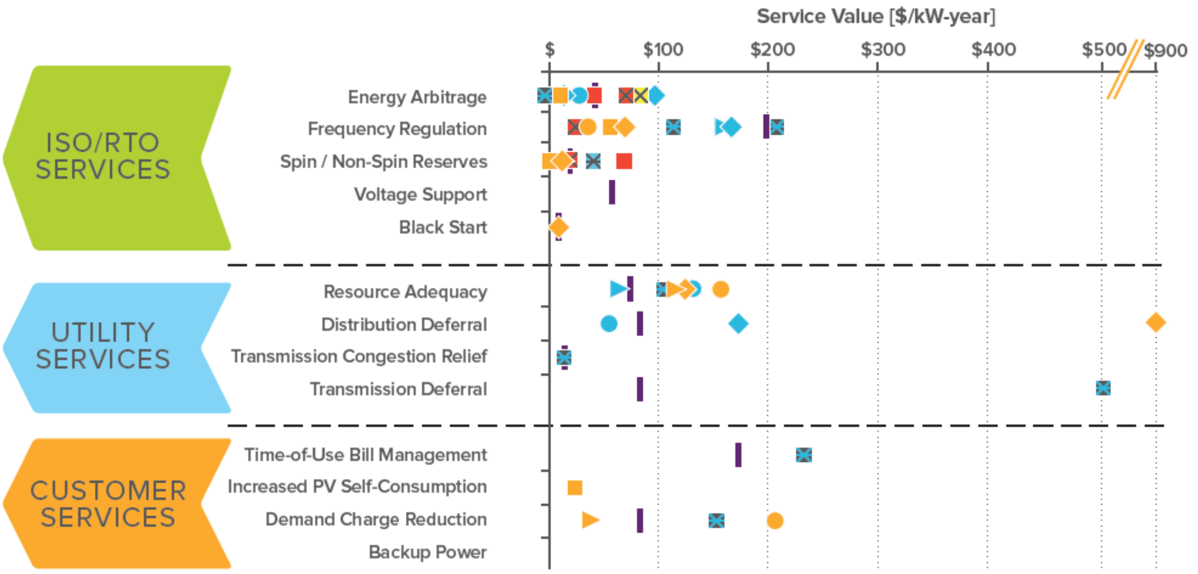


Figure 31 Comparative payback periods for distributed storage with solar PV with additional ancillary service provision (Delta-EE 2017).

6.2.6.Stacking of Storage Value Streams

For electrical storage technologies, given their relatively high current costs, over-reliance on a single revenue mechanism provides a poor business case which, studies have shown, is significantly improved if multiple benefits are stacked (Eyer and Corey, 2010; IEA, 2014). This is the case even in overseas markets where specific parameters such as high utility energy tariffs or solar resources are more optimal than in the UK (ESA, 2011).

The nature of the potential concurrent value streams is dependent on where the storage is located in relation to the wider network, and to its location relative to the point of metering i.e. ’behind the meter’ vs. ‘in front of the meter’ applications. The greater number of potential applications tends to be closer to the customer load, thus rendering community level storage as having the potential to offer more services to the wider electricity system, and thus stack a greater number of value propositions. Figure 32 shows the service value of 13 general grid services from a number of studies in the US (RMI, 2015). However, this does not answer how much value can be realised by stacking several services, since the degree of storage asset utilisation for each service is not known (thus potentially the asset may be unavailable for another service whilst delivering another). As the data demonstrates, there is a high variability due to the high number of market, regulatory and technical parameters. The latter in particular is obscured by the normalisation of revenue to $/kW-year.



Each point represents a single study

Figure 32 Summary of potential value streams from a range of studies in the US (RMI, 2015)

6.3. Value Streams for Thermal Storage

Value streams realised by thermal energy storage depend on the heat source, and the application with which a thermal energy store is coupled. Table 25 shows several heat source storage couplings.

Table 25 Thermal storage and heating source applications and benefits

Heat Store	Heat Source	Application	Benefit
Heat bank	Solar Thermal (panels)	Heat pump space heating	Improved input temperature increases COP for improved efficiency
Hot bricks / Storage heaters	Electrical (resistive)	Space heating	Energy Arbitrage Peak shaving
Domestic thermal store with immersion heater	Solar PV Electricity (resistive)	Water heating	Energy Arbitrage Load balancing
Large Thermal Store	CHP (Biomass/Energy from Waste)	Heat markets	Load balancing Ancillary services Greater efficiency

Heat banks can deliver inter-seasonal storage and because of the low cycling must have low construction costs. Thermal stores can be charged using solar thermal arrays, and during the winter months can deliver higher input temperature to heat pumps thus enhancing their coefficient of performance (COP). This places significantly less demand on the electricity grid, contributing to peak shaving, and mitigating infrastructure investments for grid reinforcement to cope with the electrification of heating.

Storage heating is a traditional heating source in the UK housing stock. By shifting demand to cheaper night time tariffs consumers can benefit from cheaper tariffs – a form of energy arbitrage. In a related context, many dwellings possess retro-fitted combi boilers and as a consequence have lost their hot water storage tanks. For dwellings which use grid electricity for water heating, this means the opportunity for time-of-use tariff arbitrage is lost. Indeed, in such settings, newer more efficient domestic scale thermal stores can be charged using surplus solar PV rather than exported to the grid.

Large thermal stores in conjunction with CHP schemes can deliver a range of potential benefits. These pertain to the ability to manage the temporal mismatch between heat and electricity demand. By storing heat when it is not needed by the heat network, the CHP generator can provide power and participate in auxiliary services in the electricity market, and potentially reduce the need for more expensive and carbon intensive spinning reserve.

6.4. Legal Considerations

The importance of legal and regulatory barriers to the expansion of the sector should not be under-estimated. In a definitive recent study (Roberts et al, 2014), a number of recommendations have been proposed in order to support the growth of community energy. Given the lack of relevant legal studies for community energy projects that include an element of energy storage, these ‘core’ recommendations can form an initial basis for deeming fundamental preconditions for supporting community energy and storage projects as summarised from the report, namely:

- National legislation and policy should not define ‘community energy’ restrictively. It should promote a wide range of models for citizen ownership and participation in the production and/or use of sustainable energy.

- Legal frameworks should ensure at least partial community ‘ownership’ of, and effective ‘participation’ in, commercial renewable projects, either by statute or best industry practice.

- In order to provide direction and certainty, governments (at all levels) should establish targets (ideally binding) for renewable energy and, more specifically, targets for community power.

- Community power projects should not be subject to competitive bidding processes in order to receive operating support; instead, they should be eligible to receive feed-in tariffs.

- National laws should incentivise community power projects based on 'self-sufficiency' (e.g. direct marketing and production for self-consumption), for instance through investment and tax relief, or reduced charges on energy consumption.

- Governments (at all levels) should provide financial support (e.g. grant-to-loan, guarantee, or cheap credit opportunities) for preliminary investigations and work on community power projects.

- Local governments, with support from national governments if appropriate, should use planning powers to require integration of renewables and energy efficiency measures into public, new and renovated buildings, streamline requirements for community power projects into a one-stop-shop approach, and provide guidance to assist navigation of regulations.

- 'Community leadership' should be eligible as a material consideration for planning decisions relating to renewable energy projects.

- Laws should provide equitable grid access for community power projects; reinforcement costs should fall on the grid operator as part of a continuing duty to ensure integration of renewables and ensure security of supply.

- National laws should not impose overly restrictive requirements on community power projects wishing to become owners/operators of network grid infrastructure or fully licensed suppliers of green energy.

6.5. Market Barriers

The work presented in the previous section demonstrates that under specific circumstances, CES projects can be viable, provided value streams arising from providing a range of local and wider system services can be 'stacked' appropriately. However, a number of barriers currently exist to prevent these multiple value streams from being realised. Selected key barriers are shown in Table 26. Foremost amongst these are a number of regulatory hurdles which were designed largely in light of the incumbent energy system, electricity market characteristics and the imperatives of prevalent commercial players.

Table 26 Selected Market Barriers to Community Storage Deployment

Policy Risk	Long term predictability of policies raises financial returns required by investors resulting in higher costs and prices
Market access issues	There are currently difficulties with regards obtaining direct value from energy trading and provision of ancillary services.
Failure to recognise societal benefits	The potential of reduced costs of the future energy system realised by storage is not passed to storage actors thus not contributing to stacking of benefits
Saturated market	Finite demand for services offered by storage may result in diminishing returns by investors
Distorted market price signals	Lack of a joint perspective by key stakeholders on the value of storage
Lack of market integration across services	Storage viability requires the 'stacking' of value streams. However different regulatory frameworks make the opportunities to provide multiple services difficult
Multiple stakeholder collaboration	In order to realise storage benefits an alignment of benefits has to occur and one player has to take the lead

The result is that in contexts of decreasing storage and renewable energy technology costs, and increasing fossil fuel prices, such barriers potentially hinder development of a sector that could control retail energy cost escalation rates, mitigate the need for additional power stations to address renewable intermittency and help ensure we hit our legally binding greenhouse gas emission targets. This underlines the need for all stakeholders (especially those involved in market and regulatory design) to work together in order to plan a development strategy for CES that optimises potential benefits for all stakeholders.

In the thermal energy storage context, depending on the specific technology under consideration, market barriers include costs, technology maturity, wider system integration, and temperature range utilisation issues. Specifically for community contexts, of the 'sensible heat' storage technologies, the main barriers to implementation are the current cost of the system and the challenge posed by the requirement to integrate the different technologies and systems so that they work in an optimal energy efficient manner, for example different heat sources and different stores (Eames et al, 2014). Also, especially for compact urban contexts, the sheer scale of thermal storage installations required to provide effective functionality is a key barrier, especially for seasonal storage applications where store volumes of up to 75,000m^3 have been utilised (Eames et al, 2014).

6.6. Summary

In the work to date, we have begun to unpick potential 'stacked' value streams which can contribute to viable business models for energy storage (Figure 33).

Firstly value can be derived from the TSO (in the UK case, National Grid), by participating in balancing markets, particularly STOR and the Frequency Response services. Small storage assets can participate in these markets by subscribing to the services offered by a system aggregator. Further value can be derived from the DNO level by taking advantage of temporally varying DUoS prices which serve as price signals for peak shaving. Finally end-user benefits can be derived from increased self-consumption from renewable generation, thus avoiding grid import costs, or by arbitrage - for example charging during low tariff periods and discharging during at high tariff times.

In comparison with system level markets, currently there is lack of clarity in the UK regarding CES access to markets for providing local balancing services, peak shaving and deferral of reinforcement costs.

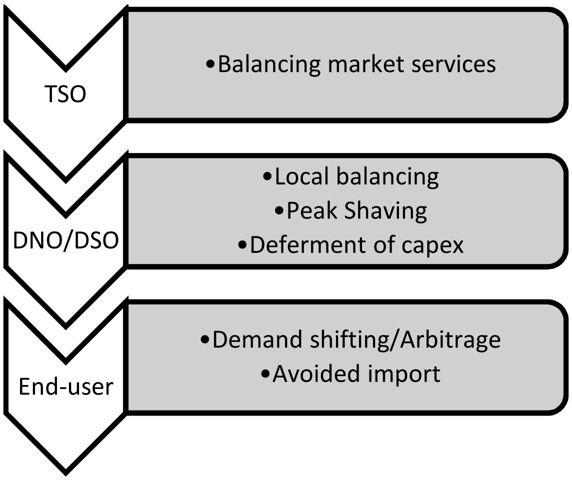


Figure 33 Stacking of value streams

As part of the process of modelling and evaluating the viability of specific energy storage configurations, as well as including revenues arising from energy sale, additional issues should be considered, in particular:

- Potential revenues arising from the provision of ancillary services such as frequency response and balancing services, possibly in partnership with third party aggregators.
- Consideration of costs avoided due to network reinforcement mitigation and transformer upgrades.
- Potential income from other system support services such as the provision of reactive power.

- The impact of assumed demand profiles and transients when modelling projects storage benefits for stakeholders.

7. Conclusions of the Work

The work described in this report explores a number of key issues associated with community-level energy and energy storage over the next decade. The roles of sector stakeholders have been explored, and potential community-scale energy business models comprising both electrical and thermal energy storage have been characterised. Techno-economic modelling was carried out for a range of technical platforms comprising embedded energy generation technologies together with electrical and thermal energy storage systems, highlighting potential value arising from a range of revenue streams. A review of key aspects of the wider energy storage and related sectors was carried out, including technologies, markets and cost aspects.

In particular, the main conclusions are:

A number of business models are evolving which offer the potential for commercially viable schemes in the community energy and storage space. To clarify the possible nature of such models, they can be characterised in terms of networks of project actors and stakeholders and their relevant relationships. It is possible to evaluate these business models from the perspective of key stakeholders, including asset owners, investors, customers and external added-value partners. The work identified the complex nature of inter-relationships between actors, and specified relative flows of cash, data and equipment. The work also identified key viability indicators, including ROI, satisfaction of customer expectations, CO_2 emissions and the impacts of market, regulatory and technical uncertainty.

Specific technical platforms comprising electrical and thermal energy storage have been evaluated, including systems comprising CHP, heat pump and PV generation technologies. The results highlight the sensitivity of financial returns to such factors as plant sizing, system efficiency and energy sale tariffs. The study also identified specific candidate platforms that offer the potential for near-term financial viability.

For both thermal and electrical storage at community-scale, the potential to ‘stack’ value streams in order to contribute to viable business models (commonly carried out in conjunction with third-party ‘aggregators’) is considerable. This is increasingly common in commercial and industrial sectors, and offers significant potential for the CES sector. Modelling the value of ancillary services income, such as from FFR, whilst also utilising arbitrage with ToU tariffs has been demonstrated in this study to significantly improve predicted CES project viability.

The ongoing rapid evolution of ICT platforms to support the delivery of networked, flexible, smart energy systems (together with the emergence of innovative service provider partners such as aggregators), offer potential commercial opportunities in this arena. However, uncertainties (and thus project risks) with regards future cash-flows from these markets remain a significant issue. Thus, step by step research of the long term performance of each potential revenue stream in conjunction with performance analysis of technology platforms in specific project scenarios is recommended.

Modelling of potential value streams suggests that development of commercially viable projects are possible in the relatively short term. However, careful context-specific due-diligence is required in order to manage risk sufficiently to deliver effective long-term development of the sector. This includes careful consideration of complex issues such as technology selection, design, and management of projects, together with those related to appropriate financial, legal and social frameworks. The open development and dissemination of the results of relevant models and techno-economic analysis can provide a valuable support for technical, policy and investment decision making suited for specific project situations.

Current uncertainty in an immature CES sector means that strong political leadership is required in order to instigate the regulatory and market evolution needed for the sector to flourish. This includes consideration of each community’s specific needs, as well as those of commercial stakeholders involved in delivering projects.

In summary, the prospects for the near-term development of a thriving community energy sector underpinned by flexible, efficient and commercially successful energy storage infrastructure are real. To ensure the sector’s success however, care must be taken to properly address the complex issues that impact upon it, which when taken together represent a significant challenge for growth. Consideration of the wider system, including the impacts of co-evolving societal, policy and regulatory aspects can help manage this complexity.

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