Enhanced Frequency Control Capability (EFCC)

National Grid

Battery Storage Investigation Report - November 2015

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Executive Summary

The purpose of this report is to provide the summary of the investigation into the use of existing battery storage facilities for the Network Innovation Competition funded project; Enhanced Frequency Control Capability (EFCC). As part of this investigation, National Grid carried out the following activities; starting from December 2014:

- Further reviewing the battery storage technologies suitable for demonstrations of fast frequency response in the EFCC project (in addition to the previous work carried out before submission of EFCC proforma to Ofgem);
- Engaging with the owners of these battery storage facilities which their technology was deemed to be suitable for providing fast frequency response;
- Carrying out site visit, request detailed implementation cost, timeline, and explore the technical and commercial aspects of use of one of those facilities; and
- Carrying out an impact assessment; taking into account the overall cost to the project, project delivery risk and value to consumers.
- Further on, we have performed a detailed cost benefit analysis (CBA) into the potential roll-out of the hybrid battery storage-renewable generation as proposed in EFCC.

The main findings of this exercise include:

- There are limited number of already installed battery storage facilities which are suitable for providing the fast response, namely: Leighton Buzzard, Rise Carr (Darlington), and Willenhall.
- The main challenges of using the existing sites include significant delays in delivering the EFCC project, expensive modifications costs (in case of Leighton Buzzard it will be more expensive than use of the new battery storage), and potential future costs that were not possible to clarify at this stage.
- More importantly, the inability to perform the demonstration of fast response capability of renewable energy resources combined with battery storage (hybrid) as proposed in this project, should we decide to use already installed battery storage.
- The hybrid battery storage and renewable generation (solar PV) will be the first demonstration of such concept in Great Britain, and will generate significant learning on the system benefits in the context of the System Operability Framework, and Future Energy Scenarios. Our CBA shows that should the EFCC trials being successful, a significant volume of extra response can be avoided by having longer availability of service from Battery Storage and Solar PV. This will in turn make the hybrid PV-Storage a financially attractive service option given the increase in revenue from ancillary services that can be attributed to this type of service.

On the balance of cost, project implementation risks, and value for money for our consumers, and roll-out potential we therefore recommend the use of new battery storage for EFCC project. This will enable the project to proceed with the demonstrations needed for the future frequency control at reduced cost from a wide range of resources.

Chapter 1 Purpose of this report

In order to meet carbon reduction targets, GB needs to significantly increase the volume of low carbon energy technologies that are connected to the GB transmission system. The overall impact of increasing these types of technology will be a reduction in system inertia.

System inertia is a characteristic of an electrical transmission that provides system robustness against any frequency disturbances and is a result of the energy stored in the rotating mass of electrical machines i.e. generators and motors.

As more renewable energy technologies such as wind, solar PV and other convertor based technologies (e.g. interconnectors) are connected to the transmission system; there will be a corresponding reduction in inertia since these technologies do not contribute to natural mechanical inertia.

In the GB the transmission system, frequency is nominally 50Hz and the System Operator caters for various imbalances caused by changes in demand or generation to maintain the frequency in accordance with the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). However, the lower the system inertia, the more susceptible a transmission system is to a higher rate of change of frequency (RoCoF) in the event of the loss of a significant volume of generation or demand and requires an increase in the speed and volume of frequency response.

The EFCC Project Full Submission report (October 2014), provided cost benefit analysis to show that under existing mechanisms to control frequency response used by National Grid, the future increase in response requirement to control frequency is anticipated to be £200m-£250m per annum by 2020. This cost is based on the Gone Green Future Energy Scenario as published by National Grid in 2014 that gives rise to an increase in RoCoF of 0.3Hz/s.

As set out within the EFCC Full Submission report, within Work Package 2.4, a proposal was put forward to trial battery storage as part of a portfolio of service providers for fast frequency response. The proposal included provision for investment in a new battery storage unit (plus two inverters for increased active or reactive power). Costs were included for trials to be carried out at two different locations, one of which would allow for combining battery storage with a solar PV plant.

Belectric were chosen as a project partner for the provision of battery storage and solar PV power plant for frequency response within EFCC through a competitive tender process in line with all partner selections against set criteria. These criteria included cost and contribution to ensure value for money; organisation to rate reputation and expertise; understanding of project requirements and the ability to deliver; offered solution that is innovative, low carbon, brings customer benefits and learning.

Belectric has developed, planned and built a number of hybrid projects where various energy sources are combined and controlled, including PV, batteries, diesel and water power generators. For the EFCC bid they provided detailed cost estimates that were verified and reviewed through a thorough internal review process that included National Grid procurement and finance departments.

A new battery storage facility represented a significant proportion of the EFCC project costs (approximately £1.1m). However, due to the containerised unit provided by Belectric, trials could be undertaken at Redruth in Cornwall and Rainbow Solar Farm (3.8MWp) in Gloucestershire. This will

Chapter 1 Purpose of this report

enable trials to be carried out at a location on the GB transmission system known to be susceptible to operability challenges (Redruth) as well as gaining valuable learning from the battery unit sited at Rainbow Solar Farm.

However, to ensure EFCC represents the best possible value for consumers in advance of any expenditure, a Decision Point was included within the project timescales to allow National Grid to investigate the use of existing battery storage sites within the UK.

This report details the outcomes of investigations considering technical and commercial implications of using existing facilities within the EFCC project as well as impact on timescales. Comparison and commercial analysis is presented between those sites deemed most appropriate for use for fast frequency response versus the installation of an additional battery storage facility. Furthermore, the benefits of a hybrid solar PV and battery storage solution are presented.

Since the initial report that was completed in June 2015, additional chapters and updates have been made in this revision. The changes are as follows

Chapter 6	Update on use of Redruth site for battery storage; Belectric contribution to solar PV and battery storage.
Chapter 7	Cost benefit analysis (CBA) for future roll out of hybrid battery storage and solar PV. This chapter provides a detailed CBA identifying the number and MW capacity of potential solar farms that could install battery storage and projected future deployment if the EFCC project is successful.
Chapter 8	Revised Project Schedule for Work Package 2.4 (Battery Storage) The original EFCC project schedule for this work package assumed an investment decision point would be reached by August 2015 hence revised timescales are proposed.
Chapter 9	Legacy options for Belectric Battery Storage Unit. This chapter outlines the considerations that will be taken into account towards the end of the project for future use of the new battery storage unit if investment is approved.

Finally, a recommendation is proposed that establishes and quantifies the benefits, potential learning within EFCC and value to consumers to enable Ofgem to determine if investment in further battery storage should be made.

Chapter 2 Use of Battery Storage within EFCC project

The objective of the EFCC project is to develop and demonstrate an innovative new monitoring and control system which will obtain accurate frequency data at a regional level, calculate the required rate and volume of very fast response and then enable the initiation of this required response. The control system will then be used to demonstrate the coordination of fast response from wind, large scale thermal generation, demand side resources (DSR), solar PV and battery storage. Utilising the output of these trials, a fully optimised and coordinated model will be developed which ensures the appropriate mix of response is utilised. This will support the development of an appropriate commercial framework at the end of the project.

Figure 1 below shows indicative GB regional zones for regional control and the proposed Alstom scheme to monitor wide area frequency measurements and control the response providers.

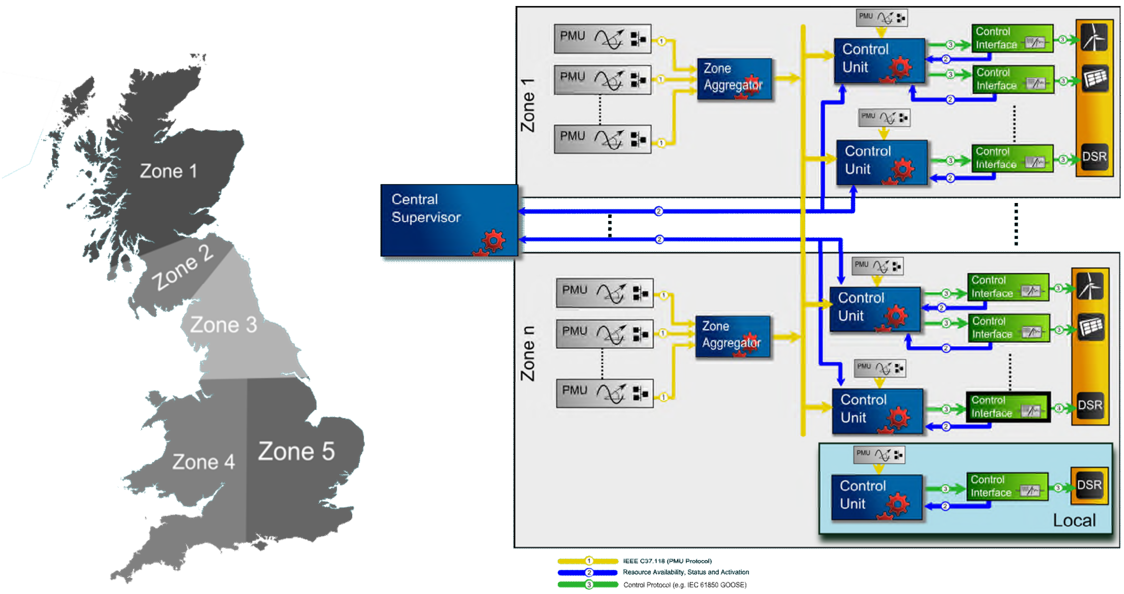

Figure 1: Control System Architecture

Battery storage is regarded as a central part of the fast services to be trialled within the EFCC project. Previous studies and practical solutions have demonstrated that battery storage is able to provide fast and sustained response on various networks to maintain stability. Connected to the wide area measurement of Alstom, the battery shall provide fast and local frequency response, based on central and locally derived response signals. The goal is to counteract local frequency deviations in order to neutralise them before they become a major disturbance. This has to be done close to the source of disturbance and in a timeframe of well below 100ms, since this is the typically measured time of such disturbances. The battery response trials shall be based on:

Chapter 2 Use of Battery Storage within EFCC project

- Maximum response to curtail reduction in frequency. Trial the fastest possible rise and sustained response until frequency is restored or stored energy is used.
- Frequency following (Proportional Control; output in response to variations in frequency). This response could be enabled locally and controlled.
- Set-point following initiated from a remote signal in combination with other response providers. This mode could be used by the monitoring and control system to sustain a frequency response.

In addition, a further trial could be to use historic data (i.e. over the previous few milliseconds) to predict upcoming frequency drops.

While the above is a way of frequency stabilisation by actively responding to a measured signal ("active response"), there is as well, a passive response which is crucial for grid stability: the grid inertia. Grid inertia is traditionally supplied by the rotating mass of synchronous generators. Due to increasing penetration levels of renewable energy in the network, the share of synchronous generation is dropping rapidly as well as inertia. The reason behind this is lack of inertia of the physical generation source (e.g. solar PV panel in case of solar energy and of the grid coupling inverter). There is simply no mass turning. A battery – on the contrary – is capable of simulating inertia, since it may provide a very high short circuit power. Given that this is combined with a fast reacting inverter, it may provide a "virtual inertia" by very fast active control (<20ms). In this way it may replace the inertia traditionally supplied by synchronous generators and shall be trialled during the project.

2.1 The Main Drivers for using battery storage

- Demonstrate the principle operability of a frequency control battery on the network.
- Demonstrate different reaction speeds.
- Demonstrate emulation of rotating generators and their inertia by implementing a very high response rate (milliseconds or tens of milliseconds).
- A direct connection to an external entity (i.e. the NETSO) shall be established, so definition of working points, response statistics or direct command and control may be done from a central point outside the unit.

2.2 Innovation and Learning Outcomes

- Innovative command and control schemes will be implemented that enable the battery to act similar to rotating machines, providing short-circuit power capacity, and respond to external control signals.
- Evaluation of the challenges of incorporating batteries in network regulation (e.g. various States of Charge) and their advantages will be studied.
- The financial benefits of operating a battery in the plant will be studied and the development of a future financial compensation and commercial policy for battery operation will be outlined. This will provide a vital new tool for National Grid as we continue to manage the GB system.

- Allow a fuller assessment of the potential for greater competition in frequency response service provision that can inform other Transmission Licensees.
- Demonstrate battery storage can best be coordinated to provide an optimised response across a range of resource providers.
- The response capabilities of new technologies are not currently being fully utilised. With the increase in the amount of renewables connected to the GB electricity system, it is vital that a more diverse range of resources are able to contribute to system stability in a more economic and efficient way.
- Potential for knowledge of the capability of batteries and solar PV power plants in delivering grid services on different levels.
- Support the development of performance requirements for roll out of an Enhanced Frequency Control Capability as a new balancing service.

2.3 Impact of Future Energy Scenarios on system operability

Annually National Grid publishes four future energy scenarios that outline possible variations in generation and demand patterns. Last year under the Gone Green scenario, predicted that in meeting the UK renewable energy targets, solar PV would contribute 2.3GW of installed capacity by 2020.

The connection of embedded generation is increasing rapidly in GB. Due to its lower operational voltage these installations are connected to Distribution Network Operators (DNOs), hence its output will offset the total demand seen at the interface boundary between the transmission and distribution systems.

In order to maintain the system frequency within statutory limits, the System Operator must balance generation and demand. However, as the volume of intermittent generation sources grows, the demand seen by the transmission system will become increasingly volatile and pose challenges in predicting demand and therefore operation of the transmission system.

Figure 2 below, shows an average demand profile for an average Sunday in July for the Gone Green future energy scenario. Historical data has been obtained between 2005 – 2008/9, excluding the impact of embedded generation and has been scaled against the summer minimum demand values to produce a base demand daily profile. Planned solar daily profiles have been derived from average output profiles and scaled to 84% of capacity (14GW). The resultant transmission demand profile is offset by the solar output. Between the dotted line, illustrating the natural load and the hard red line of the planned embedded solar case there is some 18GW of difference over the course of a day.

Chapter 2 Use of Battery Storage within EFCC project

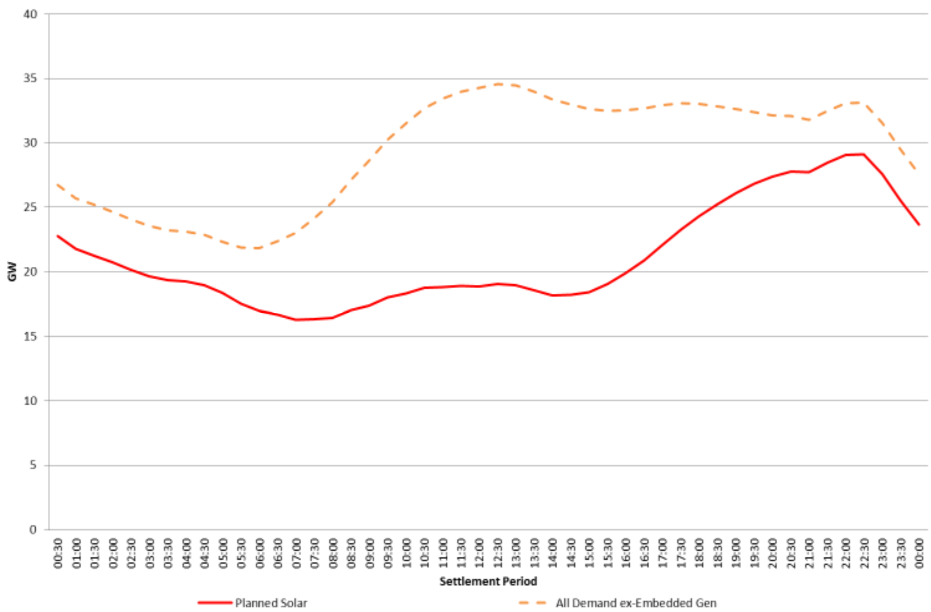

Figure 2: Impact of increasing solar PV on the transmission demand pattern (2020)

Against such declining demand levels, there is a danger that in particular regions of the network where there is high concentration of solar PV, there is potential for parts of the network to be disconnected. This could arise when there is a frequency excursion that triggers LFDD (Low Frequency Demand Disconnection) which is an operational method used to correct the imbalance between generation and demand. If LFDD action occurs, the network could represent negative demand and further contribute to any frequency disturbance which takes the system beyond normal frequency containment limits.

In addition to managing the system with increasingly volatile periods of transmission demand, solar PV is connected to the system via power electronics and therefore does not provide inertia. As mentioned in Chapter 1, this means that a system with lower inertia will be susceptible to high RoCoF necessitating increased frequency response to be held by the System Operator. Historically to operate the system in low demand periods, generation is constrained and interconnector imports restricted. However, as a greater proportion of generation is supplied from intermittent sources, more frequency response will be required from alternatives to conventional generation such as those being trialled in the EFCC project.

An alternative approach is to combine solar PV with battery storage. This will allow storage to be used to better regulate or smooth the transmission demand profile or be used to provide response during periods of rebalancing as other conventional plant ramps up to provide a sustained response to maintain frequency within limits.

Use of batteries would offer the flexibility either to reduce the effective generation contribution to the distribution system which is observed at these times of stress, or to provide additional fast response to support frequency containment under high RoCoF events, instead of reliance upon the natural inertia of (slower responding) conventional generation or LFDD action.

2.4 International Experience

In Germany renewable energy contributes significantly towards their total generation capacity. It has been recognised that due to the higher volatility of generation and demand patterns, battery storage can play an active part in smoothing this volatility as well as providing fast frequency response. The four German TNOs, Tennet, Amprion, Transnet BW and 50Hertz have enabled renewables to participate in the frequency reserve market by changing their bidding/procurement timescales and established prequalifying criteria to fully benefit from the potential combining solar and battery plants to ancillary services.

Last year in the US, the State of California passed legislation mandating that energy storage facilities be installed to support the integration of additional solar and wind energy in order to meet their utility owned energy storage target by 2020 (approximately 1.3GW)[6]. It is the first state to do this, but is recognition that storage systems can support the uptake of renewable technology connected to utility networks in addition to providing standalone peak load reduction, voltage support and frequency response services. As an example of this uptake, Invenergy (developer of clean power generation and energy storage projects) has installed a 31.5MW battery storage in central Illinois which is located near a wind farm project and solar plant to provide fast frequency response as well as other ancillary services [7].

Furthermore, in order to integrate more wind energy into an island system in Alaska, the electricity utility installed a 3MW battery storage system instead of connecting more diesel generation as spinning reserve. In addition to mitigating the curtailment of energy from wind farms, the lead-acid battery system is capable of providing frequency response within 0.5s if required [8].

The Zhangbei National Wind and Solar Energy Storage and Transmission Demonstration Project includes a total of 17MW/70MWh of energy storage through a combination of lithium-ion and vanadium redox flow battery technologies. The use of batteries supports the integration of wind, solar and other renewable energy providing frequency regulation and voltage support to the grid [12].

Chapter 3 Evaluation of existing battery storage in the UK

As a starting point for evaluating existing storage facilities for potential use with the EFCC project, information was collected using the Energy Storage Operators' Forum published documentation. In addition, a general enquiry was sent to all Distribution Network Operators (DNOs) that currently have demonstration battery storage facilities or are due to install battery storage within the timescales of the EFCC project. The email outlined our objectives, the reasons for the enquiry and the possibility of participating in the project. In addition, a technical questionnaire was compiled and attached to the enquiry to provide DNOs with information that the EFCC project would like to assess.

A full list of energy storage sites and associated technical criteria that was compiled from documentation within the public domain as well as individual site specific details provided by DNOs. This is shown in Appendix B.

From the initial information gathered, it was possible to eliminate a number of existing storage sites for suitability for inclusion within the EFCC project based on the following criteria

1. Battery technology.
   Flow type batteries as demonstrated at Nairn, FALCON and the DECC Energy Storage demonstration sites [2] were excluded on the basis that they will not provide the required fast <0.5s response times to be trailed. Due to the time taken for electrolytes to mix that is inherent with this technology to produce a change in power output, fast response times cannot be achieved. Additionally, the power to capacity ratio of these batteries is not favourable for short-term, high-power applications that are being trialled in the EFCC project.

2. Power output and Capacity
   It is preferable for the battery unit to have a high power output so it will increase its contribution to alleviating significant RoCoF by increasing or decreasing larger amounts of power. Essentially for rapid frequency response it is beneficial to have more power delivered at less installed capacity.

3. Connection to the system
   The battery unit must be connected to the electricity network, hence units sited in the Scottish Highlands that maintain security of supply could not be utilised for the project.

3.1 Timescales for EFCC trials

Within the EFCC project submission, the project plan outlined the installation and evaluation of a new battery control system between October to December 2016 for integration with the Alstom monitoring and control system. This is in advance of frequency response trials taking place from January 2017 to September 2017.

3.2 Short-listed battery units

Three sites were chosen for further investigation as possible candidates for participation in the EFCC project. These sites are Leighton Buzzard (6MW, 10MWh, Lithium Nickel Manganese Cobalt Oxide), Darlington (2.5MW, 5MWh, Lithium Iron Phosphate), Willenhall (2MW, 1MWh, Lithium-Titanate).

The respective DNOs (UK Power Networks, Northern Power Grid, Western Power Distribution and) were approached in order to discuss the viability of using these storage sites.

3.3 Smarter Network Storage (SNS) at Leighton Buzzard

The Smarter Network Storage (SNS) project at Leighton Buzzard is an LCNF project that is to explore multi-purpose use of battery storage from a technical and commercial perspective. The main driver for battery storage at this site was to defer traditional reinforcement in order to maintain demand security compliance at Leighton Buzzard, but the project is also trialling the provision of commercial ancillary services to the transmission system.

Representatives from Belectric and National Grid attended a site visit to Leighton Buzzard to further understand the battery and inverter technologies, how the site is controlled as well as the future operational timescales within the lifetime of the project. One outcome from the visit is that it is unclear if the control system can be modified to allow rapid response as per EFCC objectives.

The storage system is fully contained within a dedicated building adjacent to Leighton Buzzard substation in Bedfordshire. The building also houses separate inverter and control rooms.

The battery size (6MW, 10MWh Li-NMC, Lithium Nickel Manganese Cobalt Oxide) offers a power/capacity ratio of 0.6. There are 3 sets of 2MW battery stacks that are controlled by dedicated energy storage management units that are controlled locally by a central control system that can be accessed remotely. There is a forecasting and optimisation system for scheduling services which can be enabled via a control room so there could be the possibility of trialling both local and remote frequency response for EFCC. Overall, the speed of response will depend on the initiation being local or remote. It is anticipated that the response time could be less than half a second but it is more likely that the response time will be between 0.5s and 1s. The EFCC project is aiming for a target response time of 0.1s.

SNS is currently trialling frequency response provision under National Grid's existing ancillary services (using a demand side aggregator); hence trialling with EFCC fits within their scope of objectives.

The SNS project is due to complete in its entirety by December 2017 and it is the intention of UK Power Networks to complete all their scheduled trials by December 2016. Given this, there is not an exact alignment of timescales between the projects, and there is some risk that the trial period for SNS could be extended in order to meet their project milestones.

UKPN has provided estimated costs for using SNS within EFCC. These are summarised in Chapter 5 in the Commercial Analysis section of this report. In addition, UKPN will be entering into commercial contracts for the provision of ancillary services. The Commercial team in National Grid has estimated a cost for these services that could be paid to UKPN in order to compensate for loss of revenue during the trial period.

Image 1 (courtesy of UKPN): Smarter Network Storage (SNS) at Leighton Buzzard (6MW, 10MWh, Li-NMC).

Image 2: Site visit to SNS at Leighton Buzzard

3.4 Rise Carr (Darlington)

Northern Power Grid (NPG), as part of their Customer-Led Network Revolution LCNF project, installed a 2.5MW/5MWh LiFePO4 (Lithium Iron Phosphate) battery, unit at Rise Carr to investigate how a battery can be used to facilitate the uptake of low carbon technologies.

Chapter 3 Evaluation of existing battery storage in the UK

The project completed in December 2014 and currently NPG is considering future research and commercial opportunities for the battery storage unit. In discussions with NPG, participating within the EFCC project is being considered as an option, and a decision on the future utilisation of the battery is expected summer 2015. Since the June issue of this report, NPG has stated that the Rise Carr site is likely to be used for commercial ancillary services as well as local demand support. Indication has been given that these commercial services could be suspended for use within EFCC although this is to be confirmed.

The Rise Carr is built up of three separate shipping containers, 1 x Inverter section and 2 x Battery Rack Containers and offers a power/capacity ratio of 0.5. Similarly to SNS, it can be controlled both locally and remotely (including monitoring status and alarms, overall system data etc.). This is achieved through dedicated software that can be used via a web browser. For remote control the communication time is given as 20ms so a fast ramp response can be achieved in less than 100ms which is the target response time for EFCC.

Estimated costs for its use within EFCC have been provided and these are summarised below in Chapter 5 (Commercial Analysis) of this report. There is a possibility that NPG will undertake other trials or even participate in the ancillary services in advance of the outlined trial period for EFCC. If this occurs, for the duration of the EFCC trial period, it is likely NPG will have to suspend its ancillary services activities and possibly compensated for loss of revenue. These services are bilaterally contracted and since negotiations have not commenced, it is not possible to incorporate an allowance. This cost exposure poses a risk for the EFCC project.

Image 3 (courtesy of NPG): Battery storage unit at Rise Carr, Darlington

Chapter 3 Evaluation of existing battery storage in the UK

3.5 Willenhall

A 2MW/1MWh Li-Ti (Lithium-Titinate) battery unit is due to commission at Western Power Distribution's Willenhall substation at the end of July 2015. This is an EPSRC funded project to investigate the characteristics of Li-Ti (this is the first battery of this type to be trialled in the UK), how different battery chemistries can work together for grid use and the coordination of large storage with EV (2nd life) batteries. The project is being managed by the University of Sheffield who will be carrying out research studies on Li-Ti cell degradation and integrating battery characteristics. Aston and Southampton Universities are also involved in the project looking at the optimum use of 2nd life EV batteries and vehicle to grid research.

The battery is housed in a containerised unit sited on land leased from WPD. It has a power/capacity ratio of 2 which is more favourable than the other sites for fast frequency response. There is a dedicated management system that has a localised control interface, and in addition the University of Sheffield has developed a bespoke remote control system that separately controls the battery management system and the inverters. In this respect, any Alstom frequency control system for EFCC will have to be integrated with the University of Sheffield system to enable frequency response demonstrations. It is anticipated that a fast ramp response in line with the target response of 100ms for EFCC can be achieved.

Funding for the project has provided the battery unit, inverters and associated assets for the connection only. This is a purely research based project whereby the University of Sheffield is endeavouring to gain as much learning as possible throughout the lifetime of the battery (guaranteed for 10 years). As such, they are seeking interest in projects that could further the understanding of how Li-Ti operates, although the provision of grid services is not the primary objective.

Estimated costs for use within EFCC have been provided and are summarised in the Commercial Analysis section of this report. At the time of the June report, access to the battery for the EFCC project could be made available from October 2016 (for control system modifications) through to the end of the proposed trial period at the end of September 2017. Costs are associated with University staff and contractor resource as there is no commercial cost exposure for EFCC as the Willenhall project is for research purposes only.

Image 4 (courtesy of The University of Sheffield): Willenhall battery unit

Chapter 4 Belectric Energy Buffer Unit (EBU) Battery Storage

The Belectric solution consists of a 40” containerised high power lead acid battery that is optimised for frequency regulation. It features a capacity of 948kWh and a deliverable power of 700-1400kW depending on time and inverter configuration. The same battery type has shown to last 7000 full cycles in frequency regulation (BEWAG battery, Berlin 1986-1994) and has been integrated into a scalable and easily deployable stationary system using the technological advances of the last 20 years. The system is equipped with air conditioning and a powerful external venting for continual high power applications, with automatic water refilling, electrolyte mixing and cell detailed battery monitoring system to facilitate maintenance and remote operation. In addition it features a safety system for hydrogen venting and charge control as well as an operating system which includes operation, battery management and data provision (e.g. State of Charge, currently available power, remaining total battery capacity) linked to a central SCADA system. It can be operated remotely and has the same local and remote interface.

The battery system (developed from solar applications) is coupled to a GE based inverter skid in an outdoor configuration complete with 11kV or 33kV transformer.

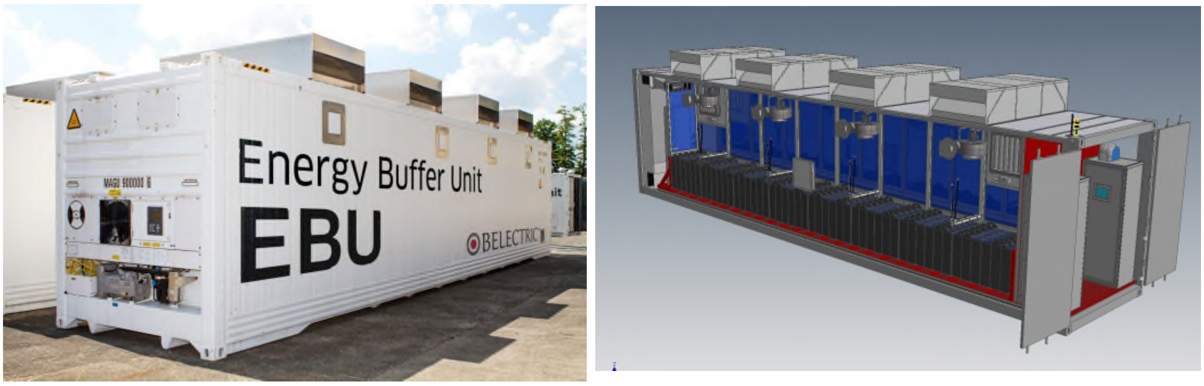

Image 5 (courtesy of Belectric): Energy Buffer Unit (EBU) battery storage

The inverter and the control system have been optimised for fast response times. Inverter based control schemes such as virtual inertia and frequency generation, feature a reaction time less than 20ms. Control schemes invoking the operating system (frequency response, central command response) feature a round trip time of under 100ms due to stringent loop time control and a real time interface between control system and inverter.

Chapter 4 Belectric Energy Buffer Unit (EBU) Battery Storage

Image 6 (courtesy of Belectric): EBU (battery storage) with inverter installation at Alt Daber, Germany

As the battery unit is containerised it can be relocated to further provide economises within the project. Belectric has nominated two different sites (Rainbows Solar Farm, in Gloucestershire and Redruth in Cornwall) where the battery can be sited during the project.

The two different locations for the battery unit were put forward as part of the EFCC submission for separate reasons. The Redruth site was proposed in order to demonstrate independently how the EBU can provide fast frequency response in a part of the network where there are existing challenges in maintaining system stability. This will allow optimising of the Alstom monitoring and control system in conjunction with this response provision in a known constrained part of the network.

Conversely, Rainbows Solar Farm was nominated to demonstrate how solar PV plant combined with battery storage can provide additional learning for rapid frequency response. This is discussed further later in this report in Chapter 6 “Opportunities for combining solar PV and battery storage in EFCC”.

4.1 Future use of potential Belectric Battery Unit

If a new Belectric battery unit (EBU) is to be used in the EFCC project, consideration must be given to its ongoing use for the lifetime of the installation.

As mentioned in Chapter 3 “Evaluation of existing battery storage in the UK”, the rapid frequency trial period is due to complete at the end of September 2017, which gives sufficient time to carry out knowledge dissemination in advance of project closure at the end of March 2018.

The proposal for use of the EBU would be to participate within the new fast frequency commercial framework to be developed by the EFCC project. The EBU would also be able to provide a range of ancillary services to National Grid through existing mechanisms to assist in system stability.

Moreover, the system would be made available for further research activities to provide knowledge of the viability and capability of the system. Further considerations of legacy options are detailed in Chapter 9.

Chapter 5 Commercial Analysis of shortlisted storage units

The analysis below outlines the cost estimates associated with using existing battery storage units at Leighton Buzzard, Darlington and Willenhall. The base costs shown have been agreed with the respective DNOs or in the case of Willenhall with the University of Sheffield. These costs are commercially sensitive and as such will only be included in the report submitted to Ofgem and with the not be made public.

As previously described in Chapter 3, SNS at Leighton Buzzard is due to enter into commercial contractual arrangements with National Grid for frequency response. It is anticipated that during the trial period for EFCC, SNS will not be able to fulfil these arrangements therefore the EFCC project will need to reimburse their potential loss of revenue. Due to commercial sensitivity with differing frequency response products that are negotiated, it is not possible to publically specify the contract terms (e.g. price per MWh or time of use etc.). The Commercial Services department at National Grid has estimated the cost of these services outlined in the report to Ofgem.

Similarly, the battery unit at Rise Carr may also need to be compensated for loss of revenue if they enter into commercial contracts for frequency response but this is yet to be determined.

The engineering costs shown below for the existing battery storage sites include labour costs for modifications to control and IS systems for the estimated 3 month period as set out in the schedules in the EFCC Full Submission. Additionally, for some sites, consideration is given to warranty extensions. It must be noted that these are high level estimates that are likely to change and be subject to site surveys and further investigations to be undertaken during the project. The cost breakdown for each site is outlined in the sections below.

5.1 Cost summary for Smarter Network Storage (SNS)

	Cost (£k)
Commercially Sensitive Information	
Additional project management	150
Alstom additional project management cost including engagement with new project partner	100
PROJECT TOTAL	**1169**

Table 1: Cost of use for SNS at Leighton Buzzard for EFCC

Chapter 5 Commercial Analysis of shortlisted storage units

Commercially Sensitive Information

- Operational Telecoms resource (to cover any design or mods to communications systems)
- IS Architectural resource (to cover any design or mods to existing system architectures)
- RTU / ENMAC integration technical resource (to cover any design or mods to SCADA systems)

Commercially Sensitive Information

The contingency estimate is based on half of total engineering design contractor costs (i.e. to account for uncertainty in carrying out the modifications as it is unclear the extent required). It will also cater for any additional expenditure prior to installation of control equipment, or additional commissioning requirements during the frequency response trial period.

5.2 Cost summary for Rise Carr (Darlington)

	Cost (£k)
Commercially Sensitive Information	
Additional project management	150
Alstom additional project management cost including engagement with new project partner	100
PROJECT TOTAL	**444**

Table 2: Cost of use for Rise Carr at Darlington for EFCC

Chapter 5 Commercial Analysis of shortlisted storage units

The category for “Other Operation & Maintenance costs” includes maintenance, communications, engineering support and future provision for battery cell replacement. The NPG engineering resource includes installation and control engineering, commissioning and some project management costs. Similarly, contract engineering has been estimated for design, commissioning and project management activities.

NPG has provided a full breakdown of these costs with estimated time to be taken for each activity as well as daily rates for each resource; this is shown in Appendix C.

It is to be noted that the base cost as provided by NPG is a budget estimate for the use of Rise Carr within the EFCC project.

5.3 Cost summary for Willenhall

	Cost (£k)
Commercially Sensitive Information	
Additional project management	150
Alstom additional project management cost including engagement with new project partner	100
PROJECT TOTAL	**483**

Table 3: Cost of use for Willenhall for EFCC

As mentioned earlier in the chapter, the battery unit at Willenhall is for research purposes only, resulting in a lower potential cost of use, and therefore does not require compensation for lost revenue associated with commercial services provision.

5.4 Cost Summary for Belectric Energy Buffer Unit

	Cost (£k)
Site preparation	14
Battery unit plus 1 inverter	520
Second inverter (to provide higher power)	96
Electrical equipment modifications at Rainbows solar PV plant	70
Electrical equipment connection at Redruth	128
IT and communications systems	24
Contingency	186
BASE TOTAL	**1100**
Additional project management	0
Alstom additional project management cost including engagement with new project partner	0
PROJECT TOTAL	**1100**

Table 4: Summary of battery storage cost of use within EFCC

As mentioned in Chapter 3 “Evaluation of existing battery storage in the UK” the total cost for the Belectric solution includes provision to mobilise the battery storage unit at Redruth and Rainbows Solar Farm. There are no additional project management costs as these have already been accounted for within the project.

The detailed cost breakdown as provided in the EFCC Full Submission Document is shown in Appendix D.

5.5 Summary

Table 5 below summarises the capability of each site for rapid frequency response, the total cost of use for each site, and the viability of inclusion within EFCC project timescales.

Chapter 5 Commercial Analysis of shortlisted storage units

Table 5: Summary of battery storage cost of use within EFCC

	Capability for rapid frequency response for EFCC	Cost of use (£k)	Inclusion of compensation for commercial services	Availability/ Timescales for EFCC	Additional learning for EFCC (hybrid-renewable & storage)
SNS (Leighton Buzzard)	Likely[1]	£1169	Yes	Uncertain	No
Rise Carr (Darlington)	Likely[1]	£444	No	Uncertain	No
Willenhall	Likely[1]	£483	Not Applicable	Uncertain	No
Belectric	Yes	£1100[2]	Not applicable	Yes	Yes

(1) The control system changes and integration into the EFCC control system is the uncertain element at this stage
(2) Cost includes site preparation, installation of new battery unit, inverters and relocation of battery system

For the SNS project due to the existing control system configuration, there is uncertainty whether even after the integration of the Alstom control and monitoring system, the target response for the project can be realised. It is an ongoing innovation project and as such has its own specific objectives that must be met. There is a risk to the EFCC project that fast frequency response trials will be delayed if SNS objectives take priority over the EFCC project.

In the case of Rise Carr, there is uncertainty whether NPG will allow their site to participate in the EFCC project. There is the possibility of obtaining rapid frequency response, though again, the extent of control system modifications may negatively impact the EFCC project as it is likely that the site will have ongoing commercial activities. Furthermore, there may be an additional cost exposure for compensation for ancillary services. At this stage it is not possible to quantify what the ancillary service cost may be as commercial contracts are not in place.

Both SNS and Rise Carr sites have lower C-rates (power/capacity ratio), that will not provide the opportunity to trial low capacity/high-C-rate installations in order to obtain the full potential of rapid frequency response and hence optimise the future value of rapid frequency response provision.

With respect to Willenhall, it has a more favourable C-rate it is anticipated that the target response to RoCoF can be achieved. At time of writing, the University of Sheffield is actively seeking research opportunities. Like the SNS project, it has specific objectives and other projects may be agreed upon during the determination process that may not align with the EFCC project timescales.

For the Belectric solution, some discussion has taken place within the EFCC project so far, leading to there being greater clarity regarding the control system interfaces between Belectric and Alstom which reduces this risk. Moreover, since this would be a new installation the risk for access to carry out modifications and carry out trials is mitigated.

Chapter 5 Commercial Analysis of shortlisted storage units

The information gathered has shown that currently there is a limited portfolio of energy storage technologies that are capable of providing fast frequency response. The three existing storage sites that have been shortlisted all utilise Lithium Ion batteries. Allowing the installation of a lead-acid battery unit provided by Belectric will provide valuable knowledge and learning from this technology in the area of fast frequency response. It will also demonstrate to the wider industry that other battery technologies can be utilised for fast frequency response and potentially other future ancillary services.

Only the installation of a Belectric battery unit will allow the full realisation of combining renewable generation (solar PV) with battery storage to trial their full potential. The battery unit can also be relocated to two different locations to provide increased learning of differing site and network conditions within the EFCC project.

The cost benefit analysis included in the full EFCC project submission showed that under the Gone Green future energy scenario, by 2020 and with the implementation of the EFCC project, the potential cost saving to consumers would be approximately £200m per annum. The investigations of existing battery storage units has shown that the estimated cost of additional learning that can be achieved through investment in battery storage plus solar PV is in the order of £69k to £693k. Only with this investment can the full realisation of EFCC objectives be achieved and therefore the full cost savings passed on to consumers. This is explored further in next chapter.

Chapter 6 Opportunity for combining solar PV and battery storage in EFCC

In the UK, there is ongoing work with innovation projects to allow battery storage resources to be used for the provision of ancillary services to support the electricity system. This may lead to the emergence of new commercial frameworks to allow storage to participate within existing commercial markets.

However, the EFCC project is seeking not only to generate a new rapid frequency response mechanism from non-conventional resources, but to understand and fully realise their full potential in providing cost savings over conventional services.

Chapter 2 discussed how significant amounts of solar PV connected to the network is offsetting the transmission system demand profile, and due to its variable output, makes maintaining the generation and demand balance (hence frequency) more challenging. Furthermore, solar PV does not provide natural inertia to the network. Battery storage can be used to alleviate the power imbalance and provide fast frequency response when required. The EFCC project seeks to realise by demonstration through the project, the benefit of combining battery storage with solar PV.

6.1 Trials for Solar PV and Battery Storage

The combination of solar PV and battery technologies will provide an opportunity to expand the scope and therefore the learning outcomes over and above rapid frequency response trials for battery storage alone. In order to increase the leverage and to reduce cost of frequency control, the battery-based response shall be supplemented by PV-based response. For overall frequency control the battery needs to be capable of providing equal response in either direction: positive and negative. This means, the battery needs to be at a state of charge (SoC) of around 60 % in order for it to have the capacity to be charged and discharged at equal rate and for equal time. Locally combining the battery with a response provider who might deliver negative response (by power curtailment) allows the battery to raise its state of charge up to 95% and therefore provide more positive response for a longer period of time (at the same time neglecting the negative response which is taken over by the PV power plant). Provided this integration takes place on the same site, communication will be sufficiently fast and failure rate will be sufficiently low in order to provide response at an acceptable reliability. A combined system of this kind will significantly increase the value of a battery for the system operator with negligible addition of cost (cost of curtailed PV energy). The value of this could be trialled during the project. Hence the following can be undertaken

1. Work out operational scheme for lowering and raising SoC of the battery to comply with the actual capability of the PV power plant to deliver negative response (corresponding to current level of irradiation i.e. PV power.

2. Optimise the response distribution between battery and solar PV e.g.

    - Battery provides 100% of battery positive response, 0% of negative responses from 95% SoC (State of Charge).
    - Battery provides 100% of battery positive response, 50% of negative responses from 80% SoC (State of Charge).

    The objective is to have an optimal operation scheme minimizing the cost of PV power curtailment and at the same time maximising the value of the battery as a response provider.

3. Integrating a variable response unit into grid management.

A battery based frequency response unit has an efficiency typically in the range between 80% and 90%. The corresponding losses during battery operation have to be replaced by an external source. This may well be done by the production of the adjacent PV power plant - especially, if the latter is currently curtailed due to distribution network limitations.

6.2 Belectric Contribution with solar PV and battery storage

Belectric provides utility-grade PV power plants that enable safe, reliable, and efficient power generation and proven experience with incorporating PV plants and battery storage for frequency regulation.

Rainbows Solar Farm 3.8MWp near the village of WIllersey in Gloucester is currently operated by Belectric. This site (also known as Willersey Solar Farm) has been nominated as a potential site where the EBU and associated equipment can be installed in order to demonstrate how solar PV and battery storage can provide additional learning for rapid frequency response in the EFCC project.

Belectric are currently in the process of progressing separate planning applications for solar PV and battery storage at Redruth. In this respect, it is anticipated a solar PV plant will be constructed in advance of EFCC trials commencing in 2017. In this respect, the proposed installation at Redruth will be configured to allow trials for battery only (as previously outlined in the EFCC submission) as well as battery plus solar PV hybrid. This will increase the potential learning gained of operational regimes by locating the battery at different locations of the electricity network.

Chapter 7 Cost Benefit Analysis of future roll out of Hybrid Battery Storage and Solar PV

7.1 Cost Benefit Analysis Introduction

When awarding funding for the project, Ofgem included a requirement that the battery storage and hybrid solar-battery solution of work package 2.4 be examined in more detail prior to the funding for this element being released. Ofgem's project direction included the following condition:

"**8. WORK PACKAGE 2.4 - STORAGE**

The Funding Licensee must secure consent from the Authority before accessing the funds, £1,122,820, for work package 2.4. The Funding Licensee must submit an application to the Authority which presents options for work package 2.4. As part of this application, the Funding Licensee must:

- Conduct an investigation into existing battery storage facilities and trials in the UK, considering both technical and commercial information, to determine if existing facilities and/or trials can be used for the Project.
- The Funding Licensee must also present cost benefit analysis of potential learning from this work package against the cost to consumers.

The Funding Licensee must present this information in a report to the Authority by 30 June 2015.

Based on the Funding Licensee's application the Authority will determine whether the funds for work package 2.4 will be released. If the Authority determines not to release these funds, the funds will be returned to customers."

National Grid submitted a storage review report to Ofgem on 30 June 2015 (EFCC Battery Storage Investigation Report June 2015). Following this further clarification was requested from Ofgem in particular relating to the cost benefit assessment.

This chapter details and explains the assumptions behind our estimates for the potential savings attributable to the hybrid solar-battery installation put forward by the EFCC project. A range of sensitivities have been considered and the resulting market potential could reach £54m-£83m/year by 2020, with estimated consumer savings of £38m-£59m, with a strong likelihood that these figures will continue to rise to at least 2030.

Chapter 7 Cost Benefit Analysis of future roll out of Hybrid Battery Storage and Solar PV

7.2 Cost benefit analysis: methodology and results

7.2.1 High-level overview

Figure 3 below shows the stages involved in the cost benefit analysis (CBA) of the hybrid project and maps out the associated subsections within this chapter. Each box represents a different stage in which assumptions are made and/or results are calculated. The arrows show the dependencies and implications of each stage. The boxes in blue are intermediary steps and the two orange boxes are the final results of the cost benefit analysis. The numbers in the boxes indicate the corresponding sections of this chapter of the report.

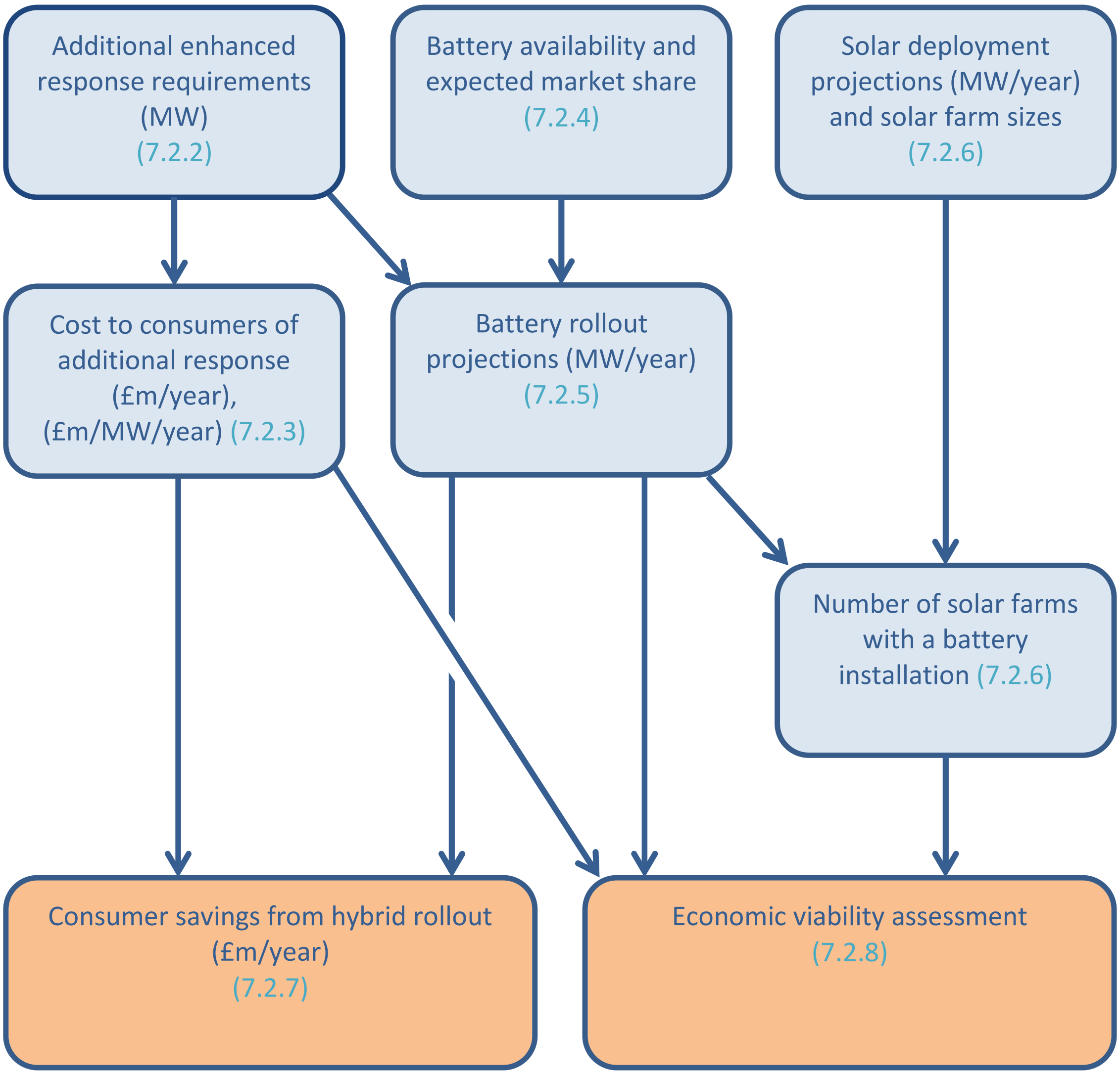

Figure 3: CBA methodology overview

In summary the following questions have been posed and considered:

- Based on SOF 2014 what volume (MW) of enhanced frequency response is expected to be needed?
- Based on an approximation of today's frequency response costs, how much could the annual additional cost be?
- The EFCC project is exploring the potential for wind, CCGT, demand response, solar alone, battery storage alone, and hybrid solar-battery to provide enhanced services. What proportion of the future enhanced response requirement could the hybrid solar-battery solution under investigation in EFCC provide?
    - o How many hybrid solar-battery installations would be required to achieve this?
    - o How does this compare with the number of existing and forecast solar farms of suitable size?
    - o Is there a viable business case for the battery rollout projections?
- What is the potential saving for consumers per annum in 2020 and 2025?
    - o How does this compare to the £1.1m required to facilitate this part of the EFCC project?

Throughout the CBA, all costs are given in terms of current prices and exclude the effects of general inflation.

The following sections explain the calculations and assumptions involved in each of the stages in the figure above. A table summarising all of the modelling assumptions is contained in Appendix E.

7.2.2 Future additional enhanced response requirements

The main motivation for the EFCC project is the expected growth in the need for the provision of enhanced frequency response in the near future. This is caused by three main factors;

- decreasing system inertia,
- decreasing availability of frequency response providers when renewable output is high
- an increase in the largest 'loss' on the system that the system operator needs to cater for to maintain system security.[1].

As the amount of traditional generation with heavy spinning masses reduces the result is a reduction in system inertia. This means the system reacts faster to sudden changes in supply and demand and hence greater levels of response, or faster response, is needed. The projected system inertia level during the summer under the Gone Green and Slow Progression future energy scenarios is shown in Figure 4. It shows the system inertia decreasing by approximately 40% over the next 10 years. This

[1] The 'largest loss' on the system is the largest single generation unit (or interconnector) that could be lost all at once due to a fault.

will have a large impact on the need for enhanced frequency response during this period to ensure the RoCoF (rate of change of frequency) limits are maintained[2].

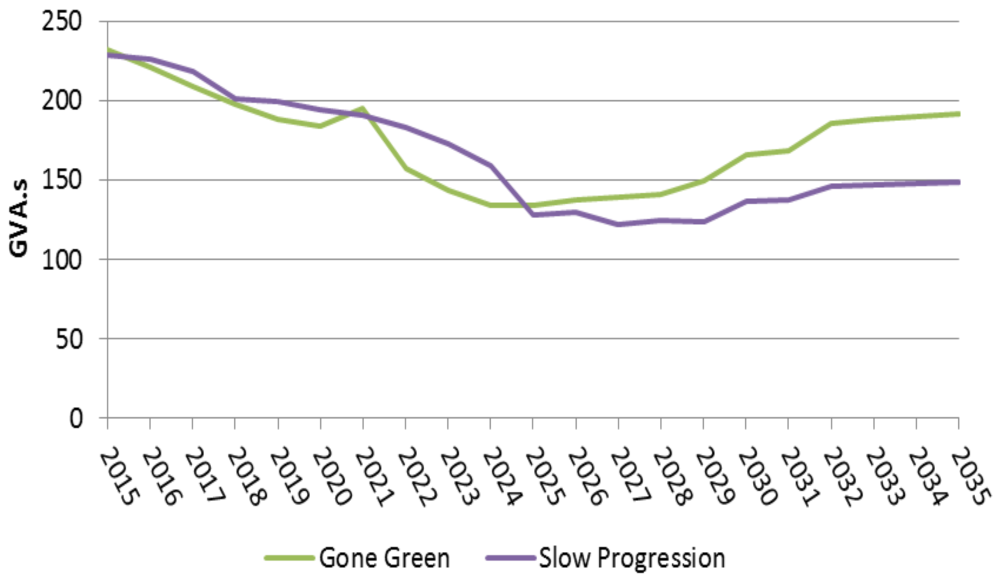

Figure 4: System inertia under the Gone Green and Slow Progression scenarios in summer

Analysis performed for the 2015 System Operability Framework (SOF) includes studies to determine the level of enhanced response required to prevent the frequency from deviating outside of operational limits in the event that the largest generator is lost in a fault. Figure 5 shows the results of this analysis (the data for all four 2015 FES scenarios are shown in this Figure; Consumer Power (CP), Gone Green (GG), No Progression (NP) and Slow Progression (SP).

[2] National Grid System Operability Framework 2014, 2015. http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/

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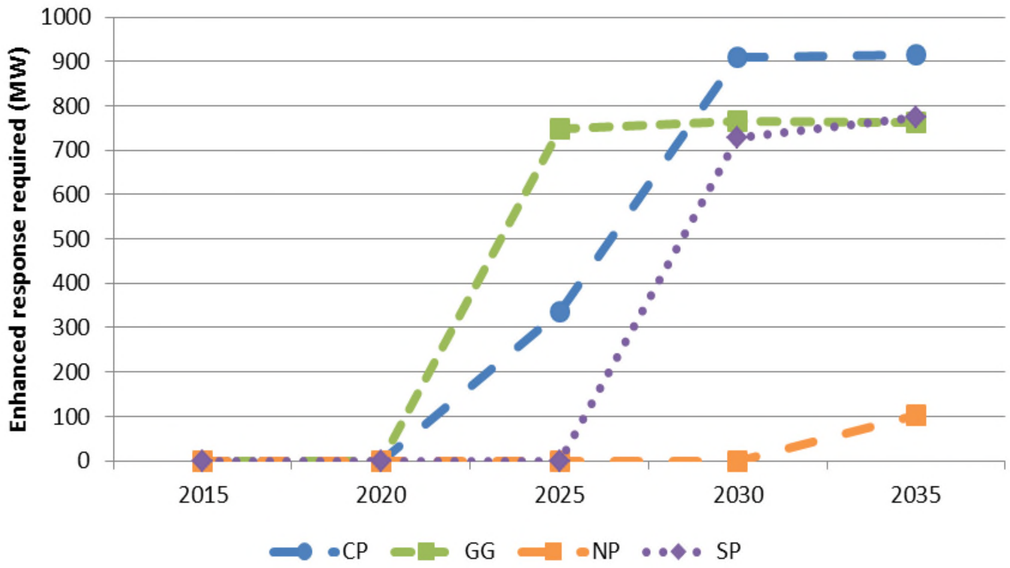

Figure 5: Enhanced Frequency Response Requirements during summer periods under each 2015 future energy scenario resulting from frequency response analysis in SOF 2015

Figure 5 indicates that additional enhanced response will be needed after 2020 (or after 2025 under Slow Progression) when response from existing providers to secure against the frequency deviation limits becomes insufficient. In addition, from Figure 4, in order to secure against the RoCoF limits the amount of enhanced frequency response will also need to increase from 2015-2025.

Using the information behind each of Figure 4 and Figure 5 it can be estimated how much enhanced frequency response will be required to ensure that the system is secured against both the RoCoF and frequency deviation limits. The response required up until 2025-2030 is driven by the decreasing system inertia (Figure 4) and the response from 2025-2035 is predominantly driven by factors contributing to results presented in Figure 5 as explained above.

For this CBA the central scenario is based on the data in National Grid’s 2015 future energy scenario ‘Gone Green’ (referred to as ‘Gone Green’ or ‘GG’) since under this scenario the UK 2020 energy targets are met. For comparison the analysis has been extend to include the ‘Slow Progression’ scenario to show how results would change if the energy targets are met on a slower timescale. Slow Progression is similar to Gone Green with the main difference being that the need for enhanced response is delayed, (largely) due to the assumption that the largest plant in operation is constructed at a later date.

The results of combining the two drivers of the increasing enhanced frequency response requirements are presented in Figure 6. The data behind this figure is included in Table 18 in Appendix I and is used in our assumptions for the battery rollout projections.

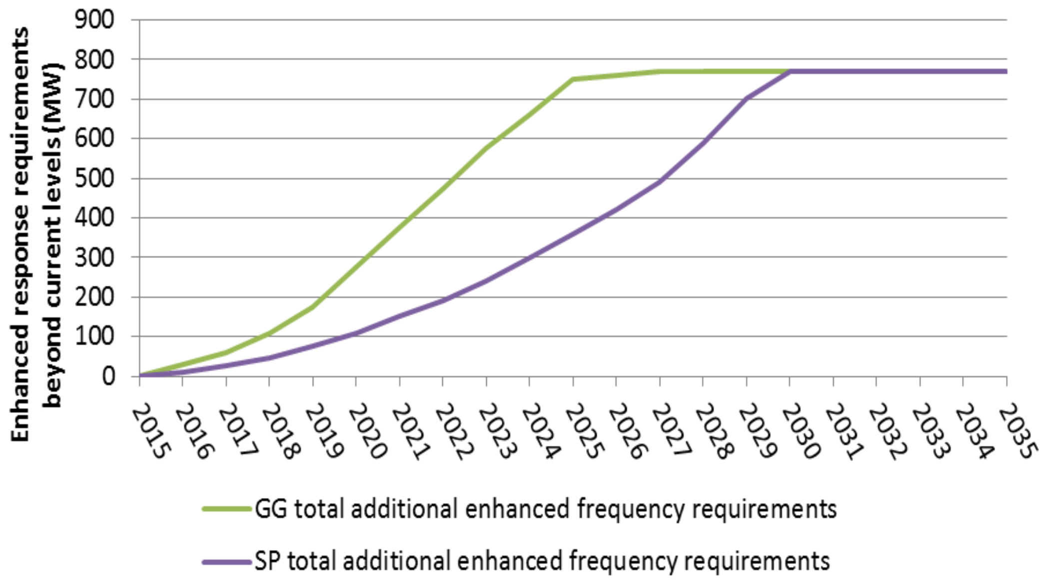

Figure 6: Additional enhanced frequency response requirements under our two scenarios (from all providers)

In this section estimates have been established for the amount of additional enhanced frequency response required in each year from 2015-2035. The next section describes how we have estimated the potential increased costs to consumers from procuring this additional response.

7.2.3 Future additional costs to consumers

Detailed modelling was performed as part of the original EFCC bid to determine the cost to consumers of additional frequency response requirements in 2020. This determined that to procure enhanced frequency response beyond current requirements, the cost to consumers could be in the range of 250-300MW (estimated to be needed from 2020) the resulting cost to consumers will be approximately £250m-£300m per year. Using these results from the detailed assessment it is possible to extrapolate to determine the cost to consumers of procuring additional enhanced frequency response in other years.

It was established that the EFCC project had the potential to reduce these costs by approximately £150m-£200m per year, and that an estimated 250-300MW of enhanced response would be required to achieve this. Using the results from the detailed assessment an extrapolation has been done to determine the cost to consumers of procuring additional response without the success of the EFCC project in future years.

In this CBA two different possible relationships between future costs and the additional enhanced frequency response requirements have been modelled. As a means of sensitivity analysis; a linear dependency (to model a situation where supply increases at no extra costs for each additional MW of response required) and a quadratic dependency (where the cost of additional supply increases

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disproportionately for each additional MW of response required) are chosen. Figure 18 in Appendix F illustrates these two relationships. In the near future this relationship makes a very small difference to the potential savings for consumers, but this difference becomes significant in the medium to long-term future. Therefore the two modelling scenarios Gone Green (GG) and Slow Progression (SP) are expanded to GGa, GGb, SPa and SPb, where ‘a’ refers to the linear price case and ‘b’ refers to the quadratic price case. The results are shown in Figure 7 and the data behind this figure is provided in Table 18 of Appendix I.

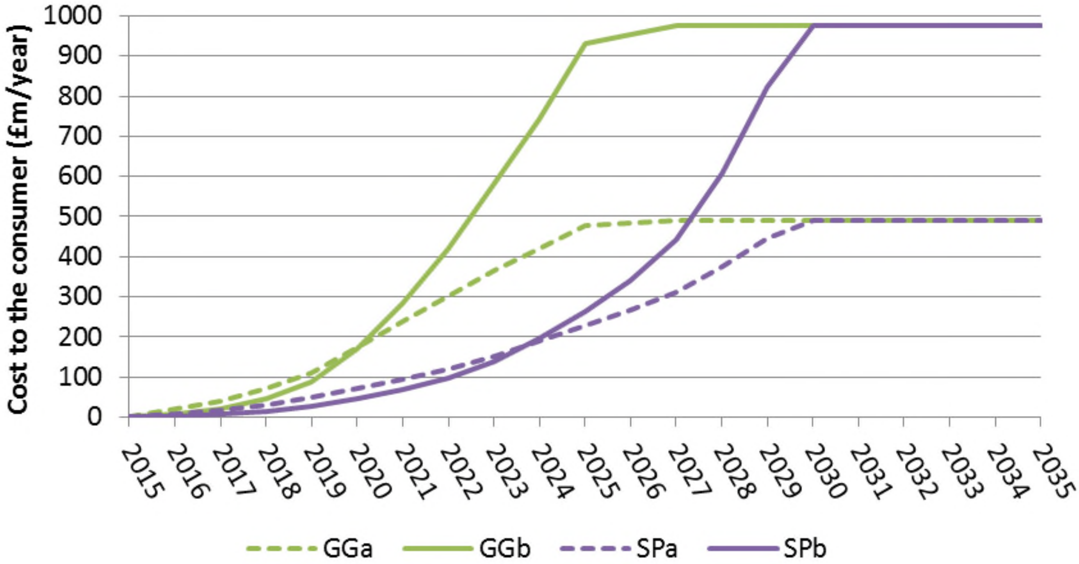

Figure 7: Cost to consumers in lieu of EFCC of procuring additional response in the Gone Green and Slow Progression scenarios and under the two cost-requirement dependency cases; linear (a – dashed line) and quadratic (b – solid line).

It should be noted that the linear case is considered to be a lower bound since increasing response requirements are likely to lead to an increase in cost per MW of response as the service becomes more valuable to the system operator. The GG and SP scenarios with the same cost dependency assumptions arrive at similar costs in each case but with a delay of approximately five years for the Slow Progression scenario. It should also be noted that although there are large differences between the two ‘a’ and ‘b’ options in the long-term, our CBA focuses predominantly on the 2018-2025 window.

The original EFCC bid considers only the potential savings in 2020. The more detailed analysis presented here illustrates how any savings in 2020 will only be a fraction of the potential in future years. Therefore the figures quoted for 2020 should be understood to be very conservative regarding the potential benefits from the EFCC project. Although uncertainty surrounding assumptions increases in later years there is a clear upward trend for the value of the project.

Having determined the future additional costs to the consumer of procuring frequency response in the absence of the EFCC project, the potential for battery-solar hybrid projects to provide enhanced frequency response in terms of availability and participation in the market is considered in the following section.

7.2.4 Battery availability and service provision assumptions

In the following analysis all batteries are considered to be those located at solar farms in the hybrid arrangement proposed by the EFCC project. For this CBA it is assumed that a battery used for enhanced frequency response will be available approximately 95% of the time for providing the service. Availability is one aspect of enhanced frequency response provision from batteries that EFCC intends to explore. Since the proposed battery will be located at a solar farm with a higher rated capacity than the battery, one operational model would be that solar power is used to charge the battery after use, and during the day, to leave it charged for the overnight period if inertia is expected to be low (such as the prediction of high winds).

During periods when inertia is high and it is not needed for frequency response the battery can be operated for other purposes and access other revenue streams. No assumptions have been made about the revenue available to a battery from other services and markets, but it is likely that any battery installed would be operated for multiple purposes. Certainly the prevention of solar curtailment will be a natural choice for the battery.

Of all of the additional enhanced frequency response required in future, the proportion that batteries could provide will depend on the number of batteries installed in GB, the cost-competitiveness of other potential providers, and the technical capabilities of batteries compared to other providers. For this CBA a range of 30%-45% is used for the contribution of batteries to the provision of additional enhanced frequency response from 2020 onwards.

Current market intelligence for an enhanced response service is showing battery storage as playing a significant role amongst other service providers (i.e. greater than 80%). However, this is based on the existing industry perception of the value of frequency response provision within business as usual services. The EFCC project is trialling other technologies for enhanced frequency response that currently don't provide these services to National Grid (e.g. wind, solar) in addition to CCGT and demand side response. In so doing, it is anticipated that the demonstration of the various technology capabilities as well as the development of a supporting commercial service (Work Package 6), will bring more providers into the market. As these aspects are being explored within the EFCC project, any estimate made now of the market share attributable to batteries is very subjective but will become more evident as the project develops.

In the figures that follow a central value of 37.5% 'market share' for the batteries is used, with error bars representing the effects of considering the whole 30%-45% range.

Having established battery participation assumptions regarding enhanced frequency response provision, the next section determines the required rollout of batteries needed to meet the service provision levels required.

7.2.5 Battery rollout projections

Using the assumptions set out in the previous section regarding battery availability and market share, the projected rollout of batteries in solar farms under our Gone Green and Slow Progression scenarios can be established. Starting with the total additional enhanced frequency response requirements for each year, this is multiplied by the percentage of the provision estimated from the batteries (30%-45% range) and divided by 95% for availability. The projected number of batteries deployed in 2019 has been reduced to allow for a small delay in installation pick-up following the completion of EFCC.

The potential savings from the EFCC project used in the CBA for the original bid document were based on the forecasts for the single year 2020 without providing additional details for later dates. Here, the analysis continues the rollout projections beyond these years to give an indication of what could be possible, acknowledging the increasing uncertainty as we go forward in time. Importantly, we do not require these projections beyond 2020 to meet the savings targets. The data behind this figure is provided in Table 18 of Appendix I.

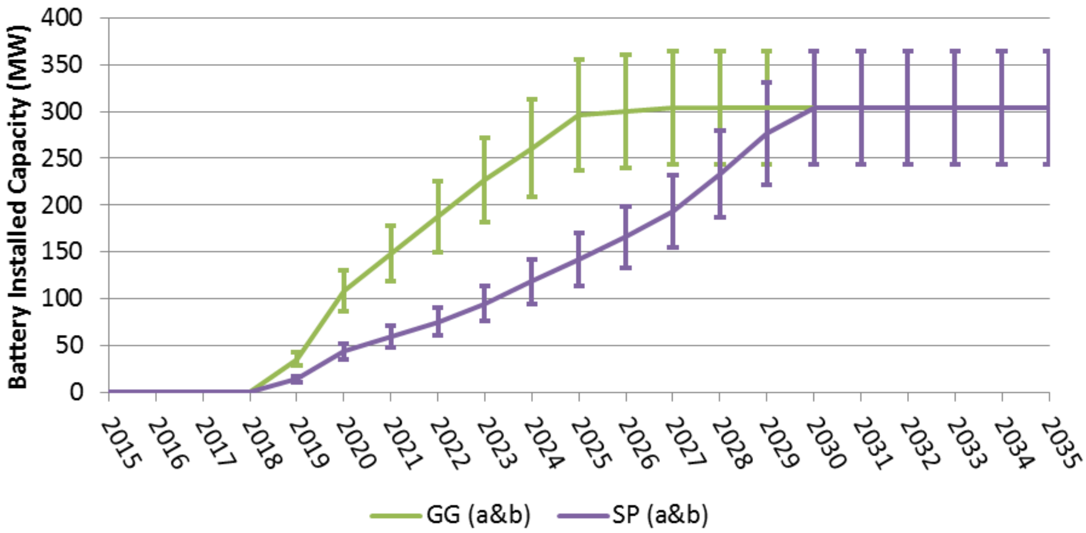

Figure 8: Battery rollout projections. Error bars show the difference when market share changes to 30% (lower) and 45% (upper) from the central 37.5% value.

The rollout of batteries to provide enhanced frequency response requires a corresponding level of solar farm participation. In the next section estimates for the requirements for solar farms to adopt the hybrid battery model are considered along with the feasibility of such participation.

7.2.6 Solar deployment and battery adoption projections

Having established the rollout projections for batteries under different sensitivity cases for each scenario consideration is now given to the projected deployment of solar PV farms of sufficient size to incorporate a 1MW or greater battery. This will allow us to determine the relative levels of installed solar PV and batteries, along with the number of solar farms that are expected to adopt a battery for enhanced frequency response.

In the first stage of this assessment focus is given to the potential rollout of hybrid solar-battery solutions based on MW capacity. In the second stage examination focus is given to how many solar-hybrid installations could be required to achieve this capacity.

National Grid's 2015 FES includes projections for the deployment of solar farms larger than 1MW from 2015 to 2035. The latest information obtained detailing the sizes of solar farms both existing and in all stages of development indicates that by 2018 approximately 77% of solar farms will be larger than 4MW[3]. Figure 9 shows 77% of the projected levels of installed solar capacity under the Gone Green and Slow Progression scenarios which we assume is the amount of installed capacity of solar PV that could be in farms large enough to adopt a battery.

Taking the 4MW as an assumed minimum size of solar plant (because the EFCC project proposes to trial a 1MW battery at a 3.8MW solar farm) and assuming that batteries need to be at least 1MW in size, we consider 'eligible' farms for batteries to be at least 4MW.

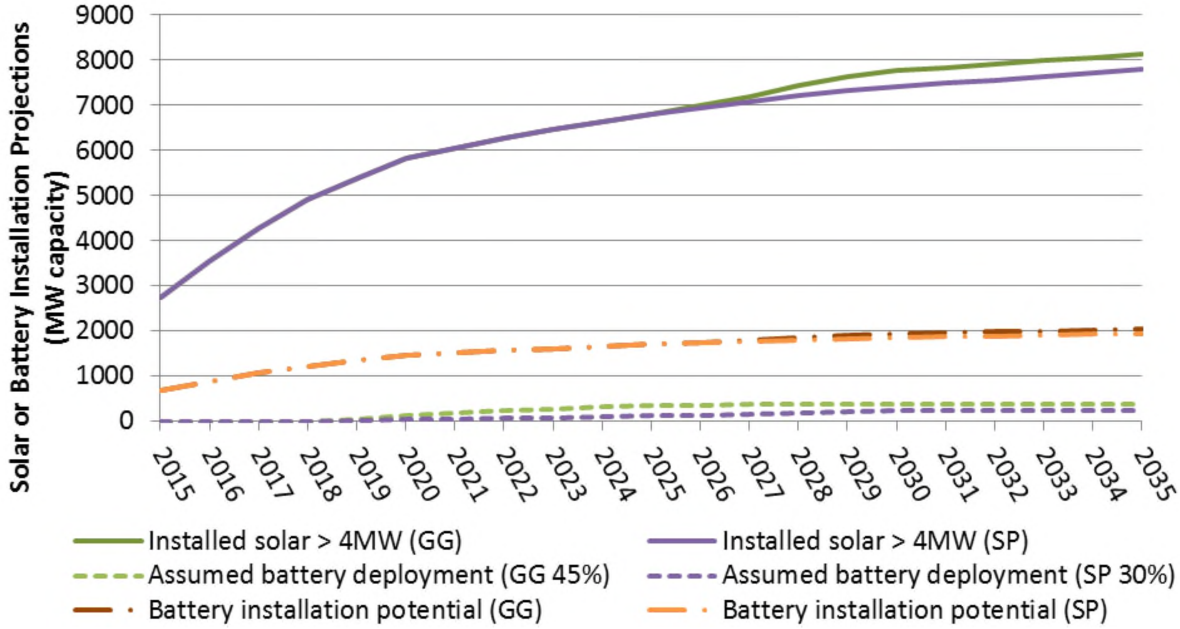

Figure 9: Solar (solid line) and battery (dashed line) installation projections alongside potential for battery installations (dash-dot line). Potential battery installations calculated as 25% of solar installed capacity (greater than 4MW).

[3] Solar Deal Tracker, IHS 2015.

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It may prove to be economically attractive for smaller solar installations to invest and participate in the new ancillary service(s) that EFCC is seeking to trial. The cost of secure communication infrastructure and complexity of instruction and monitoring will probably be among the limiting factors. Conversely, larger solar farms could install larger batteries. The viability of the battery size to solar farm ratio is one aspect of the hybrid solution the EFCC project proposes to explore.

The dashed lines in Figure 9 show the deployment of batteries under the fastest/highest and slowest/lowest scenarios (Gone Green with a 45% market share and Slow Progression with a 30% market share, respectively) that have been assumed for this CBA. For reference the estimated full potential level of 'eligible' installed solar capacity (orange and yellow dash-dot lines) has been included, which clearly illustrates that the assumptions in this CBA for hybrid solar-battery rollout require low levels of participation from solar farms, with potential for much greater rollout, and therefore value, from this aspect of the EFCC project.

Based on the latest data available for the sizes of solar farm it is possible to estimate how many solar farms would need to adopt a battery in order to meet the capacity-based battery rollout projections in each scenario. We assume that batteries will be installed at farms larger than 4MW and that the battery size will be approximately one quarter of the rated ac power capacity of the solar farm. We also assume that the number of participating solar farms in each size range is proportional to the number of solar farms in the size range. More information on the assumptions made for these calculations is given in Appendix G.

Figure 10 shows the approximate number of solar farms expected to adopt a battery under each scenario. If more of the larger solar farms install batteries of approximately ¼ of the solar installed capacity or larger, then fewer farms would need to adopt a battery to reach the projected rollouts assumed. Since it is probable that larger solar farms are more likely to install batteries than smaller farms due to economies of scale and greater potential of curtailment, our estimates are at the conservative end of the spectrum (likely that fewer solar farms will need to participate to hit projected targets).

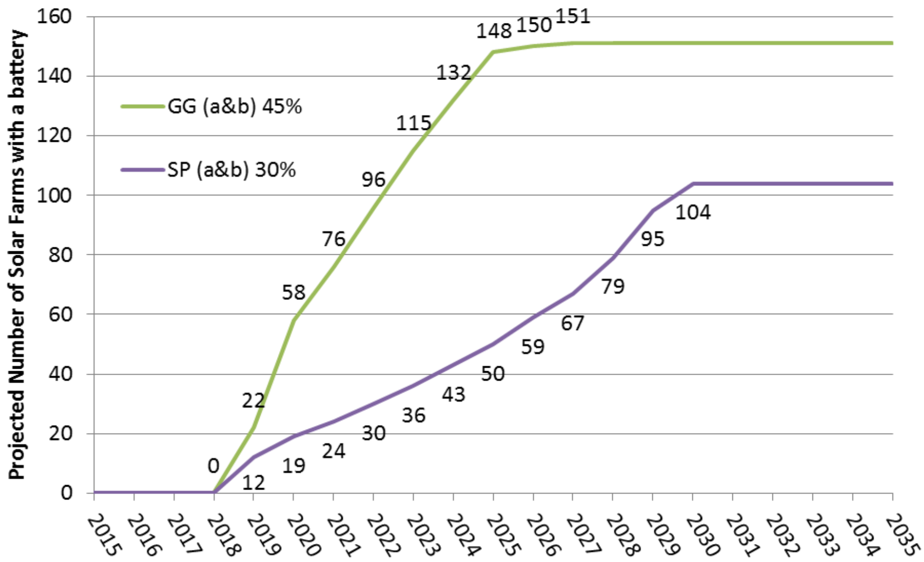

Figure 10: Number of participating solar farms under each scenario

We estimate that the number of solar farms larger than 4MW will grow from approximately 500 to 800 farms between 2019 and 2035[4]. The low levels of battery rollout required gives confidence that our battery installation projections are feasible and that participation from a conservatively low proportion of the solar farms[5] would achieve the savings described later in this CBA.

Having established the required battery rollout and solar participation, in the next section the market potential for enhanced frequency response is considered, and estimates provided for the potential consumer savings from the EFCC project.

7.2.7 Market potential for the hybrid project and possible consumer savings

The additional costs of procuring additional frequency response in future have been discussed in section 7.2.3. These costs represent the market potential for a new enhanced frequency response service. Having determined the future costs from extrapolation of the 2020 modelling data these have been divided by the MW required each year to obtain the extrapolated cost per MW of response out to 2035. Multiplying by the response required from batteries in each year, which takes market share assumptions into account, it is possible to obtain the maximum that a purely economically driven consumer would be willing to pay for the enhanced response from batteries. This is the market potential for the service.

Figure 11 shows the results for the two Gone Green scenarios. This clearly shows that there is large potential for savings beyond 2020, which will depend largely on how the value of enhanced frequency response changes and what percent of the service is provided by batteries (represented by the error bars). As stated previously, the estimated market potential in 2020 has very conservatively ignored the increasing trend in potential savings.

[4] Based on an approximate ratio of installed solar capacity in farms greater than 4MW to number of solar farms of 10:1 (Solar Deal Tracker, IHS 2015)
[5] Approximately 10% of solar farms in 2020 would be participating under Gone Green, rising to around 20% participation 2025 assuming a ratio of 10MW installed capacity to 1 farm

Chapter 7 Cost Benefit Analysis of future roll out of Hybrid Battery Storage and Solar PV

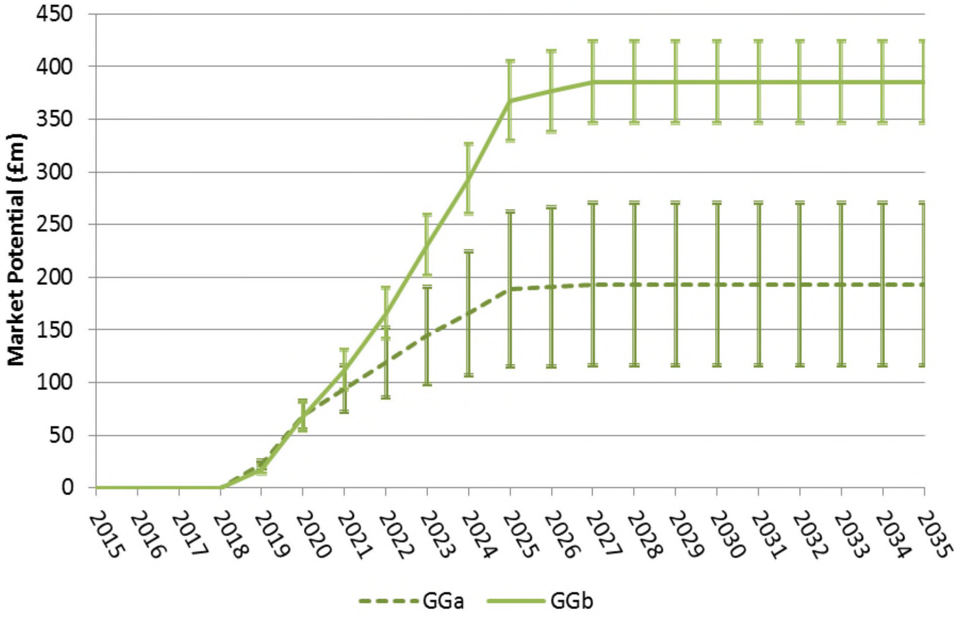

Figure 11: Market potential for batteries under GGa and GGb, with error bars showing the effects of considering a range for the market share; 30-45% around the central value of 37.5%

The equivalent results under our Slow Progression scenarios are shown in Figure 12. Although it takes longer for the savings to be realised, ultimately the results are very similar to the Gone Green scenarios. This gives us confidence in the long-term value of the EFCC project.

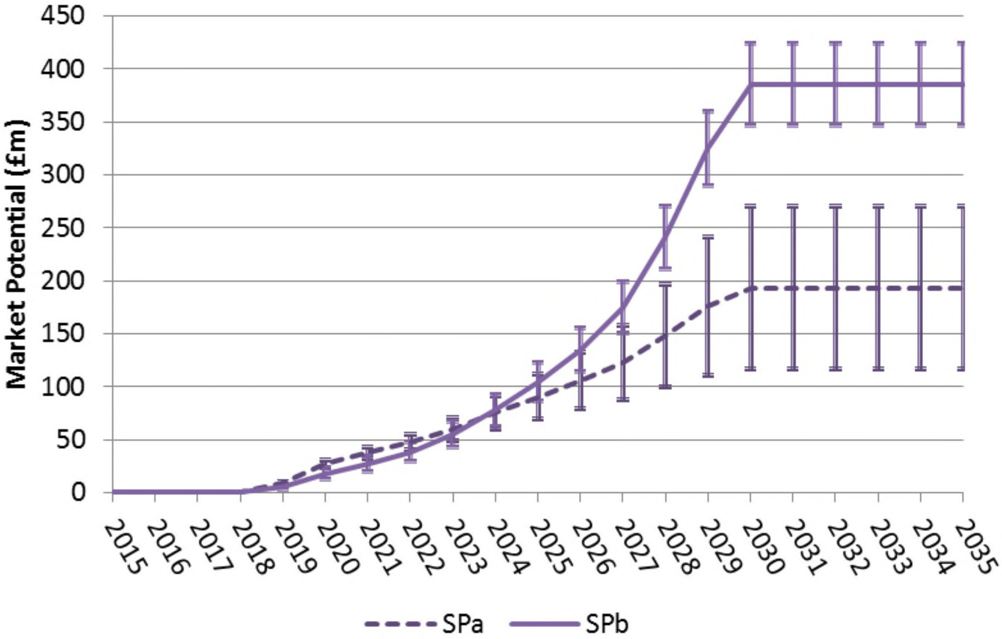

Figure 12: Market potential for batteries under SPa and SPb

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The market potential for batteries in 2020, 2025 and 2030 are shown in closer detail under each scenario in the following figures.

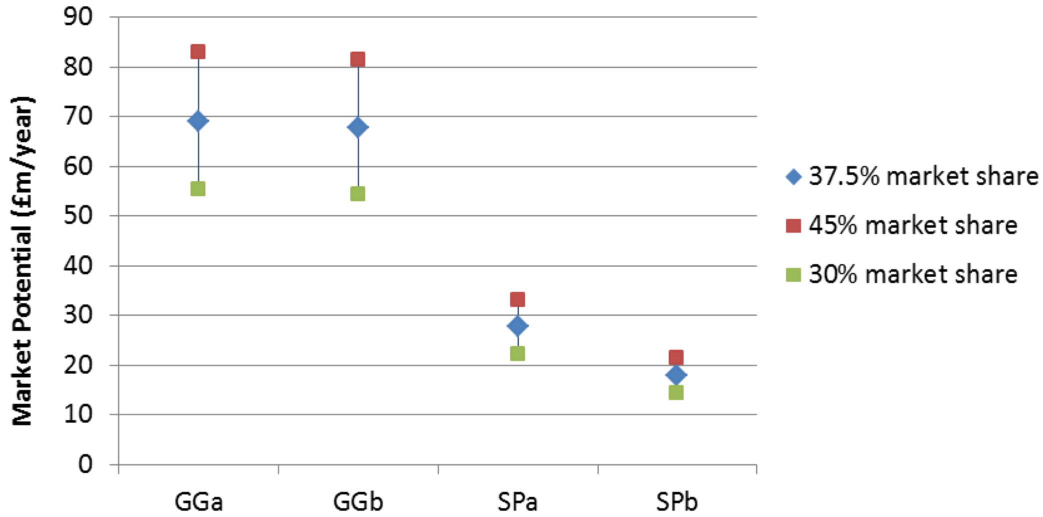


Figure 13: Market Potential in 2020 (£m/year)

The market potential for batteries under Gone Green in 2020 is in the range of approximately £55m-£80m.

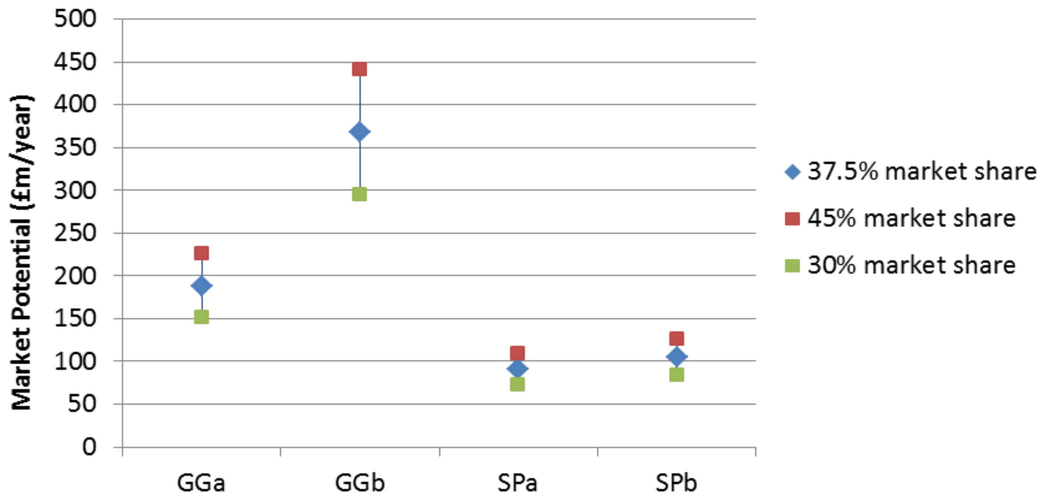


Figure 14: Market Potential in 2025

In 2025 under Gone Green the market potential has increased significantly and shows a much larger spread due to the uncertainties in our assumptions (£150m/year – £440m/year). The delay under Slow Progression is marked but still covers the £70m/year - £125m/year range.

Chapter 7 Cost Benefit Analysis of future roll out of Hybrid Battery Storage and Solar PV

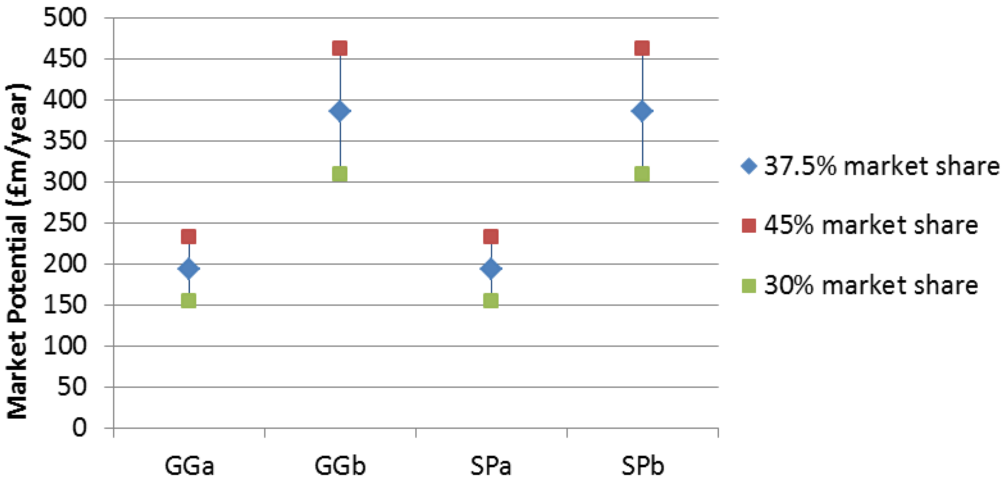


Figure 15: Market Potential in 2030

Naturally by 2030 a wide spread of market potential across the four scenarios is shown including sensitivity analysis (£155m/year - £460m/year). The assumptions surrounding the value of enhanced frequency response play a larger role as seen from the difference between the 'a' and 'b' (linear and quadratic consumer cost savings) scenarios. Even under SPa (Slow Progression, linear cost saving), the most conservative scenario in terms of market potential for hybrid solar-battery we see levels of approximately £150m/year by 2030.

The potential savings for consumers are bounded above by the market potential. This is the maximum amount that consumers would be prepared to pay for enhanced response because any higher and the alternative existing service providers would be cheaper. Up until this point no assumptions have been about how much batteries would be paid for providing enhanced frequency response. To propose a £/MWh value for the service would presuppose the result of a tendering process for a service that will be developed as part of the EFCC project. However, in order to get an estimate for the potential savings to the consumer of the project, we have chosen to assume a value for the price per MWh of enhanced frequency response availability, to show the impact on consumer savings. These payments to batteries are subtracted for the response service from the market potential to estimate the potential savings for consumers under these assumptions. The results are highly dependent on the number of players in the market, the costs of batteries, and the hours of the year that we contract the service for, among other variables. Operation cost and service contract provision will be investigated as part of the EFCC project.

For this CBA it is assumed that the number of hours in the year when the enhanced frequency response service will be tendered for will be approximately the same as the number of hours in the year when the rate of change of frequency (RoCoF) is greater than 0.125Hz/s. This was calculated as a percentage of the year as part of the modelling for the 2015 System Operability Framework. Further details are given in Appendix H. For each year we can therefore determine the number of hours when the batteries will be contracted, with the MW rating already determined in section 7.2.5. An availability payment of [redacted] is assumed for the enhanced frequency response[6] in all years. This value has been used as it represents an approximate cost National Grid has already discussed with response

[6] This value is highly subjective and should not be taken as representative of the price that National Grid expects for tenders for this service.

providers for contracting static frequency response. It can be argued that the availability payment could be higher for future low inertia scenarios as the service becomes more valuable to maintain system stability. The potential payment to batteries and other service providers being trialled will be explored in the development of the new commercial service as part of the EFCC project. In addition, future enhanced frequency response providers are expected to be called upon to provide frequency response very few times over the course of the year; hence utilisation payments have been ignored in the analysis.

The figures below show a comparison between the market potential and savings to consumers in 2020 and 2025 under our two scenarios. The results are shown as a range across all sensitivities within each of the Gone Green and Slow Progression scenarios (a and b for the three market share sensitivities).

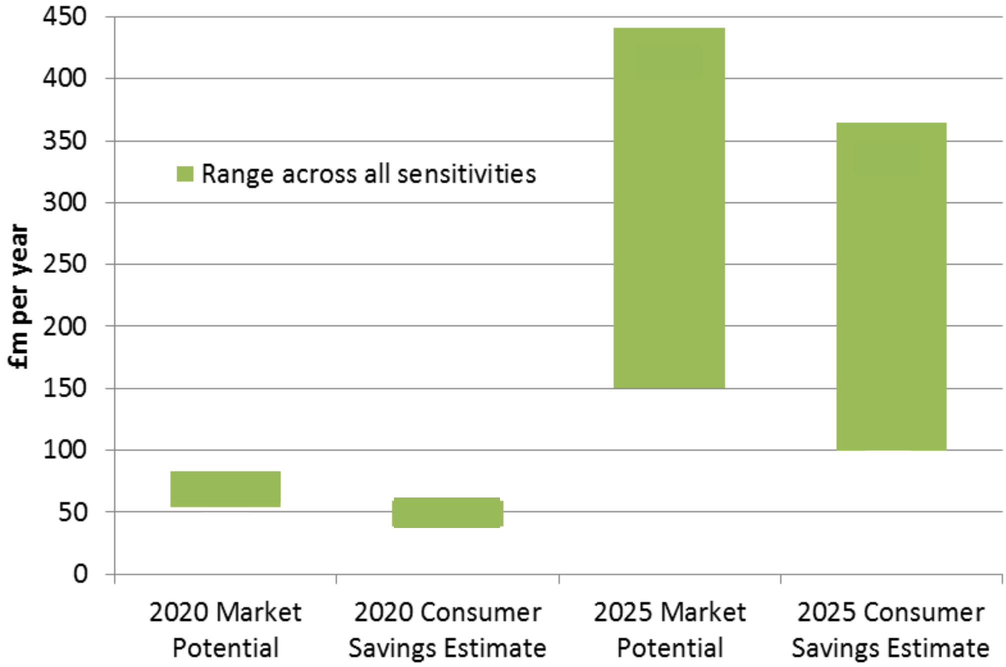


Figure 16: Market potential and one estimate for consumer savings under Gone Green in 2020 and 2025

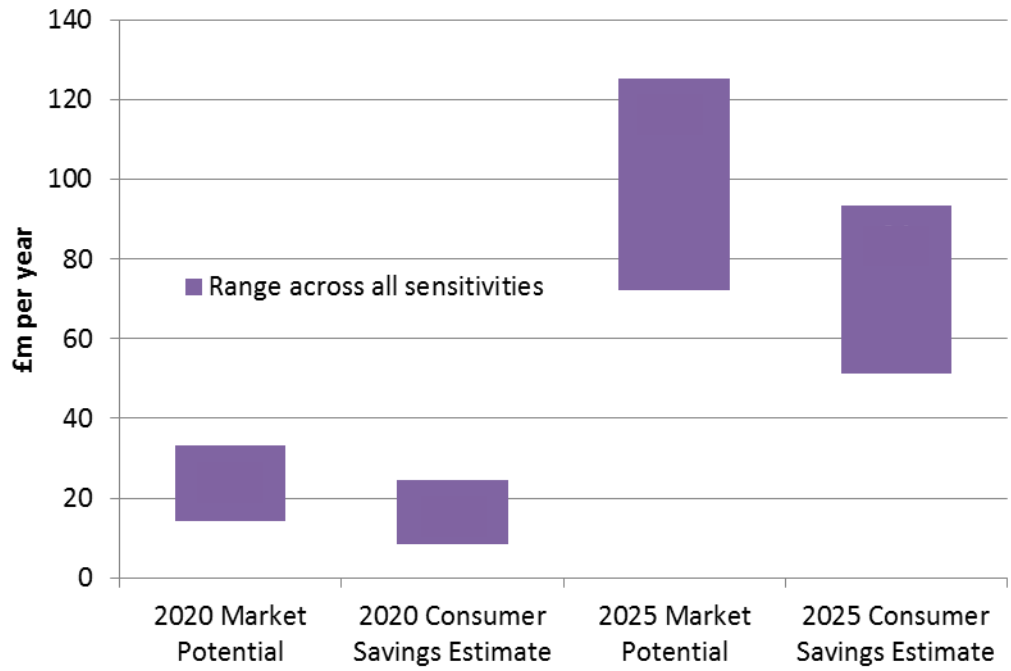


Figure 17: Market potential and one estimate for consumer savings under Slow Progression in 2020 and 2025

These figures show that in both scenarios, by 2020 for Gone Green, (closer to 2025 for Slow Progression); the potential savings to the consumer from the EFCC project are far higher than the funds requested (£1,122,820). The savings presented are savings per year, expected to increase year on year at least towards 2030. As the price of batteries reduces and more players enter the market the cost to consumers of procuring the response will decrease. The importance of the EFCC project is to determine the optimal commercial framework to allow full market participation and to understand the technical capabilities of a range of potentially viable technologies to ensure service reliability and optimal contracting.

Having shown the economic viability of the EFCC project under a range of assumptions, the final stage in our assessment is to consider the economic viability of our battery-solar hybrid rollout.

7.2.8 Economic viability considerations

In this section the validity of battery rollout projections is outlined by examining the economic feasibility of a battery built to provide enhanced frequency response is considered. The approach is to compare the net present value of the revenue for a battery over its lifetime with the estimated net present value of the lifetime costs. Under the assumptions outlined, a battery built in 2019 that becomes fully operational by 2020 could expect a return on investment of approximately 17%. In future years the revenue per MW of installed capacity will increase and the cost of batteries is expected to decrease, hence a slow initial rollout that grows over time has a strong chance of economic viability. The methods and results are discussed below.

Chapter 7 Cost Benefit Analysis of future roll out of Hybrid Battery Storage and Solar PV

Table 6 below contains the assumptions in the cost benefit analysis for a 1MW battery under the Gone Green and Slow Progression scenarios.

Table 6: Battery economic viability assessment assumptions

	Assumption	Justification and comments	Potential learning from EFCC
Battery lifespan	10 years	Literature typically quotes 8-15 years depending on usage	Understanding of how usage for enhanced frequency response affects lifespan and degradation
Battery CAPEX	£1,122,820	Cost of the battery-solar hybrid EFCC project. Likely to decrease as the cost of batteries decreases but we don't assume this	
Battery OPEX	£10,000/yr	Literature quotes fixed OPEX for Lithium-ion batteries used for frequency response as $6500-$9200/MW-yr, we round up to be conservative[7]	Clear learning outcome from the project
WACC	5.3%	Upper limit of the WACC quoted for the cap and floor to be applied to the UK interconnector regime[8]	
Discount rate	3.5%	Standard UK discount rate	n/a
Service payment	[redacted]	Approximate current cost of existing frequency response	Commercial arrangements to be fully explored
Service availability	According to RoCoF requirements	See Appendix H for full details	Availability and operational models will be investigated

The data behind the economic viability assessment for a 1MW battery under the Gone Green and Slow Progression scenarios are presented in Table 7.

[7] Table B-28 in DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA
[8] OFGEM Financeability study on the development of a regulatory regime for interconnector investment based on a cap and floor approach, 2013. The WACC values are quoted as 4.3% (floor), 4.7% (midpoint) and 5.3% (cap) and we chose the cap value since it is the most conservative of the three values.

Table 7: Economic viability assessment for a 1MW battery built in 2019, beginning operation in 2020 under Gone Green and Slow Progression

Year	CAPEX (£)	OPEX (£)	Revenue (£/MW-yr)	
			Gone Green	Slow Progression
2019	1,122,820		0	0
2020		10,000	181770	166440
2021		10,000	188778	170382
2022		10,000	195786	174324
2023		10,000	202794	178266
2024		10,000	209802	182208
2025		10,000	216810	186150
2026		10,000	216810	186150
2027		10,000	216810	193815
2028		10,000	216810	201480
2029		10,000	216810	209145
Total Net Present Value:	**1,230,259**		**1,436,425**	**1,285,598**
Benefits – Costs:			**206,167**	**55,340**
Return on Investment (%):			**16.8%**	**4.5%**

The business case for batteries in 2020 is far stronger under Gone Green than under Slow Progression, which supports our rollout projections for Gone Green being over twice as high in the first few years following the EFCC project compared with under Slow Progression. The number of batteries installed in 2020 under Gone Green is reached under Slow Progression by 2025. The equivalent results as above for a battery constructed by 2025 under Slow Progression suggest that the expected return on investment over the battery lifetime is approximately 21%. This supports our battery rollout projections for Slow Progression which reach similar levels to the 2020 Gone Green scenarios by 2025.

Assuming a battery is built in 2024 for operation in 2025 and using the same methodology already presented, under Gone Green there is a potential return on investment of 117% which is extremely high. This suggests that over time under Gone Green the price for enhanced frequency response could reduce significantly from our estimated [redacted], inducing greater savings for consumers.

In addition to the revenue available to batteries for enhanced frequency response other revenue streams may be available, particularly in the short-term when it is not expected that enhanced frequency response will be contracted for every hour of the year. Additional balancing services, energy market participation and reducing the effects of solar curtailment (if brought in) are all options which would improve the business case for a battery. Battery costs are expected to decrease over the coming years which in further increases the economic viability of battery-solar hybrid projects.

These results show that there is sufficient market potential to justify the predicted deployment rate of our battery rollout projections. This section has assessed the financial costs, benefits and economic viability of our assumptions. The next section considers the additional learnings from the EFCC project.

7.3 Additional potential benefits

The response capabilities of new technologies are not currently being fully realised and trials within the EFCC project will demonstrate how battery storage and solar can be coordinated to provide an optimised response across a range of resource providers.

Specifically for a hybrid battery storage and solar PV installation, there is potential to optimise the operational flexibility (e.g. battery storage of otherwise curtailed solar energy or utilisation of batteries for frequency response overnight typically when system inertia is reduced). In addition, negative frequency response (curtailment) can be obtained from solar while the maximum positive frequency response is obtained from the battery. Trials undertaken within the EFCC project will inform the development of prospective operating models and provide a better understanding of battery availabilities. The development of specific performance requirements will be investigated in order to define the roll out of an Enhanced Frequency Control Capability as a new balancing service, taking into account specific challenges of incorporating batteries for network regulation (e.g. various States of Charge).

The development of a commercial policy is a key element within the EFCC project. In parallel with the technology trials, a fuller assessment of the potential for future frequency response service provision from batteries and solar. This holistic assessment will provide insight into the market share of response that the EFCC service providers could contribute towards. It will also facilitate industry acceptance in order to enable realisation of the potential consumer cost savings at the end of the project.

7.4 Summary and Conclusions

The hybrid battery-solar project forms an important part of the EFCC project. It will allow us to understand how battery storage and solar farms can be coordinated to provide optimised enhanced frequency response. The EFCC project will establish reliable knowledge of the technical capabilities and limitations of this technology and of optimal approaches for utilisation. Given the increasing challenges and associated costs of procuring frequency response for system stability and security, it is important that new and reliable providers of enhanced frequency response are identified to minimise the costs to consumers of a low carbon future.

This cost benefit analysis has set out the potential savings to consumers following the successful completion of the EFCC project, specifically from the hybrid solar-battery possibility, and the subsequent deployment of batteries at solar farms.

Chapter 7 Cost Benefit Analysis of future roll out of Hybrid Battery Storage and Solar PV

At each stage the rationale behind each assumption made has been provided together with an assessment of how realistic the assumption is and four scenarios have been considered to test the sensitivity of the assessment to key assumptions.

- A thorough assessment of future additional enhanced response requirements has been carried out as part of the System Operability Framework 2015 assessments: **~250MW by 2020 ultimately rising to ~800MW**
- Calculation of the resulting additional costs to consumers in lieu of the EFCC project has been explained in detail with two potential cases over time: **£150-£200m pa by 2020 (nominal) potentially rising to £0.5bn to £1bn**
- Assumptions have been detailed for battery availability **(95%)** and share of the enhanced frequency response market **(30%-45%)**, and the methodology for battery rollout projections explained in full
- Using the National Grid 2015 FES we have assessed how many of the projected solar farms over the next 20 years would need to adopt a battery to meet our battery rollout projections and found it to be a low number compared to the amount of installed solar farms of sufficient size: **~10% of solar farms >4MW**
- Savings have been compared with the rollout cost of the batteries and have shown that a large margin exists, which implies that the battery rollout projections are likely to be economically viable: **16.8% for batteries operational by 2020 under Gone Green**.

The potential savings to consumers under a range of conditions has been explored and found to be far higher than the £1.1m investment required for this part of the EFCC project.

Based on the assumption necessarily made to establish potential future rollout costs and savings the market potential could reach **£54m-£83m/year by 2020** (with estimated **consumer savings of £38m-£59m**) and far more in years beyond.

Chapter 8 Revised Project Schedule for Work Package 2.4 (Battery Storage)

The original EFCC project schedule for this work package made an allowance for an investment decision point from the Authority by August 2015 with some contingency provision built in to cater for equipment lead times and planning activities. In practice, the time in completing a detailed cost benefit analysis and subsequent discussion with the Authority have been sufficient to materially change the original project schedule.

Belectric and National Grid have reassessed the work activities for battery storage and propose the following changes to Work Package 2.4.

Work Package	Description	Existing Start Date	Existing End Date	Proposed Start Date	Proposed End Date
2.4.1	Site preparation	Apr-16	Sep-16	May-16	Oct-16
2.4.2	Install equipment	Jul-16	Dec-16	Aug-16	Jan-17
2.4.3	Establish and modify relevant IT systems	Jan-16	Mar-16	Feb-16	Apr-16
2.4.4	Establish and test communication	Oct-16	Dec-16	Nov-16	Jan-17
2.4.5	Test and demonstrate response capability	Jan-17	Sep-17	Feb-17	Nov-17

Table 8: Revised timescales for WP2.4 activities

As a consequence of these changes to activity dates, there would be an impact on the Successful Delivery Reward Criteria (SDRC) detailed in the Project Direction. A new date for this work is proposed in Table 9 below.

Work Package SDRC	Description	Existing SDRC Date	Proposed SDRC Date
2.4.5	Complete demonstration of storage response to frequency events and their capability to respond to proportion to rate of change of frequency	1st October 2017	1st December 2017

Table 9: Revised SDRC for WP2.4.5

If investment in the Belectric battery storage unit is approved by the Authority for the project to progress with a hybrid solar PV and battery storage trial, then National Grid will formally request an amendment to the Project Direction to change this SDRC.

Chapter 9 Legacy options for Belectric Storage Unit

Investment in the battery storage unit provided by Belectric will for the first time demonstrate frequency response from lead-acid technology in GB. As outlined in Chapter 4, this unit is containerised and will be relocated during the project to enable trials to take place in differing parts of the transmission network

However, as the battery storage unit would be funded under the Network Innovation Competition (NIC) mechanism, National Grid will make the unit available to third parties to deliver knowledge of the capability of the system. Due to the containerised solution, this offers a wide range of future possibilities for use and research opportunities for the battery unit at the end of the EFCC project.

Below are the considerations that will be taken into account towards the end of the project when reviewing the ongoing usage of the battery with regards to the potential consumer benefits

- Cost of operating and maintaining the battery in order to retain it for use by other innovation projects
- Potential use either by National Grid or other Network Operators to carry out further trials or projects
- If no interest is expressed from the regulated community, the possibility of other parties to buy the unit in the open market.

As the project will close in March 2018, at this stage it is not possible to fully evaluate these options for the battery that could arise. Each possibility will be reviewed and assessed by the Project Steering Committee and recommendations made via the project governance structure for final approval by National Grid's System Operator (SO) Innovation Board. The EFCC Project Hierarchy is shown in Appendix J

Chapter 10 Recommendations

This report proposes that the Belectric battery storage unit be included within the EFCC project. It is the only option that is known to be capable of delivering the outcomes of rapid frequency response for the project, while mitigating the uncertainty of incurring further costs without risking delays to project timescales.

The Belectric battery will be the first based on flooded lead-acid technology (which is significantly cheaper than lithium-ion) will be used as a standalone frequency response unit in GB. This will give a comparison of investment cost, operational cost, lifetime and reliability between the two mentioned technologies. Furthermore, there is only one large-scale lead acid battery under construction on the island system of the Shetlands (1MW, 3MWh). This battery uses Valve Regulated Lead-Acid (VRLA) cells, limiting it to low C-rates (low power at a given installed capacity due to gel filled cells). VRLA batteries do not compare well with flooded lead acid batteries, since they deliver largely smaller C-rates than flooded batteries that minimises their effectiveness for providing rapid frequency response. Additionally they have a shorter lifespan (1500 cycles).

The combination of solar PV and battery storage within EFCC will generate learning on the benefit of linking technologies and how they can play a role in solving future network operability challenges. Any technical limitations will only be known if site trials to combine technologies are carried out. An important detail for Transmission Network Owners is the limited capacity of a battery has to be taken into account, whenever centralised control schemes and commercial models are developed. Currently a number of international approaches concentrate on the pooling of units with limited capacity (e.g. battery, flywheels, etc...) and with unlimited capacity (e.g. gas turbines, coal fired power plants).

Detailed cost benefit analysis for a hybrid solar and battery storage solution has highlighted the potential savings to consumers following the successful completion of the EFCC project, including potential deployment of batteries at solar farms. The potential savings to consumers under a range of scenarios has shown to substantially exceed the £1.1m investment requested for the Belectric battery unit.

Given the CBA assumptions, on comparing savings with the rollout cost of the batteries, battery rollout projections are likely to be economically viable; 16.8% for batteries operational by 2020 under Gone Green. The market potential could reach £54m-£83m/year by 2020 (with estimated consumer savings of £38m-£59m) and could exceed this in future years.

With the Belectric battery storage and solar PV solution, consumers will benefit from the full optimisation of EFCC outcomes from a realistic response portfolio of a wide range of service providers and industry acceptance based on realistic data. As highlighted in the EFFC Full Submission, this will enable the realisation of total potential cost saving to consumers of approximately £200m per annum.

Appendix A Questionnaire sent to DNOs

On sending out an email enquiry to DNOs about their storage sites, a request was made to complete the questionnaire below.

- What Battery technologies were used in the individual projects (Li-Ion, NAS, Lead-Acid,…)?

  - What ratio Capacity vs. Power is achieved?

  - Are these units able to also deliver reactive power i.e. voltage control?

- How is the battery operated - locally controlled, or distant control?

  - How fast is the communication in case of distant control? Is it deterministic?

  - What is measured in case of local control?

- By what scheme does is currently operate?

  - Frequency response?

  - Load shifting?

  - Emulation of rotating generators i.e. virtual inertia?

  - RoCoF control?

- What speed of response can they realize?

- What kinds of inverters were used?

  - What kind of control do they have implemented (current control or voltage control?)

- Are they black start capable?

- Are they containerized or require a dedicated building?

- Where are the units situated? e.g. isolated, in a substation,…?

  - Is there any storage system which is situated inside a PV power plant (and connected at the same point of interconnection?)

Appendix B Existing battery storage site evaluations

Table 10 below shows the compiled data initially received in response to the questionnaire, from UK Power Networks (UKPN), Northern Power Grid (NPG) and Western Power Distribution (WPD) for those sites eventually shortlisted.

Table 10: Questionnaire responses from UKPN, NPG and WPD for shortlisted sites

Project Name	Smarter Network Storage Leighton Buzzard	CLNR Rise Carr/Darlington	Willenhall
Distribution Network Operator	UK Power Networks	Northern Power Grid	Western Power Distribution
Capacity	10MWh Capacity	500MWh Capacity	1MWh
Power	6 MW	2,5 MW	2 MW
Battery Technology	Lithium Ion	Lithium Ion	Lithium Ion
Reactive Power	Yes	Yes	Yes
Operated (Locally/Remote)	Remote	Local and Remote	Local and Remote
Type/speed of remote communications	Remote control yet to be fully tested	Fast response time is (under 100 milliseconds)	Fibre
Local control (measures)	Network configuration, voltage, loading, frequency amongst others	Voltage, current, reactive power	VT, primary substation demand and frequency control
Current Operation e.g Frequency Regulation, Primary Reserve, Peak Shaving, Voltage Regulation, Peak load Management	Static and dynamic frequency response, load shifting	Load shifting	Peak shaving, ancillary balancing services & arbitrage.
Emulation of rotating generators (synthetic inertia?)	No	No	Not yet confirmed
RoCoF control?	No	No	TBC
Speed of response	Designed to be <500ms	Response time of battery ramp output from 0-100% is 20ms	
Inverters used	6 x 1MW/1.25MVA Power Conversion Systems from S & C Electric	2 x 1.25 MW Bi-Directional AC/DC Power Converter Provided by 'Dynapower' Company LLC - USA	ABB 2MVA Inverter
Black Start Capable?	Yes but no scheme currently implemented in SNS project	Currently not configured for black start due to G59 requirements	Yes but prevented due to G59 protection
Location	Existing Substation	Existing Substation	Adjacent to substation
Relevant for EFCC?	YES	YES	YES
If not relevant for EFCC - why?	Not applicable	Not applicable	Not applicable
Containerized?	Bespoke Container	Bespoke Container	Bespoke Container
Integration into PV power plant	No	No	Neglible PV plant
Comments		on-site controllers support both Modbus TCP and DNP3 protocols for the control interface.	Due to commission end of July 2015. Frequency response available, but designed to have RoCoF / Vector Phase Shift protection installed as part of G59 installation.

Appendix B Existing battery storage site evaluations

Table 11 below shows data for existing energy storage sites received from Western Power Distribution in response to the questionnaire.

Project Name	Sola Bristol	FALCON	Solar Storage	Solar Storage	Isentropic Pumped Heat Energy Storage
Distribution Network Operator	Western Power Distribution	Western Power Distribution	Western Power Distribution	Western Power Distribution	Western Power Distribution
Capacity	12kWh Capacity split between 32 single phase units ~ 2kW capacity	5 x 100kWh Capacity	Min 300kVA	Min 300kVA	5.6MWh
Power		5 x 50kW	300kWh	300kWh	1.4MW for 4hours (75% efficiency)
Battery Technology	Lead Acid	Sodium Nickel Chloride	TBC	TBC	Thermal
Reactive Power	Yes	Yes	Yes	Yes	Yes
Operated (Locally/Remote)	Local and Remote	Local and Remote	Local and Remote control via operator	Local and Remote	Local and Remote
Type/speed of remote communications	GPRS communications	WiMAX point to point radio. Typical less than 200ms round trip	TBC (likely to be requested via operator manually)	TBC (probably UHF)	UHF
Local control (measures)	Solar PV output, AC property demand, DC property demand and voltage	Voltage, frequency & LV substation demand	TBC (likely to be voltage, real power, reactive power of the site which include PV output)	TBC (expect Voltage & PV output as a minimum)	Voltage & primary substation demand
Current Operation e.g Frequency Regulation, Primary Reserve, Peak Shaving, Voltage Regulation, Peak load Management	Domestic demand reduction & Network support	Peak Shaving, Frequency control, manually kVA output & Voltage control	TBC (expected to be Network Peak Shaving, generation output control and Voltage control as a minimum) Capable of ancillary balancing but outside of the trial scope.	Tbc (expected to be Network Peak Shaving, generation output control and Voltage control as a minimum)	Peak Shaving, Balancing Var flow. and arbitrage. Capable of ancillary balancing but outside of the trial scope.
Emulation of rotating generators (synthetic inertia?)	No	Not confirmed	TBC but probably not	TBC	Real inertia from rotating mass
RoCoF control?	No	No	TBC	TBC	Yes
Speed of response			TBC	TBC	TBC
Inverters used	Studer off grid inverters	Princeton Power Inverters	TBC	TBC	No inverters required
Black Start Capable?	Protection, Inverters are capable of off grid environments but currently not configured for black start due to G59 requirements	Protection, Inverters are capable of off grid environments but currently not configured for black start due to G59 requirements	TBC (probably not)	Tbc (probably not)	Has capability but G59 protection requirements prevent this
Location	Domestic Installation and Existing Substation	Existing Substation	On PV generation site	On PV generation site	Existing Substation
Relevant for EFCC?	No	No	No	No	No
If not relevant for EFCC - why?	Power/capacity too small	Power/capacity is too small also slow response due to Flow Battery type	Power/capacity too small	Power/capacity too small	Not battery storage and the response time of the system is far too high for the given project
Containerized?		No, custom installation at each site	TBC	TBC	Within a building
Integration into PV power plant	Yes	No	Yes	Yes	No
Comments	Vector Phase Shift protection installed as part of G59 installation	Vector Phase Shift protection installed as part of G59 installation	Project in procurement phase. Any frequency response TBC. However, RoCoF / Vector Phase Shift protection installed as part of G59 installation	Project in procurement phase. Any frequency response TBC. However, RoCoF / Vector Phase Shift protection installed as part of G59 installation	Frequency response available, but designed to have RoCoF / Vector Phase Shift protection installed as part of G59 installation. Real inertia provided by rotating mass

Table 11: Questionnaire responses for WPD energy storage sites

Appendix B Existing battery storage site evaluations

The following table (Table 12) show data for existing energy storage sites compiled from publically available information.

Table 12: Data for other energy storage sites

Project Name	CLNR High Northgate	CLNR Wooler Ramsey	CLNR Maltby	CLNR Wooler St Mary	CLNR Harrowgate Hill
Distribution Network Operator	Northern Power Grid	Northern Power Grid	Northern Power Grid	Northern Power Grid	Northern Power Grid
Capacity	200kWh Capacity	200kWh Capacity	100kWh Capacity	100kWh Capacity	100kWh Capacity
Power		100 kW	50 kW		
Battery Technology	Lithium Ion	Lithium Ion	Lithium Ion	Lithium Ion	Lithium Ion
Reactive Power					
Operated (Locally/Remote)	Remote	Remote	Remote	Remote	
Type/speed of remote communications					
Local control (measures)	N/A	N/A	N/A	N/A	
Current Operation e.g Frequency Regulation, Primary Reserve, Peak Shaving, Voltage Regulation, Peak load Management					
Emulation of rotating generators (synthetic inertia?)					
RoCoF control?					
Speed of response					
Inverters used					
Black Start Capable?					
Location	Existing Substation	Existing Substation	New Substation	Existing Substation	Existing Substation
Relevant for EFCC?	No	No	No	No	No
If not relevant for EFCC - why?	Power/capacity is too small	Power/capacity is too small	Power/capacity is too small	Power/capacity is too small	Power/capacity is too small
Containerized?	Bespoke Container	Bespoke Container	Bespoke Container	Bespoke Container	Bespoke Container
Integration into PV power plant					
Comments					

Appendix B Existing battery storage site evaluations

Project Name	Chalvey	Orkney Energy Storage Park	NINES Shetland	NINES Shetland	Nairn Flow Battery Trial	Hemsby
Distribution Network Operator	SSE	SSE	SSE	SSE	SSE	UK Power Networks
Capacity	25kWh Capacity (ave efficiency 80%)	500kWh Capacity	6MWh Capacity	3MWh Capacity	150kWh	200kWh Capacity
Power		2 MW	1 MW	1 MW	100kWp	200 kW
Battery Technology	Lithium Ion	Lithium Ion	Sodium Sulphur	Lead Acid	Zinc-Bromine Flow Battery	Lithium Ion
Reactive Power						
Operated (Locally/Remote)			Local and Remote	Local and Remote		
Type/speed of remote communications						
Local control (measures)						
Current Operation e.g Frequency Regulation, Primary Reserve, Peak Shaving, Voltage Regulation, Peak load Management						
Emulation of rotating generators (synthetic inertia?)						
RoCoF control?						
Speed of response						
Inverters used	Four quadrant power converter		DC/AC inverter	Three-phase DC/AC inverter		Between AC and DC bus
Black Start Capable?						
Location	Existing Substation	Existing Substation	Existing Substation	Existing Substation	Existing Substation	New Substation
Relevant for EFCC?	No	Yes	No	No	No	No
If not relevant for EFCC - why?	Power/capacity is too small	Not connected to the National Grid, so no use for the EFCC project	Decomissioned	Not connected to the National Grid, so no use for the EFCC project	Power/capacity is too small also slow response due to Flow Battery type	Power/capacity too small
Containerized?		ISO 40 foot container	Dedicated building	Dedicated building	Off the shelf container	Bespoke Container
Integration into PV power plant						
Comments						

Appendix C NPG Rise Carr 2.5MVA Battery Unit Detailed Costs

Table 13 and 14 below are detailed costs for the use of the Rise Carr site as provided by Northern Power Grid.

Commercially Sensitive Information

Appendix D Cost of Belectric Energy Buffer Unit (EBU) Battery Storage

Table 15 below are the detailed costs associated with the Belectric battery storage unit as provided in the EFCC Full Submission report in October 2014.

	Total Cost £K									
	Labour	**Equipment**	**Contractors**	**IT**	**IPR Costs**	**Travel & Expenses**	**Payments to users**	**Contigency**	**Decommissioning**	**Other**
Site preparation Y2			0	0	33.67	0	0	0	0	0
Install equipment Y2			0	0	72.39	0	0	0	0	0
Install equipment Y3			0	0	72.39	0	0	0	0	0
Establish and modify relevant IT systems Y2			0	0	32.71	0	0	0	0	0
Establish and test communication Y3			0	0	32.71	0	0	0	0	0
Establish and test communication - Equipment & IT Y2			0	572	0	4	0	0	0	0
Test and demonstrate response capability Y3			0	0	25.65	0	0	0	0	0
Test and demonstrate response capability Y4			0	0	51.31	0	0	0	0	0
Travel expenses - Y2			0	0	0	0	0	2	0	0
Travel expenses - Y3			0	0	0	0	0	4	0	0
Travel expenses - Y4			0	0	0	0	0	4	0	0
Contingency Y2			0	0	0	0	0	0	0	62
Contingency Y3			0	0	0	0	0	0	0	62
Contingency Y4			0	0	0	0	0	0	0	62
Category totals				572	320.82	4	0	10	0	186
TOTAL									**1092.82**	

Table 15: Cost of Belectric battery storage unit

Appendix E Cost Benefit Analysis Assumptions

Table 16: Cost benefit analysis Assumptions

Assumption	Justification	Sensitivity	Additional Comments	Learning from EFCC
System inertia changes over time according to the 2015 Gone Green scenario	Gone Green meets the 2020 energy targets	n/a	Impacts the additional enhanced response requirements assumptions to around 2025	n/a
Additional enhanced response requirements are as shown in Figure 6	From initial modelling for EFCC CBA and extrapolated using system inertia and SOF frequency response results (Figure 4 and Figure 5)	Requirements according to Gone Green and Slow Progression scenarios (Slow Progression is delayed requirements)		n/a
Batteries have 95% availability for enhanced frequency response	Infrequent usage allows batteries to be available most of the since they can be charged during the day for overnight periods	n/a	Coordination between response delivered by solar PV alone, PV plus battery storage and storage only is different in terms of duration and level of response.	Trials to be carried out on these solar and battery combinations to deliver learning. Battery availability will be clarified from the project.
Batteries have a 10 year lifespan	Literature typically quotes 8-15 years depending on usage	n/a		Understanding of how usage for enhanced frequency response affects lifespan and degradation
Battery CAPEX £1,122,820	Cost of the battery-solar hybrid EFCC project. Likely to decrease as the cost of batteries decreases but we don't assume this	n/a		

Appendix E Cost Benefit Analysis Assumptions

Assumption	Justification	Sensitivity	Additional Comments	Learning from EFCC
Battery OPEX £10,000/yr	Literature quotes fixed OPEX for Lithium-ion batteries used for frequency response as $6500-$9200/MW-yr, we round up to be conservative[9]	n/a		Clear learning outcome from the project
No similar projects are constructed before the completion of the EFCC project and the earliest new batteries could become operational would be 2019	Reasonable and conservative to assume the rollout of such projects will only start after the completion of EFCC	2020 in the delayed rollout scenario	Assume the battery rollout starts slowly and picks up pace as market confidence grows and technical learnings have been achieved	n/a
Weighted Average Cost of Capital (WACC) 5.3%	Upper limit of the WACC quoted for the cap and floor to be applied to the UK interconnector regime[10]			
Discount rate 3.5%	Standard UK discount rate	n/a		
Service payment [redacted]	Approximate current cost of existing frequency response			Commercial service to be developed in Work Package 6
Service availability based on RoCoF requirements	See Appendix H for full details			Availability and operational models will be investigated

[9] Table B-28 in DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA
[10] OFGEM Financeability study on the development of a regulatory regime for interconnector investment based on a cap and floor approach, 2013. The WACC values are quoted as 4.3% (floor), 4.7% (midpoint) and 5.3% (cap) and we chose the cap value since it is the most conservative of the three values.

Appendix E Cost Benefit Analysis Assumptions

ASSUMPTION	JUSTIFICATION	SENSITIVITY	ADDITIONAL COMMENTS	LEARNING FROM EFCC
Batteries comprise 37.5% of the enhanced frequency response market share from 2020 onwards	Batteries have the potential to comprise a large amount of the market share due to their technical capabilities once their rollout gets underway	Low value (30% of the market share) and high value (45% of the market share) and rollout delay to hit assumed market share by 2025	A large sensitivity range has been chosen as the market share will depend on technical and commercial learnings from the EFCC project	Far better understanding possible of potential market share for batteries from project learning outcomes
Total savings to consumers/additional enhanced response requirements are calculated from data behind Figure 18 (£m/MW)	Detailed assessment revealed total savings of £150m for 250MW additional response required, £200m for 300MW response required	Linear dependency between price and MW compared to quadratic dependency (Appendix F)	As more response is needed it is likely that the cost/MW will also increase, therefore the linear option is a lower bound. Quadratic dependency is one option to model the increasing costs	This will be clarified during the project with the development of the commercial service
Solar deployment of farms above 1MW from 2015-2035 follows the Gone Green or Slow Progression scenarios	National Grid produces the FES using an evidence-based approach	The Slow Progression scenario is used as a lower bound and corresponds to the delayed response requirements from above	Both scenarios forecast almost identical levels of solar deployment until 2027 when Gone Green sees a slightly greater deployment	n/a
77% of solar deployment will exist in farms of size greater than 4MW	Our current knowledge of all solar projects planned through to operational shows this figure	n/a	Relevant because EFCC plans to use a 1MW battery for a 3.8MW solar farm, so we assume 1MW batteries can be deployed on all farms above 4MW (approximately)	n/a
The distribution of sizes of solar farms will remain the same going forward	We do not have any evidence to suggest how it could change	n/a	This allows us to estimate the number of farms we expect to install a battery according to the rollout, however larger batteries would require fewer participating farms	n/a

Appendix E Cost Benefit Analysis Assumptions

Assumption	Justification	Sensitivity	Additional Comments	Learning from EFCC
Solar farms will typically install batteries with a rated capacity of ¼ of the rated capacity of the solar farm	This is approximately the ratio in the EFCC project and the first time a hybrid solar PV and battery storage installation would be trialled	n/a	This number is approximate but a highly accurate figure is not crucial for the results of this CBA	The benefits and challenges of this ratio will be assessed in the project
A battery combined with renewable generation is likely to increase the availability of frequency response service and volume that can be achieved	Existing pool of frequency response providers is limited to conventional generation plant and demand side	n/a	How much contribution that can be attributed to renewable generation such as solar PV is currently unknown	Proposed hybrid solar PV and battery storage trials will provide learning on availability and contribution of renewables alongside other providers
Complete integration of battery to the grid (no technological barriers to utilisation)	Hybrid solar PV and battery storage likely to use spare inverter capacity of the PV farm	n/a	No network reinforcements will be required to integrate the battery	Site specific technical limitations will be investigated and disseminated as learning from the project
Hybrid solar PV and battery storage installation only participates in the EFCC new frequency response market	See Section 7.2.6	n/a	Solar farms combined with battery storage are capable of providing other grid services (e.g. voltage support)	Any additional learning on technical performance capabilities obtained during EFCC trials will be gathered for dissemination

Appendix F Consumer cost of additional Enhanced Frequency Response

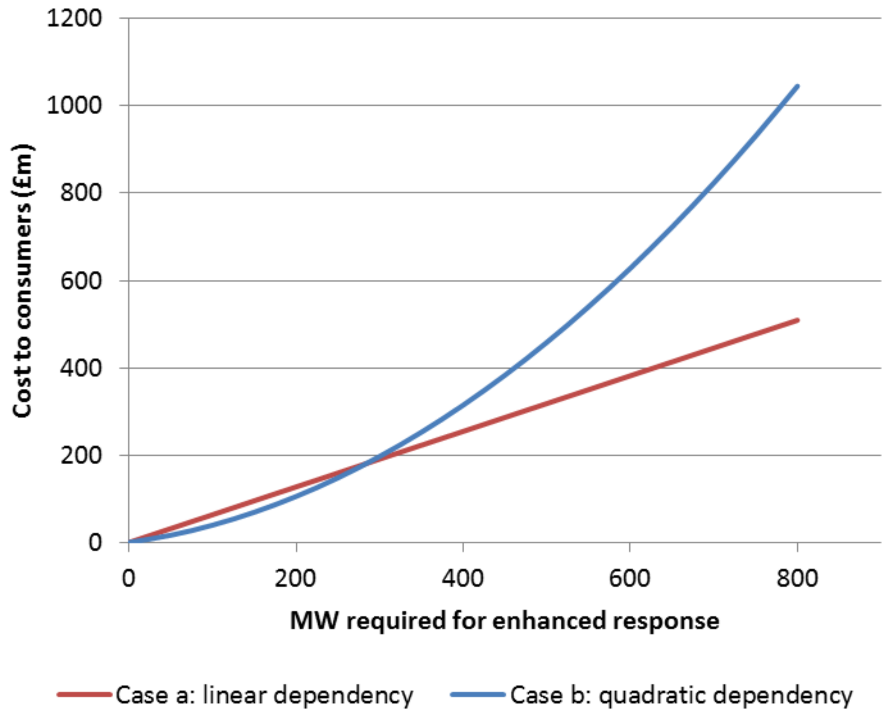


Figure 18: Cost to consumers of procuring additional enhanced frequency response. We consider two different relationships to provide sensitivity analysis to our modelling.

Appendix G Solar farm participation projections

National Grid has access to data on the details of solar farms in all stages of development. The histogram below shows the number of farms in each size category. The most common size of solar farm is 4-5MW which constitutes 12% of the installed solar capacity in GB (farms not domestic panels). We assume that the distribution of the sizes of solar farm remains the same as the number of solar farms increases. To determine how many farms adopt a battery, we allocate the battery installed capacity proportionally to each size category of solar farm and calculate how many solar farms in each size category are required to install the batteries allocated.

For example, under Gone Green in 2020 we expect 32MW battery storage. Batteries sized 5-6MW comprise 6% of the installed capacity of solar PV above 4MW, hence we allocate approximately 1.85MW of batteries to solar farms in this size category. The mean size of farm in this category is approximately 5.5MW and so at 25% of capacity we would expect each farm to adopt a battery of size 1.4MW. Therefore 2 solar farms in this category would be needed to adopt a battery in order to cover the 1.85MW battery installation assumed. This is of course a conservative estimate, and it is highly likely that fewer solar farms would need to participate than we estimate with this method.

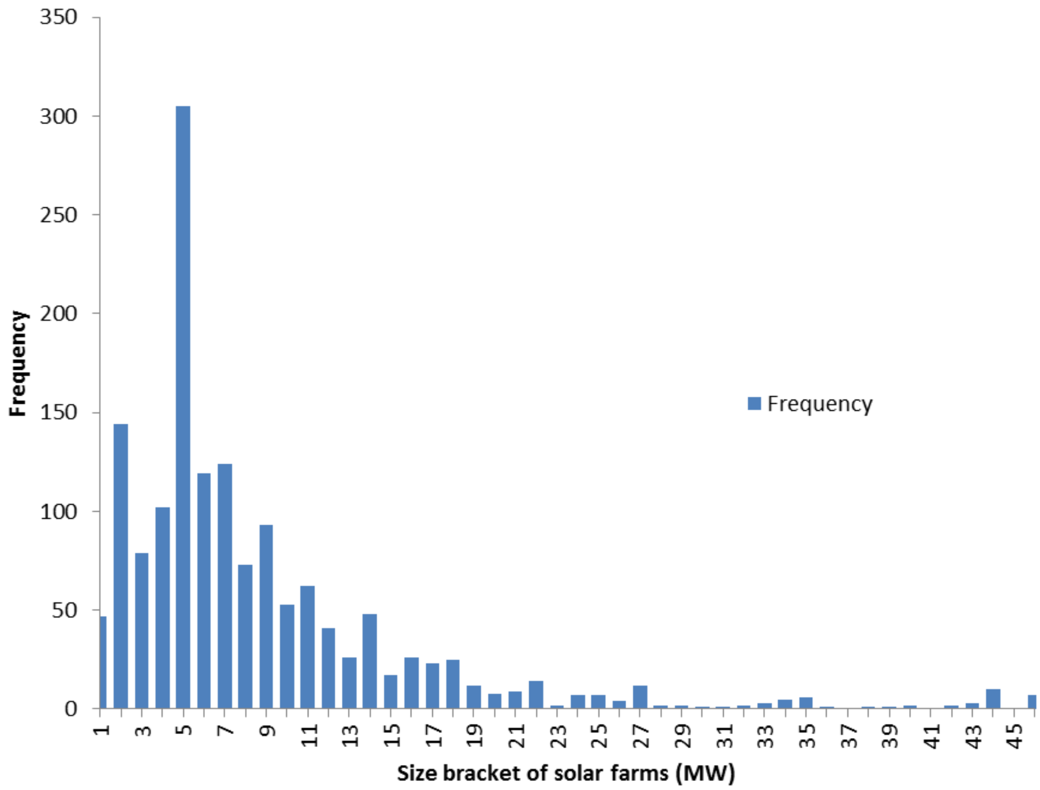


Figure 19: Histogram of solar farm installed capacities for solar farms in all stages of development from potential to operational.

Appendix H Availability requirements for enhanced frequency response

Assessments contributing to the National Grid 2015 SOF have determined the percentage of the year when the rate of change of frequency (RoCoF) is greater than the existing setting of 0.125Hz/s. The following tables show are assumptions for the number of hours the enhanced frequency response will contract availability from providers, based on this data.

We assume that the hybrid batteries contract to be available for the full hours shown, and that the 5% unavailability is due to faults or other un-planned issues rather than opting out of a contract.

Since usage is rare the payments for the service are considered to be restricted to availability payments [redacted].

	Gone Green		Slow Progression	
	% of year	hours	% of year	hours
2019	78.8%	6903	73.2%	6412
2020	83.0%	7271	76.0%	6658
2021	86.2%	7551	77.8%	6815
2022	89.4%	7831	79.6%	6973
2023	92.6%	8112	81.4%	7131
2024	95.8%	8392	83.2%	7288
2025	99.0%	8672	85.0%	7446
2026	99.0%	8672	85.0%	7446
2027	99.0%	8672	88.5%	7753
2028	99.0%	8672	92.0%	8059
2029	99.0%	8672	95.5%	8366
2030 onwards	99.0%	8672	99.0%	8672

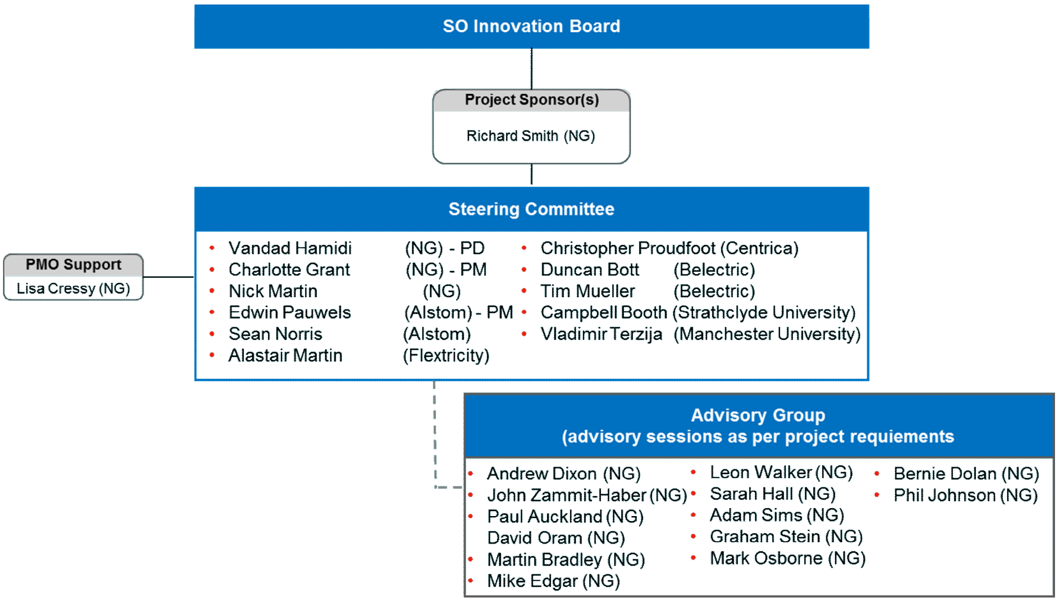
Table 17: Percentage of the year when RoCoF > 0.125Hz/s and resulting hours of enhanced frequency response contracting

Appendix I Data Tables for Figures 6 - 8

Table 18: Data for figures 6-8

	Figure 6		Figure 7				Figure 8					
Description	**Additional Enhanced Response Requirements (MW)**		**Cost to the consumer without EFCC (£m/year)**				**Battery rollout projections (percentage refers to percentage of enhanced frequency response market attained) (MW)**					
Scenario	**GG a&b**	**SP a&b**	**GGa**	**GGb**	**SPa**	**SPb**	**GG 30%**	**GG 37.5%**	**GG 45%**	**SP 30%**	**SP 37.5%**	**SP 45%**
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	30	10	19	9	6	3	0	0	0	0	0	0
2017	60	25	38	21	16	7	0	0	0	0	0	0
2018	110	45	70	45	29	15	0	0	0	0	0	0
2019	175	75	111	86	48	27	28	35	42	11	14	17
2020	275	110	175	172	70	45	87	109	130	35	43	52
2021	375	150	239	283	95	69	118	148	178	47	59	71
2022	475	190	302	420	121	98	150	188	225	60	75	90
2023	575	240	366	583	153	139	182	227	272	76	95	114
2024	660	300	420	742	191	197	208	261	313	95	118	142
2025	750	360	477	931	229	264	237	296	355	114	142	171
2026	760	420	484	954	267	341	240	300	360	133	166	199
2027	770	490	490	976	312	443	243	304	365	155	193	232
2028	770	590	490	976	375	610	243	304	365	186	233	279
2029	770	700	490	976	445	824	243	304	365	221	276	332
2030	770	770	490	976	490	976	243	304	365	243	304	365
2031	770	770	490	976	490	976	243	304	365	243	304	365
2032	770	770	490	976	490	976	243	304	365	243	304	365
2033	770	770	490	976	490	976	243	304	365	243	304	365
2034	770	770	490	976	490	976	243	304	365	243	304	365
2035	770	770	490	976	490	976	243	304	365	243	304	365

Appendix J EFCC Project Hierarchy



- System Operator (SO) Innovation Board

  Governance, oversight, business alignment, approval of strategic decisions, conflict resolution.

- Project Sponsor

  Richard Smith, Head of Network Strategy, National Grid

  Provide project direction and alignment with strategic business objectives, ensure business issues are resolved in a timely manner and provide an escalation route for key risks.

- Project Steering Committee

  Each project partner has provided a dedicated lead representative (as named in Figure 1) and employed appropriate additional resource support to ensure successful delivery of project objectives. The project has benefitted from the continuity of resource within the partner organisations that had been involved with the project proposal submission.

  The Steering Committee is responsible for developing and undertaking project activities, completing deliverables, raising, evaluating and mitigating identified risks and authorising changes to the project plan.

  Project Director (Vandad Hamidi), Technical Project Manager (Charlotte Grant), and Project Manager (Lisa Cressy) track and challenge progress against the project plan, manage interdependencies and risks ensuring interventions are in place, escalate concerns, whilst ensuring National Grid Project Management procedures are adhered to.

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