Cost and Value of Storage in the UK Market

Abstract

Grid-connected electrical energy storage (EES) is growing industry in the United Kingdom (UK) as a result of increased renewable generation. However there is currently no standardised method to establish if an EES project has a good business case. This project aims to outline the tools necessary to inform a model that can estimate the cost and value of installing storage onto the UK grid. This was done by conducting a literature review of the technical and economic aspects of storage in the UK market and establish the important features which would need to be accounted for in a model. It was found that from a technical aspect, sizing of the storage facility can be achieved by outlining parameter such as the power rating, energy capacity, storage and discharge duration. Whether this is technically feasible is governed by the location (both physical and in relation to the properties of the grid at that point), geography and environment in which the storage unit is located. From an economic perspective, there are a number of revenue streams which can be taken advantage of in the UK. However regulation makes it difficult for more than one stream to be used and restricts which industry players can take advantage of the revenue streams. Therefore modelling from an economic perspective must consider who the player is and hence which revenue streams will be used. The cost and revenue valuations can be achieved through net present value or levelised cost of electricity. Finally the risks to a project must be assessed (such as changes in regulation, variability of electricity prices etc.).

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Introduction

Electrical energy storage (EES) has been classed as one of the eight great technologies in which the United Kingdom (UK) can become a global leader. Grid connected EES is a rising market for many reasons. There has been a drive to reduce fossil fuel emissions due to climate change, with countries setting targets for CO_2 reduction (the European Union (EU) has CO_2 reduction targets of 40 % by 2030). This has resulted in an increase in renewable electricity generation (6.7 % across the EU since 2004), the closure of large fossil fuel power plants (such as coal fired plants in the UK) and a drive to increase the efficiency of fossil fuel generation plants. The increase in renewables generation and closure of large power plants has led to grid balancing issues as a result of intermittent and more distributed generation. [1],[2] These problems are exacerbated by increasing peak demand.

EES technologies allow flexibility when balancing instantaneous demand with instantaneous supply of electricity. This is due to the ability to time shift electrical power, act as a generator (by supplying electricity) and act as a load (by extracting electricity from the grid). Ultimately grid connected EES has the potential to improve the security of power supply and quality and minimise both the financial and environmental cost of renewable generation [3]. As a result of this companies are becoming interested in installing energy storage. However they need a method to identify if this is viable.

The aim of this project is to identify the tools necessary to inform a model that can estimate the cost and value of installing storage in the UK grid. This will be done by reviewing both the technical and economic aspects (although mostly focusing on the economic aspects) to installing EES and using this to suggest components any potential model may need to consider.

Technical Modelling

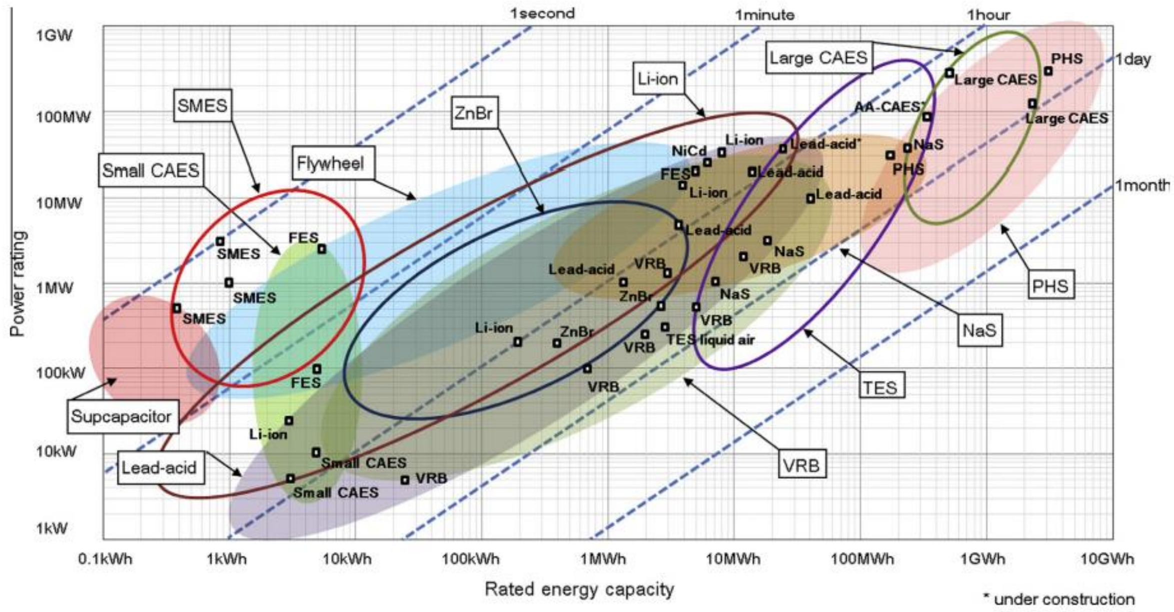

Figure 1: Graph comparing rated power vs rated energy with discharge at rated power [3]. CAES- Compressed Air Energy Storage, SMES- superconducting magnetic energy storage, VRB- vanadium redox flow battery, TES- thermal energy storage, PHS- pumped hydro storage, ZnBr, Li-ion and NaS- batteries

The aim of technical modelling is to establish the sizing and suitability of an EES system for a particular application and location. General sizing rules do not exist for the majority of grid connected EES applications as it is strongly dependent on the properties of the grid (such as power line maximum voltage) in the chosen location. This report will give details on general parameters that are important when choosing an EES device to install.

EES systems are complicated devices. A grid connected EES device consists of the physical device, storage and energy management systems, periphery and auxillaries, the converter and transformer. The physical devices can be defined by 4 sub-categories: electrochemical storage, electrical storage, mechanical storage and thermal storage which each have their own physical characteristics [3], [4].

EES can be used for a number of applications on the grid. Each application has specific requirements in terms of power rating, energy capacity, storage duration, discharge time, response time, charge/ discharge efficiency and lifetime [3], [5], [6] (some shown in Figure 1). The good practice guide has outlined general applications for different EES systems based on power rating and discharge time at that power rating (Figure 2). Suitability of an EES for an application can be assessed by matching the application requirements with the properties of an EES. Ultimately the final power rating and energy capacity are chosen based on the location of the storage and whether the grid can support the load caused by the connection.

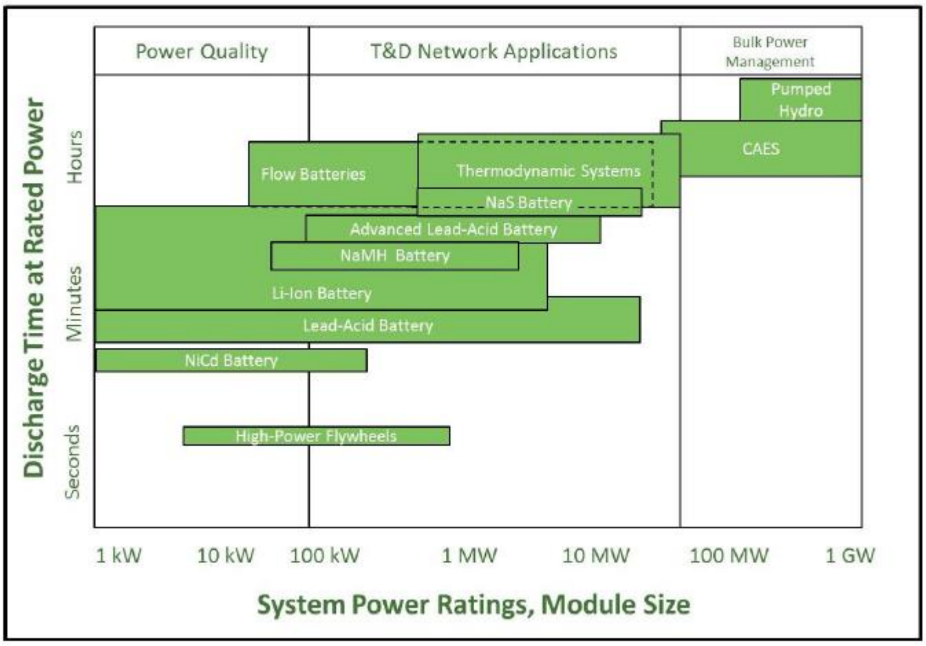

Figure 2: Energy Storage examples and their applications [4]

Technical parameters are important, however a number of other parameters must also be considered. The suitability of the location is vital- geographically, environmentally and connection suitability. PHS and CAES applications, for example, require specific geographies, such as mountainous regions and salt caverns. This often results in them being installed in rural locations, where the grid is not necessarily robust enough to support them. Other geographic considerations for operation include susceptibility to natural disaster (in the interests of safety) and temperature (some EES systems such as batteries do not work at low temperatures). The location also influences the economics of the installation as distance to generators, substations and ease of maintenance will also impact the operation costs of a project. [7]

Overall this section has given a very brief overview of the sizing parameters and considerations for grid connected EES. There are many parameters not considered in this broad review but are important technical and economic considerations such as systems other than the physical EES device (converters etc.).

Economic Modelling

This section will consider the shape of the UK electricity market, potential revenue streams within the market, the risks affecting the market and finally compare these with the current market to understand its current state.

Trading in the UK electricity market is governed by the British Electricity Trading and Transmission arrangement [8]. These are outlined in Figure 3.

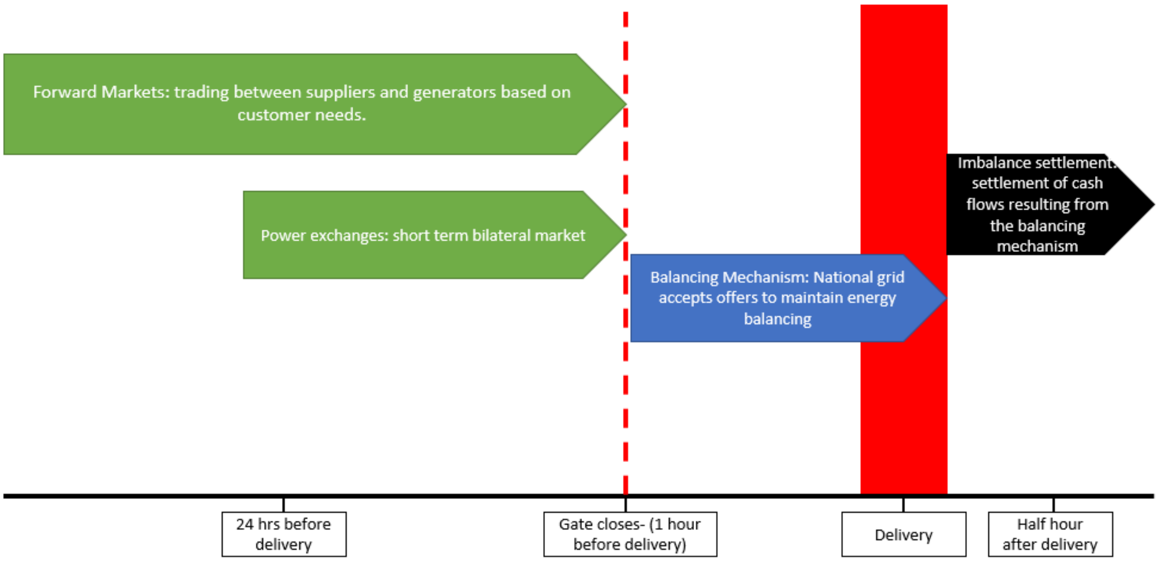

Figure 3: British Electricity Trading and Transmission Arrangements schematic. Electricity trading (wholesale) occurs up until 1 hour before delivery (gate closure). After this, bids are closed and the balancing mechanism market opens where National Grid accepts bids to maintain system balance. Finally 30 mins after delivery, settlement of the cash flow from the balancing mechanism occurs.[8]

The market is made up of the following players who have different regulations governing them. The simplified relationship between the players is shown in Figure 4.

- Consumers (also known as end-users) - anybody who uses electricity (householders or factories). In most cases these are connected to the distribution grid with the exception of large industry.
- Distribution Network Operators (DNOs) - operate the distribution grid, maintain the infrastructure on the distribution grid and ensure frequency and voltage stability.
- Transmission System Operator (TSO) – operate and maintain the transmission grid, ensure frequency and voltage stability and ensure the balance of supply and demand of electricity. After gate closure and before delivery the balancing mechanism market is open. This is where the TSO accepts offers and bids for system energy balancing.
- Generators – generate electricity. In moments of imbalance, the TSO can request for more or less electricity. Generators are charged if they do not provide the correct amount of electricity.

- Electricity Supplier – Acts as the interface between the customers and generators. They charge customers for electricity (the retail market) and then pay generators to provide it (wholesale market). Up until an hour before delivery time (gate closure) they make contracts with generators to supply electricity either through the forward market (for long term projects) or via the short term bilateral market (for quick exchange).

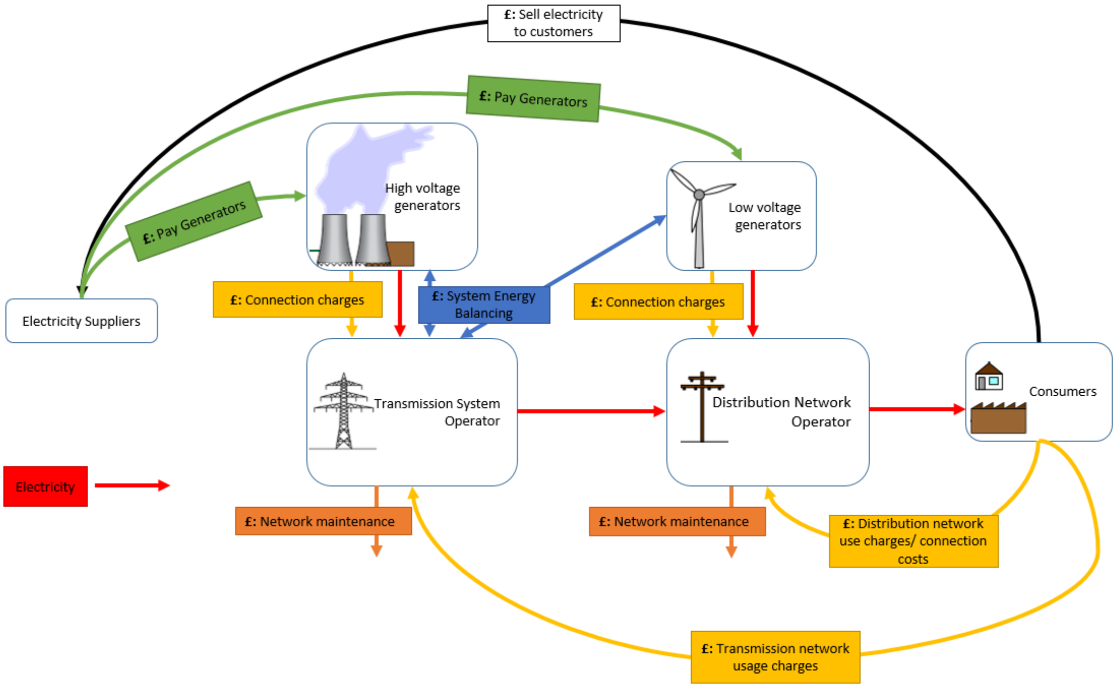

Figure 4: Simplified schematic of the relationship between players in the UK electricity market based on [8], [9], [4]. The major simplification is that settlements occur through companies such as Elexon rather than between the TSOs and generators.

EES has the potential to tap a number of revenue streams in markets identified in Figures 3 and 4. These are outlined in Table 1.

Table 1: Potential revenue streams for UK installed EES and the markets which they would affect. Coloured cells correspond to service use cases in Table 2. White means unused stream. [4], [10], [11]

Revenue Stream	Description	Market	Beneficiaries	Example Streams
Bulk Energy Management	Energy storage is used to store energy when the price is low and discharged when the price is high as well as to protect the generator from imbalance charges.	Wholesale market	Energy suppliers and generators	Arbitrage Avoidance of imbalance charges
DNO streams	These applications essentially protect the present and future assets of the DNO to ensure quality of supply. Figure 4	DNO capex avoidance and equipment protection	DNO	Network security

	shows renewables are connected to distribution networks. This coupled with most demand side connections creates frequency, voltage and thermal stability problems. Moreover in the future increases in electrical load demanded is likely to require network upgrades. Energy storage can mitigate these issues.	Balancing mechanism market (if third party owned)		Voltage and frequency control Stationary distribution upgrade deferral Improved quality of supply
System balancing services	It is the responsibility of National Grid (the TSO) to ensure supply and demand are always balanced. These revenue streams are intended to help National Grid ensure security of supply and maintenance of frequency and voltage on the network	Balancing mechanism market	TSO Suppliers and generators Aggregators and demand side response providers	Frequency response System security services Load following (tertiary balancing)
Capacity market	A new market introduced as part of electricity market reform. Due to closure of large generators, security of supply issues have arisen. The capacity market offers a revenue stream to capacity providers to provide power when the system is under stress. The capacity market does not make a distinction between technologies so diesel generators, for example, would be in direct completion.	Capacity market	Aggregators and demand side response providers	
Customer streams	These revenue streams essentially minimise the cost of electricity for the customer and to ensure quality of supply.	Customers	Industry, commercial and domestic customers	Minimising distribution and transmission network use charges and connection charges

				Use as an uninterruptible power supply
				Minimising energy use during peak price times
Renewable generation	Renewables are intermittent sources of energy. Moreover they are typically located in rural areas where there are grid constraints. EES can be used to un-constrain the generation.	Levy exempt certificates	Generators	Renewables Energy Time Shift
				Electric Bill Management with Renewables
				Onsite Renewable Generation Shifting

Assigning a value to the potential revenue streams presents an issue when modelling as some of the applications listed provide value as a result of buying and selling of electricity (such as Arbitrage) whilst others provide value as a result of avoided cost (such as infrastructure deferral). [12] have identified 3 approaches to estimating the value of storage. It is difficult to assign a specific method to a specific revenue stream as the use depends on circumstance. However also listed are some example revenue streams where the methods may be used.

- Based on market price: (eg. For arbitrage and frequency regulation)
- Based on Avoided cost (eg. Upgrade deferral applications)
- Based on competing technology/ willingness to pay (eg. Shutting down renewables vs. storing for later)

The valuation for the revenue streams is often done using net present value (NPV) or levelised cost of electricity (LCOE) methods [4], [13]. However, particularly for the LCOE method, risks to installing the technology and the future may have a significant impact on the value calculated.

[14] categorised EES risk into 3 categories: techno-economic risks, market risks and regulation and policy risks. Techno-economic risks are related to the specific technology chosen (such as redox flow batteries being developing technologies and hence a riskier investment tha lead-acid batteries). Market risks include electricity price volatility and risks resulting from the design and structure of the market. Finally regulation and policy risks are related to how current and future policy and regulation will impact the storage facility. The market and policy risks will be discussed here.

The market risks for energy storage stem from the cost. Competition for energy storage includes interconnection, demand side control and more traditional fossil fuel technologies, such as diesel generators or combined cycle gas turbines. Energy storage presents a higher risk than these technologies due to higher cost and less knowledge. Funding support mechanisms are available for EES installations, however they are mostly focussed on research and development. The funding mechanisms available are:

- DECC energy storage technology demonstration competition (eg. Orkney storage park)

- LCN fund for the DNO sector (eg. the Smarter Storage Networks projects)
- ETI- Energy Storage and Distribution Programme (eg. 1.5 MW system at Western Power Distribution substation)
- Capacity market (not R&D focussed and discussed in Table 1) [15]

The consensus is there is not enough support or funding from government. Overall this makes securing funding to cover high capital costs difficult, leading to less uptake. [4], [12], [16], [17]

Current regulation hindrances include a lack of definition for storage, the inability to operate storage with multiple revenue streams and policies such as unbundling which prevent DNOs from owning and operating storage. Storage can be classed as both a generator and an end user which can result in operators being over-charged for services. National grid contracts limit the number of revenue streams that can be taken advantage of. EES systems can provide multiple services so this limits the potential revenues. Finally unbundling means network operators cannot own and operate storage despite storage being highly beneficial for them.[4], [10], [16], [18]

The current regulations mean that only certain players are allowed to operate under certain revenue streams. For example, if a DNO wanted to operate storage, the storage facility may have to be run by a third party on behalf of the DNO- risking something other than the ideal choice, or operate the EES system but not be able to trade with it. Therefore before selecting revenue streams, it is important to identify which streams are available [10].

The risk with basing any model on these regulations stems from what will happen in the future. The UK government can control the grid make-up through policy and currently has a policy of increasing the number of renewables on the grid, creating intermittency problems. It known that increasing renewables makes EES more financially viable [19]. Despite this EES is not currently listed under any of the National Grid future energy scenarios (FES). However they have acknowledged that changes in legislation would open up the market and make EES more financially viable. [20] Moreover the government may adjust its renewables policy to encourage more stable generation, decreasing the financial viablility of storage. The existence of these hindrances and the potential for change creates uncertainty and hence risk. [13]

Table 2 outlines the currently operational EES systems connected to the grid. There are 28 systems which make up a total of 3.2 GW of storage. The table highlights the infancy of the grid connected energy storage market in the UK. The non-demonstrator projects consist of PHS, used for balancing services, and small Pb-acid batteries which support small island communities. The majority of the projects are DNO demonstrators. This is symptomatic of the funding support mechanisms being research and development and the desire for DNOs to start taking advantage of energy storage as renewables increase on the grid. In terms of modelling potential EES, this highlights the importance of considering various support mechanisms and the effect of foreseen future markets on which revenue streams may become profitable.

Overall, when modelling for an EES system from an economic perspective in the UK market it is firstly important to understand the type of player you are, the revenue streams available, regulations which bound that type of player, which support mechanisms are available and hence the chosen revenue streams. Subsequently the value and future value of the project must be assessed. To do this, techniques such as NPV or LCOE can be used to assess a certain EES system for a specific revenue stream. Risks and future trends must then be considered to understand the impact of these on the project.

Table 2: List of operational energy storage installations in the UK. The table shows the technology type, the service use case, the commercial drivers and notes showing more details for each project. The colour codes are indicated by Table 1. Developed using [11], [4]

Technology	**Project Name**	**Rated Power (kW)**	**Service Case**	**Commercial Drivers**	**Notes**
Pb-Acid Battery	Flat Holm Microgrid Project	5	🟧🟩🟩	Grid Support	Small islands separated from grid. Previously reliant on diesel generators as back-up to hydro or wind power. EES installed to replace diesel generators and support renewable generation. [21]
	Horse Island Microgrid Project	12	🟩🟧🟩	Grid Support	
	Foula Community Electricity Scheme	16	🟩🟩	Grid Support	
	Isle of Muck Microgrid System	45	🟩🟧	Grid Support	
	Isle of Rum Microgrid System	45	🟩🟧🟩	Grid Support	
	Isle of Eigg Electrification Project	60	🟩🟧🟦	Grid Support	
Na-Ni-Cl Battery	WPD Falcon Project, GE Durathon	250	🟨🟫🟨	Demonstrator	11kV grid demonstrator. Used to replace conventional reinforcement which must meet peak demand. [22]
Li-ion Battery	Northern Powergrid CLNR EES3-2, Wooler	50	🟫🟨🟨	Demonstrator	Test technical viability and cost effectiveness of moving to a smart grid as a result of the low carbon economy. 3 locations chosen: Rise Carr- urban, Denwick and Wooler- rural, Maltby- PV cluster. [23]
	Northern Powergrid CLNR ESS3-1, Rise Carr	50	🟫🟨🟨	Demonstrator	
	Northern Powergrid CLNR ESS3-3, Maltby	50	🟨🟨🟨	Demonstrator	
	Northern Powergrid CLNR ESS2-1, Rise Carr	100	🟫🟨🟨	Demonstrator	
	Northern Powergrid CLNR ESS2-2, Denwick	100	🟫🟨🟨	Demonstrator	
	Northern Powergrid CLNR EES1, Rise Carr	2500	🟫🟨🟨	Demonstrator	
	Slough Zero-Carbon Homes Community Energy Storage	75	🟩🟩	Demonstrator	Zero carbon homes with solar panels. EES allows spread of generation loads. Driven by solar feed in tariffs [24]
	ABB & UK Power Networks Energy Storage Installation (DynaPeaQ)	200	🟫🟨	Demonstrator	Small demonstrator to test EES as alternative to traditional reinforcement. Used to inform smarter storage networks project. [25]
	Slepe Farm: Solar + 250 kWh storage	598	🟦🟩🟩	Grid support	Supports Farm Power Apollo's solar PV array so it can load shift generation. [11]
	Orkney Storage Park Project	2000	🟨	Demonstrator	Project to show that it is possible for a DNO to incentivise energy storage providers to install storage. [26]

	Smarter Network Storage	6000	🟨	🟫	🟨	🟨	Demonstrator	Installed to understand economics of energy storage. Predicted to defer £8.6m in traditional reinforcement. Done through deferring of investment in reinforcement by a new subsea cable between Thurso and Scorradale. [27]
	AES Kilroot Station Battery Storage Array	10000	🟩	🟩			Demonstrator leading to Grid Support	Provides ancillary serves to transmission grid. First step towards planned 100 MW array which will provide £8.5 m in system savings and 123000 tones CO_2 by displacing an out of merit back up thermal plant. [28]
Li-ion Titanate Battery	EPSRC Grid Connected Energy Storage Research Demonstrator with WPD and Toshiba	2000	⬛				Demonstrator	Research facility designed to test energy storage technology (eg. Imbalance, voltage and frequency control) on a 11 kV grid. [29]
V- Redox Flow Battery	redT Wokingham Development Facility	5	🟧	🟩			Demonstrator	Market seeding unit to demonstrate Vanadium redox flow technology as a low cost support for PV installations. Area chosen due to high PV penetration. [30]
Flywheel	EFDA JET Fusion Flywheel	400000	⬛				Customer support	Supports fusion experiment [31]
Liquid Air Energy Storage	Highview Pilot Plant	350	🟩	🟧	🟩	🟩	Demonstrator	Pilot plant to demonstrate Liquid Air Energy Storage technology. [32]
Pumped Hydro Storage	Foyers Pumped Storage Power Station	300000	🟧	🟧			Grid Support	Provide key grid balancing services to National Grid during peak times. Located in mountainous regions due to geological requirement of PHS [4]
	Ffestiniog Pumped Hydro Power Plant	360000	🟧	🟧			Grid Support	
	Cruachan Power Station	440000	🟦	🟧	🟧	🟦	Grid Support	
	Dinorwig Power Station	2000000	🟦	🟧	🟧	🟦	Grid Support	

Conclusions and Model

In conclusion this project has identified some key areas, both technical and economic, which will need to be considered (see Figure 5). There are many areas not considered in this framework which are likely to be important- from a technical aspect: safety, operation and maintenance, end-of-life. Moreover although a couple of methods to evaluate cost and value have been established (NPV and LCOE), there would need to be some method to evaluate risk. Further work would be to look into the technical aspects in more detail and find a method to evaluate the parameters and construct a model.

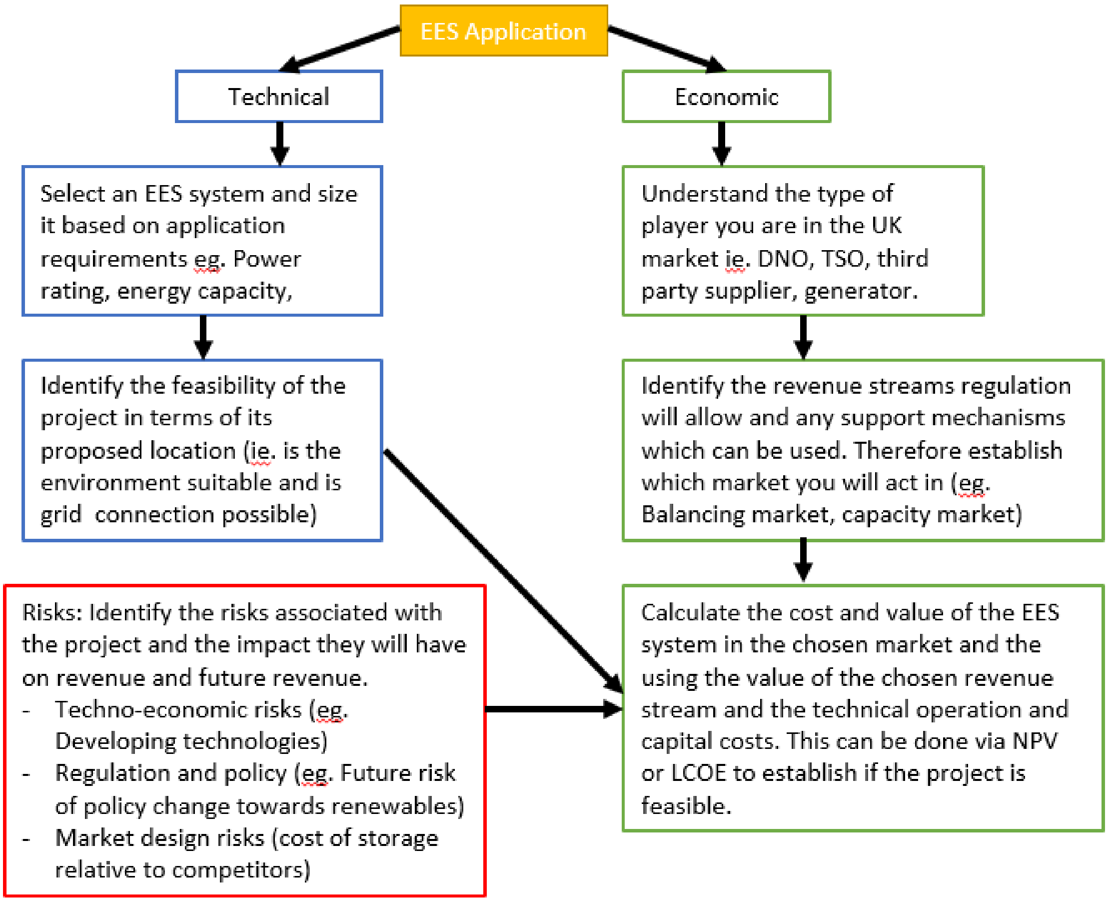

Figure 5: Framework showing the considerations a model to establish the cost and value of UK grid connected EES would need.

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