RaaS
Resilience as a Service

Work Package 4:

Optimisation Assessment for RaaS Battery Operation at the RaaS Trial Site and a generic site

(E4.2 & E4.3)

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Contents

List of abbreviations

BESS	Battery Energy Storage System
CMZ	Constraint Managed Zone
DC	Dynamic Containment
DER	Distributed Energy Resources
DM	Dynamic Moderation
DNO	Distribution Network Operator
DR	Dynamic Regulation
DSO	Distribution System Operator
FEED	Front End Engineering Design
EFA	Electricity Forward Agreement
ENA	Energy Networks Association
ESO	Electricity System Operator
FFR	Firm Frequency Response
FR	Frequency Response
NGESO	National Grid Electricity System Operator
NIC	Network Innovation Competition
Ofgem	Office of Gas and Electricity Markets
RaaS	Resilience as a Service
ROI	Return on Investment
SSEN	Scottish and Southern Electricity Networks
TSO	Transmission System Operator
WP	Work Package

1 Executive Summary

This report was prepared by Cornwall Insight on behalf of the Resilience as a Service (RaaS) innovation project partners, Scottish and Southern Electricity Networks (SSEN), E.ON and Costain. It contains quantitative analysis carried out by Cornwall Insight to support the RaaS project in its consideration of wider flexibility markets that may be participated in alongside the provision of a RaaS service to stack revenues and thereby reduce the potential cost of RaaS.

The RaaS project is investigating the technical application and commercial opportunities associated with a new flexibility service that could be offered to Distribution Network Operators (DNOs) to improve network resilience in remote or rural areas. The service could be provided by a battery energy storage system (BESS), potentially together with local distributed energy resources (DER), to ensure security of supply customers in the event of a fault on the distribution network.

The RaaS service requirements are still being defined, however it is expected that the storage technology implemented to provide the RaaS service would also have 'headroom' capacity above its RaaS obligations which could support the provision of additional services – for example, participating in other flexibility markets in GB such as the Balancing Mechanism and frequency response services. The amount of headroom available will depend on both the level of RaaS service required by the DNO, and the sizing of the battery for the location of the point of connection to the network.

The analysis presented in this report assesses the potential revenues that a RaaS battery asset could earn from other GB flexibility markets over and above potential revenues received from provision of the RaaS service primarily the wholesale market, the capacity market, and balancing services required by the Electricity System Operator (ESO). As the details of the RaaS product are to be further defined through project work, we have carried out the modelling based on a number of assumptions agreed with the project partners.

Three RaaS **Product Design Scenarios** were defined through prior project work for the purposes of modelling. These represent different approaches to the specification of requirements for a RaaS service, and vary based on how granular the service requirement is (i.e. on a daily basis or on a 4-hourly block basis), and how the DNO's requirements are determined (i.e. pre-agreed and determined in the RaaS contract itself, or dynamically determined at some point in time ahead of an operational day). The RaaS Product Design Scenarios modelled are:

- **Product Design Scenario 1** – RaaS minimum reserved capacity changes seasonally, with contractually defined service windows for working and non-working days for Spring, Summer, Autumn and Winter
- **Product Design Scenario 2** – seasonal and working/non-working day changes, with more granular windows reflecting the six four-hour Electricity Forward Agreement (EFA)[1] blocks throughout the day
- **Product Design Scenario 3** – dynamic RaaS service requirement with the RaaS service requirement (informing minimum reserved capacity) notified by the DNO at a point in time in advance, allowing varying requirements over the course of the contract. For the purposes of modelling, the varying requirements were simulated using historical DNO data.

[1] EFA blocks are the standard unit of trading in the wholesale electricity market. The EFA day runs from 11pm to 11pm the next day. Balancing services from National Grid Electricity System Operator (ESO) are tending towards using EFA blocks as granularity to allow stacking with the wholesale market.

In addition to the three Product Design Scenarios, further scenarios related to different wholesale price forecasts (low, central and high) as well as different site attributes (e.g. location and battery asset sizing) have been modelled.

As the details of the RaaS product are to be further defined through project work, and because of the nature of modelling, some assumptions were necessary to represent the RaaS products and potential revenues that could be earned. For example:

- The RaaS requirements are based on meeting the 90th percentile of the peak demand for each delivery window (daily or EFA block).
- For RaaS Product Design Scenario 3 the RaaS requirements were set in advance for the modelling. In practice the DNO will be able notify its requirements in a more sophisticated way to reflect its more up-to-date view of its system and conditions, and this could include different notification points to be available and to 'stand down'.
- Similarly for Product Design Scenario 3, the decisions of the DNO are emulated using wind speed as a proxy. In practice, the DNO's decisions will be driven by a more sophisticated and up-to-date view of its system and conditions, for example load on the system and availability of other assets, rather than just wind speed.
- The effective network constraint on the system is likely to be dynamic, relating to load on the system. As the Cornwall Insight model is set up to model static network constraints only, we used a sensitivity to capture outcomes from a range of network constraints ("Network Constraint A", "Network Constraint B", "Network Constraint C"). In practice the network constraint will not be fixed, and this will impact the volumes that the asset can import and export.

The analysis showed that:

- There are clear opportunities for revenue stacking from participation in other flexibility markets in addition to the provision of a RaaS service to a DNO. The scope to do so will depend on the level of battery headroom capacity available to offer into other markets.
- As to be expected, an asset offering RaaS will receive lower revenues from participation in additional flexibility markets than an asset not offering a RaaS service as the provision of RaaS reserves a proportion of battery capacity which is not able to participate in those other markets. Further work within the project will incorporate the potential revenues from participation in the RaaS service into the business cases for an investor in a RaaS battery asset.
- The decision around battery sizing is important. Battery capacity degrades over time and under some of the scenarios analysed here, the battery capacity is not sufficient to meet the minimum reserved capacity required for some RaaS product design scenarios beyond a certain age of the battery. Further, battery capacity degrades with usage - an asset that is used, or 'cycled', more frequently will degrade more quickly than assets cycled less often.

With regard to the potential revenue from other flexibility markets (beyond the provision of RaaS), and with implications for further RaaS product design development:

- Under Product Design Scenario 1 – the asset has the lowest level of granularity of service specification, and the headroom capacity available for optimisation in other flexibility markets provides margins from those services starting at £24/kW per year, falling to £12/kW per year after five years and close to £1/kW after ten years.
- Under Product Design Scenario 2 – the RaaS requirement is more variable compared to scenario 1, allowing greater variation in the headroom that can be offered into the flexibility markets. Margins were similar but slightly lower than Product Design Scenario 1, starting at

£23.30/kW per year falling to £10/kW per year after 5 years, and just less than £0/kW per year after ten years. Although this product has more granularity than Product Design Scenario 1, this meant that the requirement was comparatively higher during peak periods, rather than smoothed across a longer period, so that the available headroom across the peak periods was less, compared to Product Design Scenario 1. It must be noted, however, that the methodology used for modelling purposes to specify requirements under Product Design Scenario 1 does not fully consider the risk associated with meeting demand at specific points in time, and so a DNO may take a different approach to specifying requirements under Product Design Scenario 1 (as described in Section 4)
- Under Product Design Scenario 3 – the DNO has the ability to dynamically notify the level of resilience that it requires in advance of the operational day, allowing the RaaS Service Provider to adapt operation and make use of the available headroom for participation in other flexibility markets. This option would require greater levels of analysis and more refined communication processes for both the DNO and RaaS Service Provider. Margins from flexibility revenues started at £34/kW per year, falling to £29/kW per year in year 5 and rising to £30/kW per year in year ten.

In addition, it can be noted that:

- The RaaS service will likely provide a more reliable / steady revenue stream compared to revenues from other flexibility markets, in which revenues can often only be guaranteed at the day-ahead or the within-day stage. This may be more attractive to some types of investors.
- The RaaS service may have a lower impact on the degradation of the battery because the asset would be expected to cycle (charge and discharge) less, compared to providing flexibility in other flexibility markets. This impact is not captured in the modelling, but in practice would extend the asset's life and therefore may be more attractive to some kinds of investors, and/or may lead to lower assumptions regarding battery degradation which influence the modelling results.
- Approaches that use more dynamic notification of requirements would require greater levels of analysis and a more refined communications process for both the DNO and RaaS Service Provider.
- Across the different types of potential RaaS of investors there will be different degrees of risk appetite – with some preferring long term price certainty over shorter term, more volatile revenues.

The analysis presented within this report illustrates the range of factors that would need to be considered by a RaaS Service Provider with regard to revenue stacking across other markets, to inform the business case for investment in a RaaS asset. Different potential RaaS Service Providers may have different capabilities, and different costs, for providing different minimum reserved capacities for RaaS.

Similarly, a key consideration for DNOs relates to the balance between the benefits of a RaaS solution and potential costs. DNOs therefore need to consider the fact that a service which does not meet full (ideal from a technical perspective) requirements for RaaS at a given location may still represent an improvement in service to customers, and so where this may be more cost effective than procuring the full requirements, this option should still be considered.

A recommendation here is for DNOs to consider including a number of options in the tender process (essentially reflecting different durations for the provision of a RaaS service during an outage) and inviting quotes for each. It is acknowledged that a DNO's engagement with the local community to understand their preferences and expectations would also be of value to inform the decisions made by a DNO for the implementation of RaaS at specific locations.

Next steps

The next steps for the project are to use this analysis to inform the design of the RaaS service, both for the trial site and for the future roll out of RaaS, and evaluate the appropriate pricing level for the service through the investor business case analysis to be undertaken in WP5 ‘Business Model’.

2 Introduction & purpose of report

2.1 Project Overview

The RaaS - Resilience as a Service - project is funded by the Network Innovation Competition (NIC) of the UK's Office of Gas and Electricity Markets (Ofgem). It is being delivered by three partners; Scottish and Southern Electricity Networks (SSEN), E.ON and Costain. SSEN are the distribution network operator (DNO) for the project evaluating the technical feasibility and financial viability from a DNO perspective; E.ON are an energy solutions provider who are leading the technical delivery of the battery system and developing the investor business case; Costain are a management consultancy acting as programme managers and providing input to the market design assessment.

The aim of the project is to investigate the technical application and commercial opportunities associated with the provision of a new market-based flexibility service that could be used by DNOs to improve network resilience in remote or rural areas. This service would use a Battery Energy Storage System (BESS) together with local Distributed Energy Resources (DER) to supply customers in the event of a fault on the network.

The project will determine how network resilience can be improved in a cost-effective manner for customers in areas susceptible to power outages, where traditional reinforcement or use of DNO owned standby generation to improve security of supply would be prohibitively costly. This can be achieved by a DNO procuring RaaS from a third-party service provider, who can stack revenues through participation in other flexibility markets. In addition to developing the technical solution, the project seeks to evaluate the financial case from a DNO perspective while giving insight to RaaS service providers on the investment case necessary, and optimal flexibility markets to operate in.

In the first phase, the project focuses on site selection, system design for the chosen demonstration site, and refinement of the business case. This phase will validate whether the concept is technically feasible and financially viable and will inform a decision to be made in 2021 on whether to proceed with the deployment and operation of a RaaS system at the chosen site for a trial period of up to two years.

Phase two of the project comprises the delivery, commissioning, and operation of the system in a test phase which is due to start in 2022. This will involve monitoring and evaluation of the system's performance as well as examining different combinations of flexibility services.

The Resilience as a Service concept offers a market-based solution to improve operational reliability and provide customers with a low carbon, cost effective and secure electricity supply.

The project is structured with the eight working packages described below.

WP1 – Project Coordination
WP1 comprises all core project management activities carried out by each partner, with Costain leading the overall coordination.

WP2 – Front End Engineering Design

This work package develops the initial design for the RaaS BESS and associated EMS, including external peer review of the proposals to provide a validated foundation for creating the detailed design for the scheme.

WP2 includes the following key tasks:

- Demonstration site selection and requirements capture
- Initial network modelling and analysis
- Creation of the Front End Engineering Design (FEED) for the RaaS BESS and associated EMS

WP3 – Detailed Design

The Detailed Design work package concentrates on the full technical design of the RaaS scheme and its interaction with existing network assets to meet all requirements for safe and effective operation.

WP3 includes the following key tasks:

- Detailed network modelling to understand potential impacts and requirements associated with such things as inrush currents during islanded energisation procedures, and protection and earthing schemes.
- Detailed design of the operational controls, electrical integration, and communication systems necessary to apply RaaS and incorporate available Distributed Generation (DG) schemes into islanded operation, including the BESS Energy Management System (EMS) and DNO side control system.
- Identification and qualification of potential equipment suppliers.
- Development of the construction, integration, commissioning, and testing plans for the demonstration site.
- Formation of the proposed trial programme.

WP4 – Planning for Operational Commercial Optimisation

This work is focused on evaluating the range of additional potential flexibility markets that a RaaS BESS could participate in, and using this to inform development of an operational schedule for the BESS over the demonstration period at the proposed trial site.

WP4 includes the following key tasks:

- Analysis of existing, and future, flexibility markets that a RaaS BESS could also participate in.
- Techno-economic modelling of potential operational strategies to participate in those other markets.
- Development of the proposed operational principals for the trial site.

WP5 – Business Model

The project considers the RaaS concept from the perspectives of both the DNO and the RaaS Service Provider, and this work package assesses the potential business case for RaaS service providers, in the context of DNO RaaS requirements.

WP5 includes the following key tasks:

- Construction of the investment business case for a RaaS Service Provider.
- Development of draft Heads of Terms for BAU application of RaaS for consultation.
- Evaluate options for revenue stacking in other flexibility markets.

WP6 – Supply Chain Engagement

This work package aims to build the foundations for RaaS market development by ensuring that DNOs and potential market participants have the skills, tools and confidence to procure or provide RaaS solutions.

WP6 includes the following key tasks:

- Deep dive investigation into the potential applications of the RaaS across Great Britain.
- Creation of a system model and enterprise design for the RaaS market.
- Development of a commercial strategy for RaaS and defining value structures.
- Engagement and consultation with potential RaaS Service Providers and supply chains.
- Optimisation of commercial, delivery and operational models for RaaS.

WP7 – Demonstration Site Construction and Operation

Subject to a successful stage gate decision, WP7 will see the implementation and demonstration of a RaaS scheme on SSEN's network. The project will install and operate RaaS at the selected trial site, and following successful demonstration will develop plans for a second site to be implemented beyond the conclusion of the project.

WP7 will include the following key tasks:

- Procurement of required equipment and services
- Obtaining all relevant permits and approvals
- Construction of the RaaS scheme and integration with the network
- Testing and commissioning
- Training
- Operation, monitoring and optimisation
- Conclusion of the trial via decommissioning of assets or transfer to business as usual and ongoing operation

WP8 – Dissemination

WP8 covers dissemination and consultation activities to raise awareness of the project and share learning with all stakeholders.

A range of approaches will be used, with presentations, publications, and events tailored to the relevant project stakeholders. Dissemination will be carried out in line with key stages of the project, and in conjunction with other relevant innovation projects and the ENA's Open Networks project where appropriate.

2.2 Report purpose

As part of WP4 Operational Optimisation, this report assesses the potential revenues that battery operators could earn alongside revenues provided by the RaaS service. This will support analysis of the investor business case in WP5 'Business Model', and, subject to a positive stage gate decision, will provide the basis for RaaS operation within WP7 'Demonstration Site Construction and Operation'.

The assessment considers three RaaS 'Product Design Scenarios' developed through prior project work, as described in the E4.1 'Flexibility Scenarios' report, and evaluates a range of available revenue streams for battery storage assets.

For all three Product Design Scenarios the principle is that battery operators must hold a minimum capacity ready to be utilised if called on by the DNO for a resilience event at any point in time – termed 'minimum reserved capacity' in this report. The different product design structures then lead to differences in the minimum reserved capacity required to meet demand during defined service windows under each scenario.

- **Scenario 1** – RaaS requirements are specified seasonally, with contractually defined service windows for working and non-working days in Spring, Summer, Autumn and Winter.
- **Scenario 2** – requirements are specified seasonally and for working and non-working day changes, however with six Electricity Forward Agreement (EFA)[2] blocks throughout the day to provide more granularity in the required service definition.
- **Scenario 3** – uses the same structure as scenario 2, however the requirements can be specified dynamically, e.g. week ahead or day ahead, to incorporate information relating to e.g. changes in capacity requirements due to load patterns or expected events, or likelihood of requiring a RaaS response over the short-term based on weather forecasts. For the modelling wind speed has been used as a proxy for the DNOs decisions, however in practice the DNO's requirements will vary based on its detailed expectation of system requirements.

An overview of the RaaS product design features under the three Product Design Scenarios is provided in Table 1.

Table 1: RaaS Product Design Scenarios

<table>
<tr><th>RaaS Product Scenarios</th><th>Service window</th><th>Notification period</th><th>Duration of service</th><th>Average load</th><th>Number of utilisations</th></tr>
<tr><td>Scenario 1: Lower granularity</td><td>4 seasons with a split between working days and non-working days</td><td>Contractually fixed</td><td>4 h</td><td rowspan="3">Calculated individually for each service window</td><td rowspan="3">Low level of utilisation events assumed (e.g. not more than 1 per year)</td></tr>
<tr><td>Scenario 2: Medium granularity</td><td>4 seasons with a split between working days and non-working days, and the day split into 4 hour EFA blocks</td><td>Contractually fixed</td><td>4 h</td></tr>
<tr><td>Scenario 3: Higher granularity</td><td>4 seasons with a split between working days and non-working days, and the day split into 4 hour EFA blocks</td><td>Dynamically at the day-ahead stage</td><td>equivalent of 2-8 h depending on service level</td></tr>
</table>

These scenarios vary in complexity and in scope for optimisation with other flexibility market services. The additional revenues to be gained from the battery, in addition to those from the RaaS service itself, relate to the headroom of capacity of the battery (MWh) which can be offered into other flexibility markets.

[2] Electricity Forward Agreement blocks (EFA blocks) are defined periods of four hours (six blocks each day), starting at 11pm. These are used in wholesale trading to reflect different load profiles across the day, and are used in other balancing services procured by NGESO.

The requirements under Product Design Scenario 1 are contractually fixed, and vary per day only, rather than across the day as with the other scenarios. Therefore, scenario 1 leaves the least room for commercial optimisation overall.

Product Design Scenario 2 provides more granularity compared to scenario 1 with the requirement varying across the day. However, setting the requirement on this more granular basis, means there is comparatively higher requirements across peak periods, which limits the ability to earn revenues in the flexibility markets when prices are highest. It is acknowledged, however, that the methodology used for modelling purposes to specify requirements under Product Design Scenario 1 does not fully consider the risk associated with meeting demand at specific points in time, and so a DNO may take a different approach to specifying requirements under scenario 1 (as described in Section 4).

Product Design Scenario 3 in comparison is more complex and less predictable for the RaaS Service Provider before the notification point, however it is expected to provide greater room for optimisation outside of the RaaS service, leading to increased revenues from other flexibility market revenue streams.

The objectives of this report are to:

- Evaluate flexibility revenues available to RaaS Service Providers under each RaaS Product Design Scenario, to help inform assessment of the benefits or limitations of the different product designs by investors and by DNOs
- Provide information on revenue forecasts from other flexibility markets to feed into WP5 'Business Model' and its analysis of the investor business case which will also draw in scheme costs and potential income from RaaS
- Recommend a Product Design Scenario to take forward to Phase 2 of the RaaS project, which will trial the RaaS service at a demonstration site
- Develop operational schedules for the demonstration site battery as well as for a 'generic' site at a different location

3 Overview of flexibility products modelled

3.1 Modelled flexibility products

To make the RaaS service a viable product for DNOs and investors, a proportion of the battery capacity is always reserved for potential resilience events to supply the network in islanded mode following a fault. The remaining 'headroom' is then available for participation in other flexibility markets to earn additional revenues during normal network operation. The aim of this report is to assess the potential revenues from this headroom capacity and explore how these can be optimised. The supporting analysis has been carried out using Cornwall Insight's Storage Asset Optimiser model. This revenue optimisation model is explained in more detail in chapter 4 and considers the following revenue streams and costs:

- Wholesale markets, including day-ahead and within-day trading
- Balancing Mechanism
- Frequency response
- Capacity Market
- Network charges
    - These include transmission network charges (TNUoS), balancing services charges (BSUoS), transmission losses and Assistance for Areas with High Electricity Distribution Costs (AAHEDC)
    - Also included are distribution charges and any relevant embedded benefits

This section briefly describes each of these revenue streams, then commentary on additional potential revenue streams that have been excluded from this analysis is provided in section 3.2. A full description of these revenue streams is provided in the Flexibility Markets in GB overview report by Cornwall Insight (the RaaS E4.1 'Flexibility Scenarios' report).

3.1.1 Wholesale trading

Wholesale trading is a key revenue stream for battery energy storage system (BESS) operators. By charging the battery when market prices are low and selling stored energy when market prices are high, BESS operators are able to arbitrage between different times of day, in a way that other generation assets cannot. BESS assets and other types of storage therefore benefit from increasing volatility of prices, which is expected as the proportion of intermittent capacity on the system increases.

Revenues from wholesale trading are relatively uncertain, with prices driven by a wide range of external factors such as the generation mix in GB, gas prices and carbon prices.

3.1.2 Balancing Mechanism

The Balancing Mechanism (BM) is the main mechanism used by National Grid ESO for balancing the grid and managing transmission constraints in close to real time, operating on a one hour before delivery timeframe.

Battery storage can participate in the BM, and can do this alongside wholesale trading if capacity considerations allow. Prices in the BM can exceed those available in the wholesale markets, and this is expected to continue as utilisation of the BM increases with more intermittent generation on the system.

3.1.3 Frequency Response (FR)

Frequency response (FR) is included in the analysis as an important revenue stream for flexibility providers.

In its current form as Firm Frequency Response (FFR), it is not possible for a battery or battery capacity committed to FFR to offer other balancing services or participate in wholesale trading while providing FFR. This is managed through 'revenue jumping' to target other services at other times outside of these windows, or by offering only a proportion of the capacity into the auction.

FFR is not 'stackable' with other revenue streams, so the battery is prevented from carrying out other actions during FFR windows. In the modelling for this analysis FR (currently FFR) is carried out overnight (between 23:00 and 07:00), as there is typically less volatility to take advantage of in wholesale markets or the BM at these times.

FFR will be replaced by a number of new National Grid ESO services, including Dynamic Containment (DC). Currently, DC is in a trial phase, with limited extent and undersubscribed auctions. As such, little information is known on future pricing and market parameters, therefore we do not yet model DC services. The approach in this report is to continue to model FR services as a reasonable proxy for value achievable from future frequency response services, based on an internal view of market dynamics in frequency response. It is acknowledged, however, that the FFR service is not likely to exist at the point where the RaaS trial site is due to commence operation. This has therefore been flagged as a risk in the RaaS Investor Risk Register developed within the project, as reported in E5.2 'Investor Risk Evaluation'.

3.1.4 Capacity Market

The Capacity Market (CM) is a mechanism introduced by Government to incentivise investment in new capacity or keeping existing capacity open, and is administered by National Grid ESO in its role as Electricity Market Reform Delivery Body[3].

Capacity payments are made on an annual basis (calculated based on the capacity of the asset and not the level of operation), so are treated separately from other revenue streams in this work as no optimisation is required to establish the amount of revenue achievable.

Technology-specific de-rating factors determine the level of payments received by each technology type, with storage de-rating factors depending on the duration of the storage (longer duration storage receives higher payments).

Receiving CM payments does not tend to impact an asset's ability to access any other flexibility revenue streams, however there are exceptions to this[4].

[3] www.emrsettlement.co.uk/about-emr/emr-roles

[4] Flexibility revenue streams that cannot be stacked with CM payments currently include DSO flexibility and Dynamic Containment at the time of writing, although it is expected that these issues will be resolved. See RaaS risk register for further detail.

3.2 Flexibility products not included in the optimisation modelling

Some additional potential revenue streams have not been included in this modelling work due to a current lack of information or certainty on these revenue streams, and with recognition of the fact that some revenue streams are highly site specific. These are described in turn below.

3.2.1 Dynamic Services

As noted above, frequency response services are changing and FFR will be replaced by DC, Dynamic Moderation (DM) and Dynamic Regulation (DR) services. FFR is scheduled to continue until early 2022, with DC currently in a trial phase and continuing to evolve through 2021 and 2022, alongside the new DM and DR products. As little information is currently available from the trials about future market dynamics, the new DC service is not yet modelled by Cornwall Insight.

3.2.2 DSO services

In their transition to becoming Distribution System Operators (DSOs), GB Distribution Network Operators (DNOs) are developing localised flexibility services to better manage specific issues experienced at certain points on distribution networks. The ENA (Energy Networks Association) is overseeing the Open Network[5] industry project to evaluate and evolve DSO flexibility products, and many DNOs have implemented schemes, e.g. Constraint Managed Zones (CMZs)[6]. However, these services will tend to be highly locational in scope and requirements, and potentially price levels, therefore specific consideration of such options would be needed for any individual RaaS scheme considering the requirements in the local area.

3.2.3 National Grid ESO Pathfinders

At present National Grid ESO is running three Pathfinder[7] projects to develop future flexibility services. These are currently procured on an ad-hoc basis and tend to be highly location-specific. While these may give rise to more widespread services in the future, currently the uncertainty on acceptance and utilisation rates (as well as uncertainty about the evolving future of the schemes and available revenues) prohibits these potential products from being modelled.

[5] ENA Open Networks collaborative industry project
[6] SSEN CMZ flexibility services call, 2021
[7] National Grid ESO Pathfinder projects

4 Overview of the modelling approach

This section outlines Cornwall Insight's approach to modelling the participation of battery storage assets in flexibility markets, and the scenarios that were assessed as part of the analysis.

The scenarios modelled reflect:

- The three potential RaaS product designs ("**RaaS Product Scenarios**")
- Different views of wholesale pricing ("**Wholesale Pricing Scenarios**")
- Different site and asset characteristics ("**Site Scenarios**")

In addition, we modelled sensitivities to assess the impact of three different network constraints which could apply to the Drynoch site. In practice the site has a dynamic network constraint, depending on the load, however we can currently only model static network constraints. For this reason sensitivity analysis was used to capture potential ranges for the network constraint:

- "**Network Constraint A**" – with a fixed import limit of 1.98MVA and a fixed export limit of 3.02MVA
- "**Network Constraint B**" – with a fixed import limit of 0.72MVA and a fixed export limit of 4.28MVA
- "**Network Constraint C**" – with a fixed import limit of 1.5MVA and a fixed export limit of 2.5MVA

An overview of the full list of scenarios and sensitivities is provided in Table 2.

Table 2 - Overview of modelling scenarios and sensitives

Wholesale Pricing Scenarios		RaaS Product Scenarios		Site Scenarios		Network Limit Sensitivity	
Name	**Definition**	**Name**	**Definition**	**Name**	**Definition**	**Name**	**Definition**
Low	Low view of wholesale, BM and frequency response prices	**Scenario 1:** Lower granularity	RaaS requirements set on a daily granularity	**Drynoch - pilot scheme**	4.2MW/4.2 MWh sized battery at the Drynoch site	**Network Constraint A**	Fixed import limit 1.98MVA Fixed export limit 3.02MVA
Central	Central view of wholesale, BM and frequency response prices	**Scenario 2:** Medium granularity	RaaS requirements set on a 4-hr EFA block granularity	**Drynoch - over-sized**	4.2MW/5.8 MWh sized battery at the Drynoch site	**Network Constraint B**	Fixed import limit 0.72MVA Fixed export limit 4.28MVA
High	High view of wholesale, BM and frequency response prices	**Scenario 3:** Higher granularity	RaaS requirements set on a 4-hr EFA block granularity, with DNO requirement	**Generic RaaS providing battery**	2.5MW/3.5 MWh sized battery using network charges for East Midlands DNO region	**Network Constraint C**	Fixed import limit 0.72MVA Fixed export limit 4.28MVA
		No RaaS – baseline	Results for a comparable asset not providing RaaS				

4.1.1 Defining the RaaS products for modelling

The three RaaS Product Design Scenarios developed through prior project work, as described in the E4.1 'Flexibility Scenarios' report, are defined as set out in Table 3. These were created to represent a potential range of products for modelling purposes, in practice the RaaS products adopted for future roll out may be different to these.

Table 3 - Overview of RaaS Product Design Scenarios

RaaS Product Scenarios	Service Window	Notification period	Duration of service
Scenario 1: Lower granularity	4 seasons with a split between working days and non-working days	Contractually fixed	4 h
Scenario 2: Medium granularity	4 seasons with a split between working days and non-working days, and the day split into 4-hour EFA blocks	Contractually fixed	4 h
Scenario 3: Higher granularity	4 seasons with a split between working days and non-working days, and the day split into 4-hour EFA blocks	Dynamically at the day-ahead	equivalent of 2-8 h depending on service level

The primary driver of the required minimum reserved capacity for RaaS is the load at the Drynoch primary substation selected for the potential trial of RaaS, as presented in the E2a.1 'Site Selection' report. Half hourly load data (MVA) for 2019 was provided by SSEN and used to represent future requirements for the purposes of modelling. The RaaS minimum reserved capacity requirement for the modelled RaaS Product Scenarios was then calculated as follows:

- Scenarios 1 and 2 – the average load for each service window was calculated (a unity power factor is assumed so load in MVA is equivalent to MW load)
    - Scenario 1 takes the 90th percentile of the half hourly load profile for each season (split by working days and non-working days in Scotland)
    - Scenario 2 takes the 90th percentile of the half hourly load profile for each four hourly Electricity Forward Agreement (EFA) block in summer, autumn, winter and spring (also split by working and non-working days)
    - The required duration for providing resilience during an outage is assumed to be 4 hours, reflecting a typical amount of time required to transport a temporary diesel generator to site if the fault will take some time to fix
- Scenario 3 – a 'service level' based on the level of demand expected in the event of a resilience event is defined for each EFA block for the next day.
    - The energy required to deliver resilience services during an outage is dynamic and depends on the load requirements within a service window.
    - For the purposes of this modelling work, this has been represented using figures for the energy required to provide different durations of service, with four service levels: green = energy required for 2 hours of demand, amber = 4 hours, red = 6 hours, black = 8 hours. The service level associated with each EFA block is allocated based on the (historic) wind speed of the day before delivery, as higher wind speeds are assumed to lead to a higher risk of overhead line damage, which would take time to repair. For

the real world application & operation of RaaS, it is expected that the DNO would determine its requirements for each EFA block based on a range of factors, including historic and forecast demand levels, in addition to windspeed and/or storm forecasts as potential indicators of the likelihood of a RaaS event occurring

- The rolling average load over each four-hour EFA block is then calculated and multiplied by the associated service level duration to give the total MWh requirement for each EFA block
- A black service is only required for maintenance periods, however, no maintenance work took place at the Drynoch site in 2019 so this has not been captured in the modelling
- Only green and amber service levels were required based on the 2019 data as there were no high wind speeds/storm warnings during high grid load service windows

The modelled MWh requirements for the RaaS Product Scenarios at the Drynoch site are shown in the following figures. Scenario 3 figures cover each EFA block throughout the year, so the figure is illustrative to show the dynamism in that scenario, compared to scenarios 1 and 2.

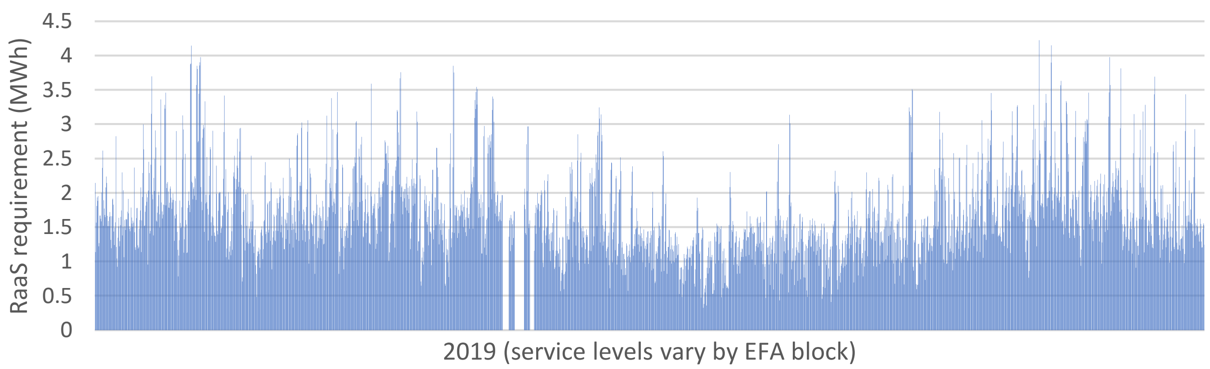
Figure 1: Product Scenario 1 reserved capacity for the Drynoch site (MWh)

Season	Non-working day	Working day
WINTER	3.46	3.54
SPRING	3.46	3.33
SUMMER	2.67	2.67
AUTUMN	3.62	3.50

Figure 2: Product Scenario 2 reserved capacity (working days) for the Drynoch site (MWh)

Season	EFA1	EFA2	EFA3	EFA4	EFA5	EFA6
WINTER	3.13	3.45	3.62	3.69	3.78	3.22
SPRING	2.88	3.42	3.56	3.19	3.46	3.29
SUMMER	1.91	2.62	2.86	2.54	2.88	2.63
AUTUMN	2.96	3.38	3.50	3.54	3.97	3.35

Figure 3: Product Scenario 3 reserved capacity for the Drynoch site (MWh)



For RaaS Product Scenarios 1 and 2, choosing the 90th percentile of load in each relevant period means that for 10% of the time, the demand over a 4 hour period (as taken to be the working assumption for required RaaS duration within this analysis) in 2019 would not have been completely covered by the RaaS minimum reserved capacity. However, taking out these peak periods reduces the RaaS minimum reserved capacity requirement (by up to 1.5 MWh in some periods), therefore reducing the size of battery needed to provide the service, or increasing spare capacity to optimise in other markets. This is a key consideration for DNOs and RaaS Service Providers when considering the balance of benefit against cost for a RaaS solution to improving security of supply.

It should be noted that this approach is an approximation for how the RaaS product would work in practice, especially in the case of scenario 3, which would be determined by the DNO on a dynamic basis (e.g. day ahead or week ahead) based on its forecasted expectation of demand and associated RaaS service requirement.

For the optimisation model assessment considering a 'generic' RaaS service, the same analysis has been carried out, though scaling down the Drynoch load data by 56%, and considering a location in the East Midlands, representing a 'median' network charging arrangement. This is based on an assumed peak load of 1MVA at the theoretical 'generic' site, as distinct from the peak load of 1.8MVA at Drynoch. As such, the overall RaaS minimum reserved capacity requirement is simply 56% less for the generic battery than the Drynoch site in any given period.

4.1.2 Battery optimisation modelling

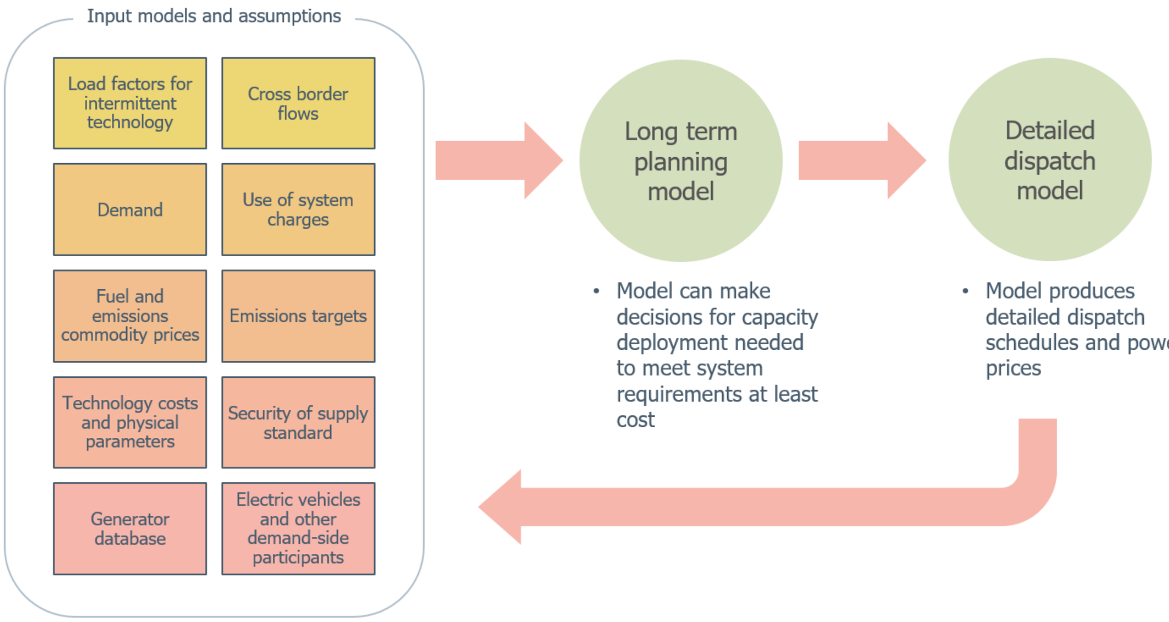
The modelling carried out for this report uses the Cornwall Insight Storage Asset Optimisation model, which determines the optimum revenue stream for the asset on a half-hourly basis.

The front-of-meter (FOM) storage optimisation model is used to forecast participation in locational and site-specific elements of flexibility revenues, including embedded benefits and ancillary services, and reflects specific attributes of battery storage, such as degradation over time. It also allows revenues for storage sites that are 'co-located' with renewable generation sources such as solar, wind and gas to be modelled.

The storage optimiser takes its starting point from Cornwall Insight's Benchmark Power Curve (BPC) which provides a half-hourly forecast of long-term wholesale prices. The BPC is created using the PLEXOS detailed dispatch model. PLEXOS is widely considered the leading energy market modelling environment allowing us to use best-available techniques used by widely industry and academia in the context of different markets across the globe.

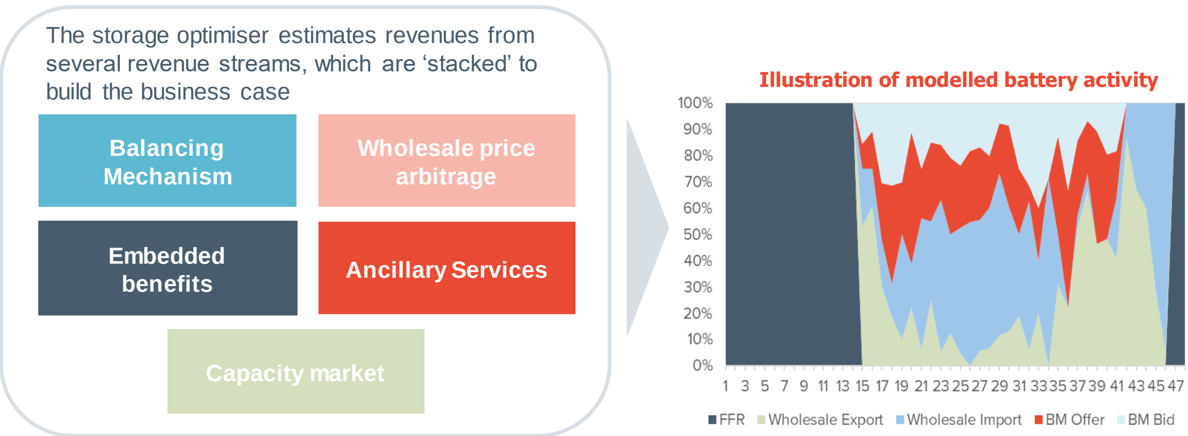
The PLEXOS platform allows model long term capacity build and short-term dynamic dispatch of the GB energy system, down to 5MW granularity, to be modelled.

Figure 4: GB high-level power model structure



The storage optimiser model then builds on the BPC to create more detailed revenue outcomes for storage sites on a site-specific basis. It does this by simulating the operation of the asset by identifying revenue stacking opportunities and developing an optimal operating regime to access the most lucrative revenue sources, reflecting the physical capabilities of the assets and allowing for degradation due to repeated cycling of storage assets.

Figure 5: Storage optimiser illustration



There is inherent uncertainty in any long-term forecast of market conditions. This is managed by considering a series of underlying market scenarios. When considered in combination, the scenarios aim to represent the range of plausible outcomes. National Grid ESO's Future Energy Scenarios 2020[8] have been used as the basis for these scenarios.

[8] www.nationalgrideso.com/future-energy/future-energy-scenarios

4.1.3 Changes made to the model for the RaaS optimisation

The RaaS product is implemented as an additional option in an adapted version of the optimisation model. Including the RaaS product in a model run sets limits on the state of energy (SoE, in MWh) within each defined window to reflect the minimum reserved capacity that is always maintained to respond to a resilience event. These service windows and SoE requirements vary between the three RaaS Product Scenarios that are set out in section 4.1.1 above and described in detail in the E4.1 'Flexibility Scenarios' report.

The associated SoE requirements govern the optimisation of the battery in flexibility markets, including ensuring that the battery achieves the relevant SoE in time for the start of each next RaaS service window. Outside of the RaaS SoE requirements the model operates 'normally', using the remaining battery capacity to optimise operations in the selected flexibility markets suitable to be 'stacked' with RaaS.

The following charts show the implementation of these restrictions. Figure 6 shows the baseline scenario, which does not include the RaaS product. This shows typical battery characteristics, with FFR provided overnight (23:00 – 07:00), charging during typically cheaper periods during the day, and discharging during typically more expensive periods in the evening.

Figure 6: Baseline SoE over sample winter period

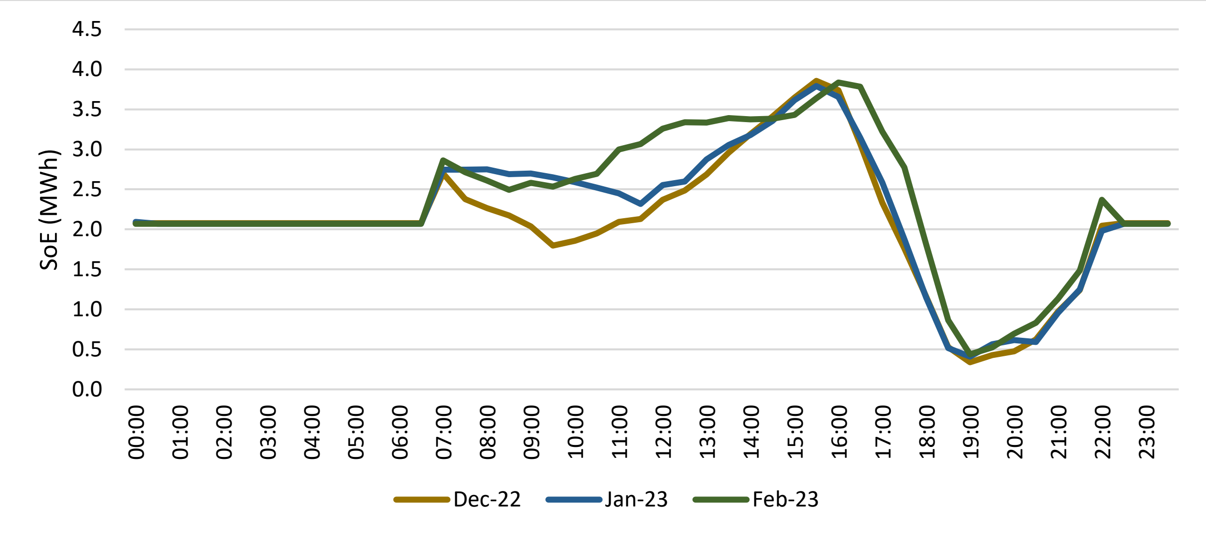


Figure 7 shows a battery operating in the same markets but also providing the RaaS service under scenario 1, and indicating the RaaS minimum reserved capacity for that scenario. A notable feature is the restriction on the depth of discharge in the evening period. The 'baseline' battery (no RaaS) reaches a minimum SoE of 0.44 MWh, while the RaaS Product Scenario 1 battery must retain a SoE of at least 3.46 MWh throughout the day.

Figure 7: RaaS Product Scenario 1 SoE over sample winter period

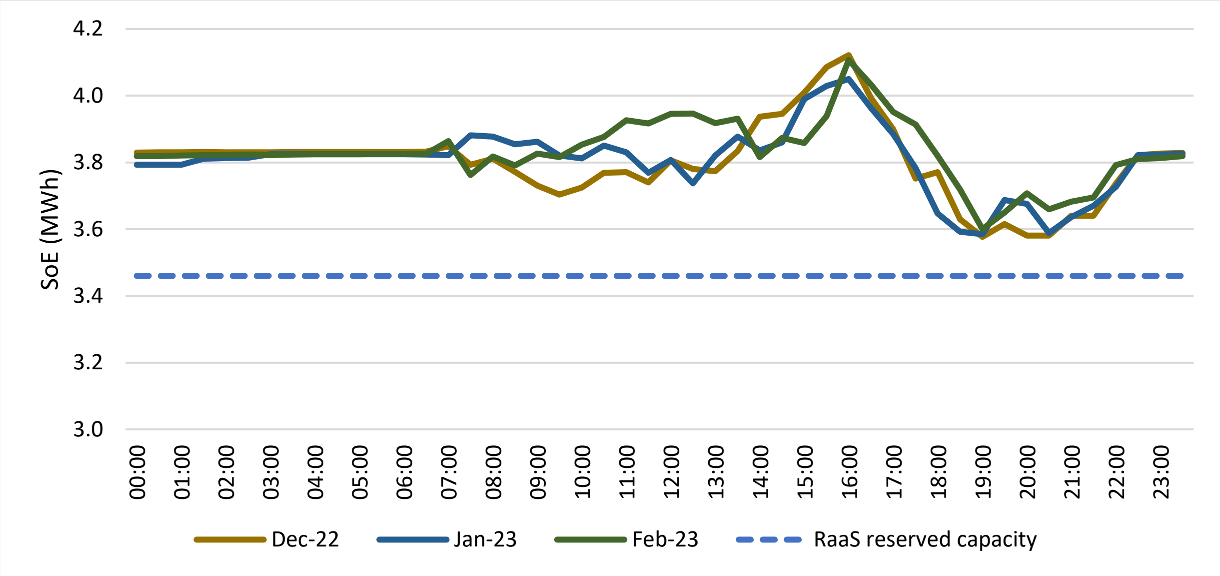
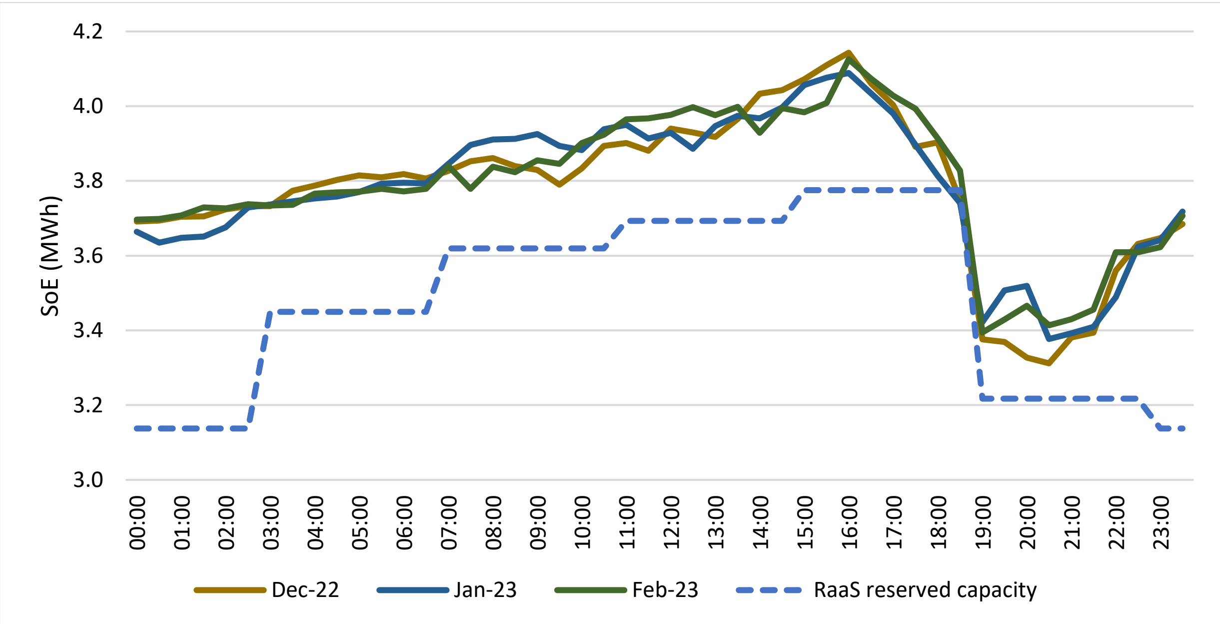


Figure 8 shows the same output for a battery providing RaaS under scenario 2, which imposes limits that vary in each four-hourly EFA block across the day. There is a restriction on capacity in the early part of the evening peak, where the 'baseline' battery would have started discharging. Once this restriction is lowered (at 19:00) the battery discharges immediately to take advantage of typically higher electricity prices.

Figure 8: RaaS Product Scenario 2 SoE over sample winter period



4.1.4 Site scenarios

Three battery configurations are modelled to assess the impact of different configurations of battery size and physical site. These are:

- The Drynoch pilot scheme battery
    - A 4.2MW/4.2MWh battery
    - Configuration according to the RaaS E2a.2 'FEED' report
    - Provides RaaS and additional balancing services
- The Drynoch 'oversized' battery
    - A 4.2MW/5.8MWh battery
    - A battery larger than that proposed for the pilot scheme to understand the financial value of oversizing the asset to have more capacity available for commercial optimisation
    - Provides RaaS and additional balancing services
- A 'generic' RaaS providing battery
    - A 2.5MW/3.5MWh battery
    - A battery downsized to what is assumed could be the typical size of a RaaS battery
    - Provides RaaS and additional balancing services
    - Located in the East Midlands DNO region, representing a median network charging arrangement

4.1.5 Network constraint sensitivity

The Drynoch battery scenarios are constrained by the characteristics of the network at that site, as per Figure 9.

The Storage Asset Optimisation model used cannot be configured with dynamic network limitations, so an approximation was used to model this restriction. The 'standard' (Network Constraint A) approach used for the majority of runs was to reduce the transformer capacity (2.5MVA) by the p50 (50^{th} percentile) value of the historic annual load data used (0.52MVA), which gave new limits of:

- Fixed import limit = 2.5MVA – 0.52MVA = 1.98MVA
- Fixed export limit = 2.5MVA + 0.52MVA = 3.02MVA

A further sensitivity (Network Constraint B) was developed to reduce the transformer capacity by the maximum of the historic annual load data (1.78MVA), giving the following limits:

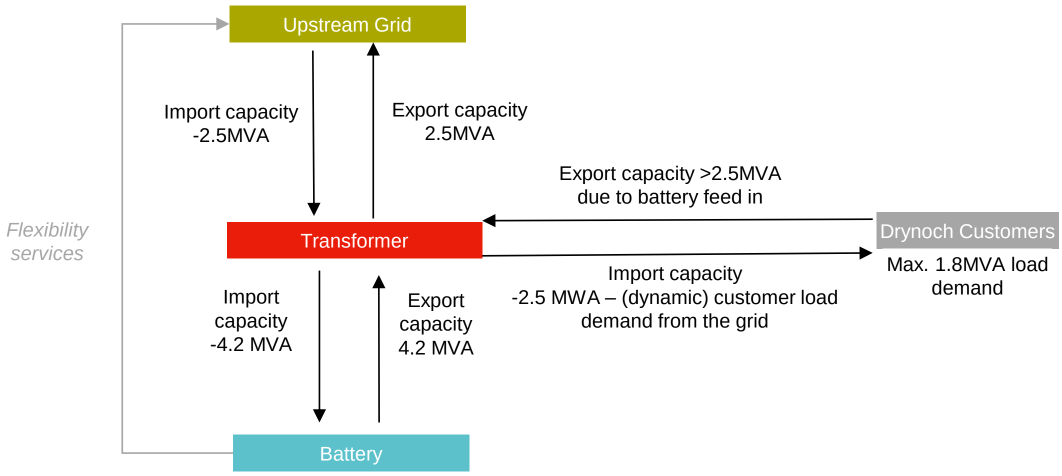
- Fixed import limit = 2.5MVA – 1.78MVA = 0.72MVA
- Fixed export limit = 2.5MVA + 1.78MVA = 4.28MVA

Recognising that Network Constraint B is particularly restrictive on import, an additional sensitivity was developed to reduce the transformer limit by 1MVA for import and leave it unchanged for export, giving the following limits:

- Fixed import limit = 2.5MVA – 1MVA = 1.5MVA
- Fixed export limit = 2.5MVA + 0MVA = 2.5MVA

The constraint assumptions were included in one set of runs for the Drynoch battery only to provide sensitivity analysis around network constraints, with a comparison of the results presented in section 5 of this report.

Figure 9: Network constraint at the Drynoch site



The 'generic' RaaS providing battery is assumed to have a network connection sized to the battery (i.e. 2.5MW for both import and export). It is assumed to have equivalent DUoS and TNUoS charges to a high-voltage connected battery in the East Midlands - selected as an area of median TNUoS charges in 2021-22.

4.1.6 Inputs

Assumptions that are constant across all battery configurations and scenarios are:

- A daily and quarterly cycle limit of 1.5 cycles per day
  - This is in line with typical battery warranties in Cornwall Insight's experience
  - In reality the RaaS product inherently restricts this cycling as a large proportion of the battery's capacity is held for RaaS
- An import efficiency of 88% and export efficiency of 100%
  - These figures are based on typical figures seen by Cornwall Insight in the market
  - Total 'round trip' efficiency (i.e. accounting for losses incurred when the battery is both exporting and importing) is incorporated into the model by restricting the import efficiency
- DUoS rates are assumed to reduce by 50% from 2024, based on anticipated outcome of Ofgem's Network Access and Forward Looking Charges Significant Code Review[9] ("the Access SCR")
- TNUoS credits (embedded export tariff (EET)) are removed from 2024 and replaced by a capacity-based charge equivalent to that paid by transmission-connected assets
  - This is also an assumed outcome of the Access SCR
  - The Drynoch site would not have received the EET due to its location in North Scotland
  - The generic site using the East Midlands charges would receive a small credit before 2024 based on output during Triad periods[10]

Other assumptions used as inputs to the battery optimisation modelling are shown in Appendix 1.

[9] http://chargingfutures.com/charging-reforms/access-forward-looking-charges/what-is-the-access-forward-looking-charges-review

[10] The three half-hourly settlement periods of peak demand between November and February, separated by at least 10 clear days

Based on our modelling assumptions, there could also be some situations with certain battery sizing and RaaS Product Scenario combinations in which, with degradation over time, the battery would not have sufficient usable capacity to meet the RaaS requirement. In these periods, the model is set up so that the battery holds as much capacity as possible (despite this being too small for the RaaS product). In this situation the battery would not participate in other markets, and so the only revenues would be from RaaS.

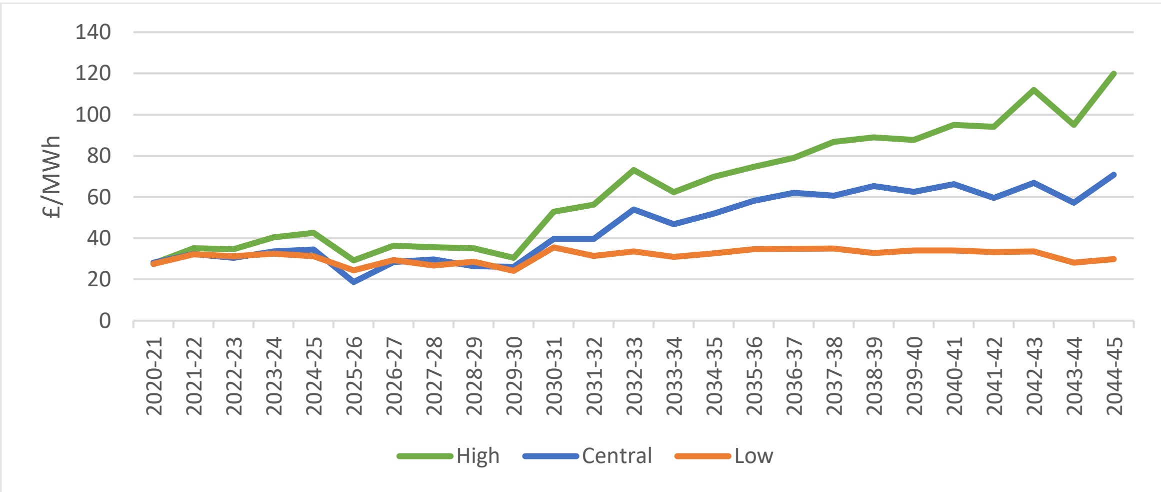
4.1.7 Battery optimisation wholesale and balancing service scenarios

For each battery configuration and each RaaS Product Scenario, three wholesale optimisation scenarios are applied, giving a central, high and low case. The three wholesale scenarios result in high, medium and low values for the revenues of the 'headroom battery capacity' that is available beyond the provision of resilience services. This differentiation affects wholesale market prices, the balancing mechanism and frequency response.

Wholesale market price scenarios are taken from the BPC as noted in section 4.1.2 above, with the forward curves for each scenario shown in Figure 10. Further detail can be found in Appendix 5.

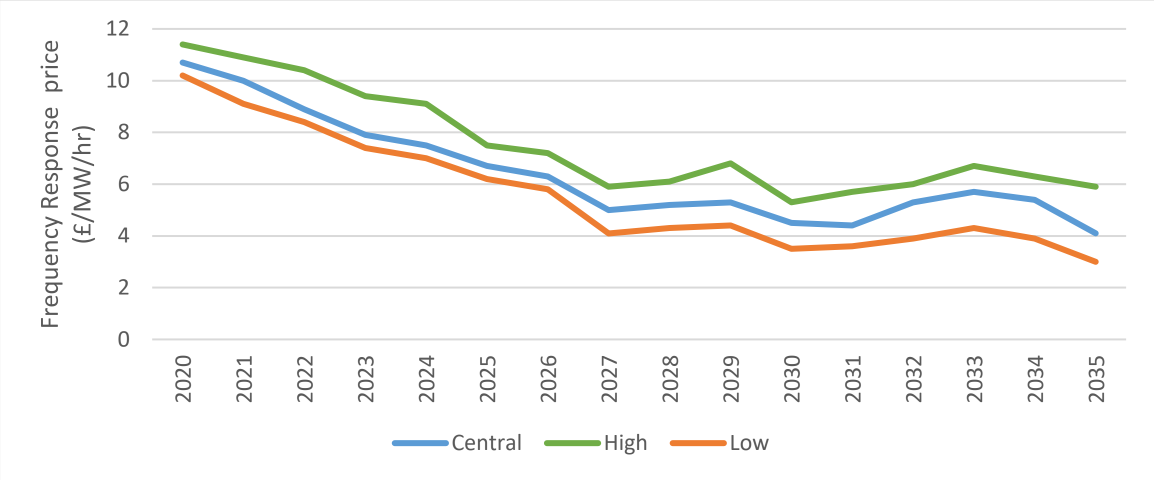
Wholesale price scenarios are also used as a baseline for BM prices. Overlaid on this baseline are separate scenarios for the scale and frequency of variation in BM prices against wholesale prices.

Figure 10: Cornwall Insight BPC power curves used for wholesale scenarios



Frequency response prices are taken from Cornwall Insight's in-house forecasts. These are shown in Figure 11. Frequency Response is provided overnight (between 23:00 and 07:00) in the optimisation modelling. This is a typical strategy, as volatility (and therefore arbitrage opportunity) is usually lower overnight, and frequency response is a more stable revenue stream compared to wholesale market trading.

Figure 11: **Cornwall Insight Frequency Response curves**



4.1.8 Battery degradation

A degradation curve was used across all scenarios with a linear 2% reduction in battery capacity per year. This assumption is in line with the RaaS FEED report. The implications of this, alongside interaction with minimum and maximum RaaS requirements under different scenarios, is discussed within the results presented in section 5.

5 Modelling results

This section compares the modelling results from the different scenarios, with a focus on overall margin (total revenues net of any network charges or credits, together with wholesale market purchases, including those used to charge the battery).

A breakdown of the derived revenue for selected scenarios is also provided. All margin results are provided as £/kW of total battery capacity.

The analysis compares across the different site configurations (“Site Scenarios”), RaaS product design scenarios (“RaaS Product Scenarios”), and central, high, low pricing scenarios (“Wholesale Pricing Scenarios”) as described in the section 4 above and outlined in the table below.

Table 4 - Overview of modelling scenarios and sensitivities

Wholesale Pricing Scenarios		RaaS Product Scenarios		Site Scenarios		Network Limit Sensitivity	
Name	**Definition**	**Name**	**Definition**	**Name**	**Definition**	**Name**	**Definition**
Low	Low view of wholesale, BM and frequency response prices	**Scenario 1 – Lower granularity**	RaaS requirements set on a daily granularity	**Drynoch - pilot scheme**	A 4.2MW/4.2MWh sized battery at the Drynoch site	**Network Constraint A**	Fixed import limit 1.98MVA Fixed export limit 3.02MVA
Central	Central view of wholesale and BM prices	**Scenario 2 – medium granularity**	RaaS requirements set on a 4-hr EFA block granularity	**Drynoch - oversized**	A 4.2MW/5.8MWh sized battery at the Drynoch site	**Network Constraint B**	Fixed import limit 0.72MVA Fixed export limit 4.28MVA
High	High view of wholesale, BM and frequency response prices	**Scenario 3 – higher granularity**	RaaS requirements set on a 4-hr EFA block granularity, with DNO requirement	**Generic RaaS providing battery**	A 2.5MW/3.5MWh sized battery using network charges for East Midlands DNO region	**Network Constraint C**	Fixed import limit 1.5MVA Fixed export limit 2.5MVA
		No RaaS service – baseline	Results for a comparable asset not providing RaaS				

5.1.1 Overall margin under each RaaS Product Scenario

Each battery configuration, and each set of price scenarios, show a similar pattern when comparing the different RaaS Product Scenarios:

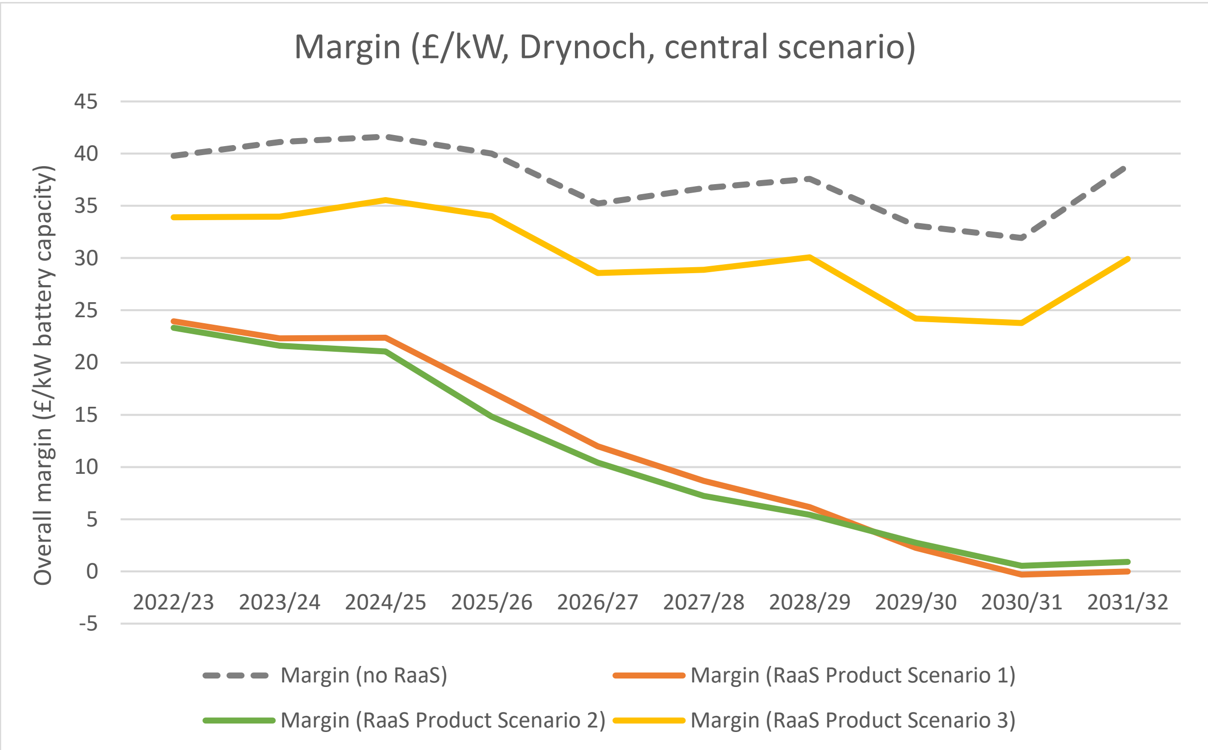
- All RaaS Product Scenarios reduce revenues compared to the baseline (no RaaS service).
  - This is expected as the battery is required to hold some capacity for the RaaS service at all times, and that capacity cannot be used for wholesale trading or other flexibility services.
- RaaS Product Scenarios 1 and 2 reduce margin to a greater extent than scenario 3.
  - Scenarios 1 and 2 are less dynamic and overall have a greater average requirement for the battery to hold capacity as requirements are forecasted and fixed at the beginning of the delivery period in the contract.
  - Scenario 3 has more dynamic RaaS requirements, typically allowing more space for optimisation in the wholesale and flexibility markets due to the day ahead notification of the required reserved capacity for the next day.
- The difference between RaaS Product Scenarios 1 and 2 is small:

- On average, the RaaS requirements for scenario 2 are smaller than for scenario 1 due to the 4 hourly service windows.
- However, in all seasons, the requirements for the minimum reserved capacity for scenario 2 are higher in EFA block 5, which runs from 15:00 to 19:00 (as well as EFA block 3 from 07:00 to 11:00).
- The higher share of battery capacity that is reserved for resilience events during grid peak load service windows such as EFA block 5 removes some of the value available to the battery at the start of the critical evening period. A typical battery would be discharging to take advantage of typically high prices in the wholesale markets or BM (see Figure 6 for an example of battery operation over a day).

5.1.2 Overall margin for the pilot scheme battery at Drynoch

The results for the pilot scheme Drynoch battery are shown in Figure 12. Flexibility market margins in the baseline scenario with no RaaS requirement are approximately £35-40/kW/year. With RaaS Product Scenario 3, the margins for participation in other flexibility markets sees a consistent gap of ~£5/kW. RaaS Product Scenarios 1 and 2 then see lower margins from other flexibility markets, starting at £20-25/kW/year, then falling away steadily to approximately zero in the last two years of the modelling horizon as the available capacity for optimisation is degraded away.

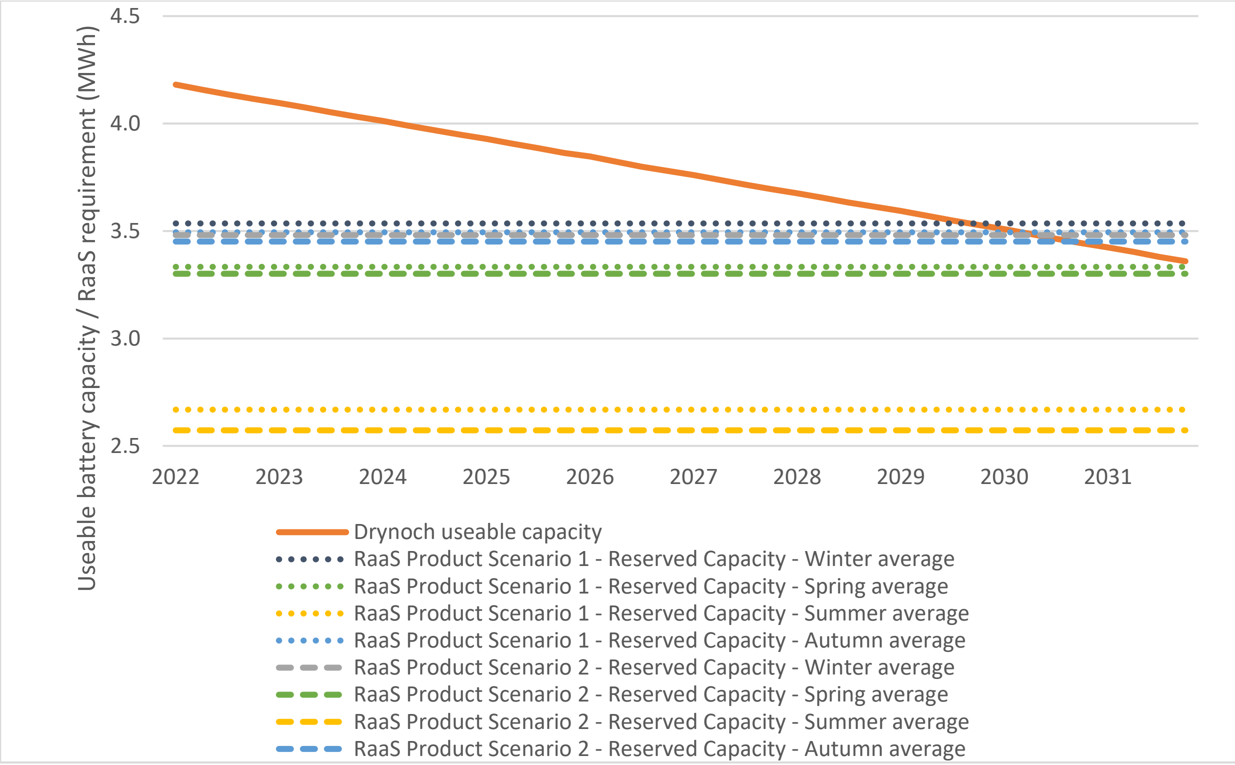
Figure 12: Overall margin (£/kW) comparison for RaaS Product Scenarios, Drynoch pilot scheme battery



The more pronounced reduction in margin for the batteries in RaaS Product Scenarios 1 and 2 relates to the average reserved capacity requirements, which are higher than for RaaS Product Scenario 3. The associated lower headroom available for participation in other markets therefore experiences a greater impact from battery degradation. Figure 13 shows the average reserved capacity requirements under scenarios 1 and 2, compared to the useable capacity of the Drynoch battery over time when factoring in degradation. Scenario 3 is not shown here as the average for all seasons is much lower, ranging between 1.3 MWh (summer) to 1.8 MWh (winter).

As the chart shows, towards the end of the 10 year modelling horizon the battery cannot meet the average RaaS service level for winter (grey lines) and autumn (blue lines) under both scenarios 1 and 2, and can just meet the average requirement in spring and summer (green and orange lines). This will significantly limit the capacity of the battery available to optimise in other markets during those later years. It must be acknowledged here that the Drynoch battery has been sized for a 5 year timeframe, so this would not affect the ability of the asset to meet the DNO service requirements for RaaS over that period.

Figure 13: Average reserved capacity and headroom battery capacity for RaaS Product Scenarios - Drynoch pilot scheme



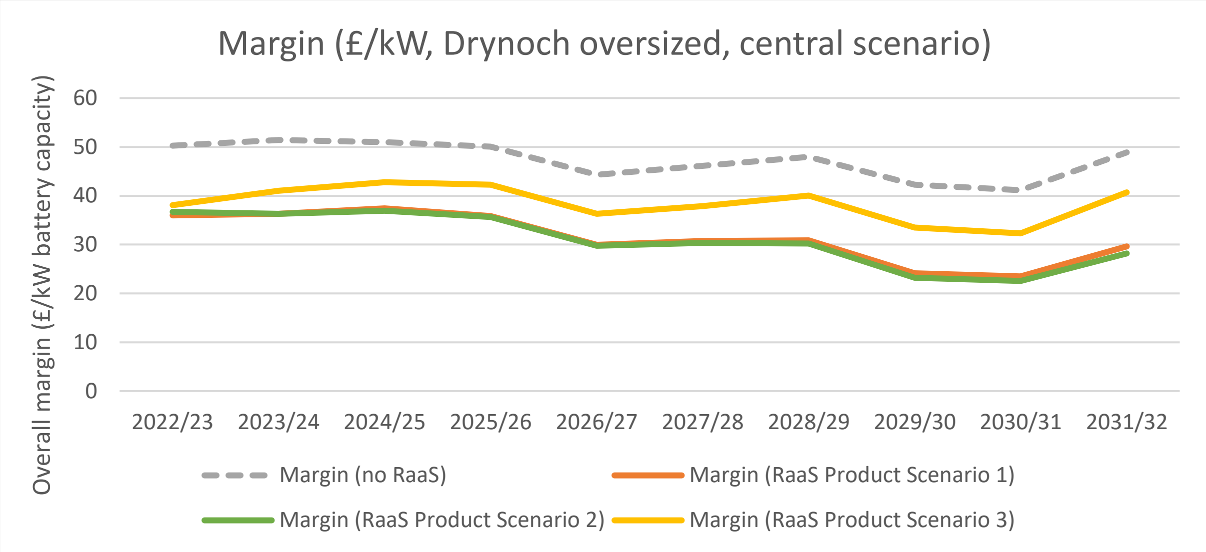
5.1.3 Overall margin with an oversized battery at Drynoch

For modelling the oversized battery at Drynoch the power capacity remained the same (4.2MW), but the overall energy capacity was increased to 5.8 MWh. No variation was made to network constraints as this still relates to the Drynoch site. This analysis was undertaken to explore the commercial value of oversizing a RaaS battery.

Overall profit levels are higher than the pilot scheme Drynoch battery size, as shown in Figure 14. This is expected for a battery that is otherwise identical but has a higher energy capacity equating to higher headroom for participation in other flexibility markets.

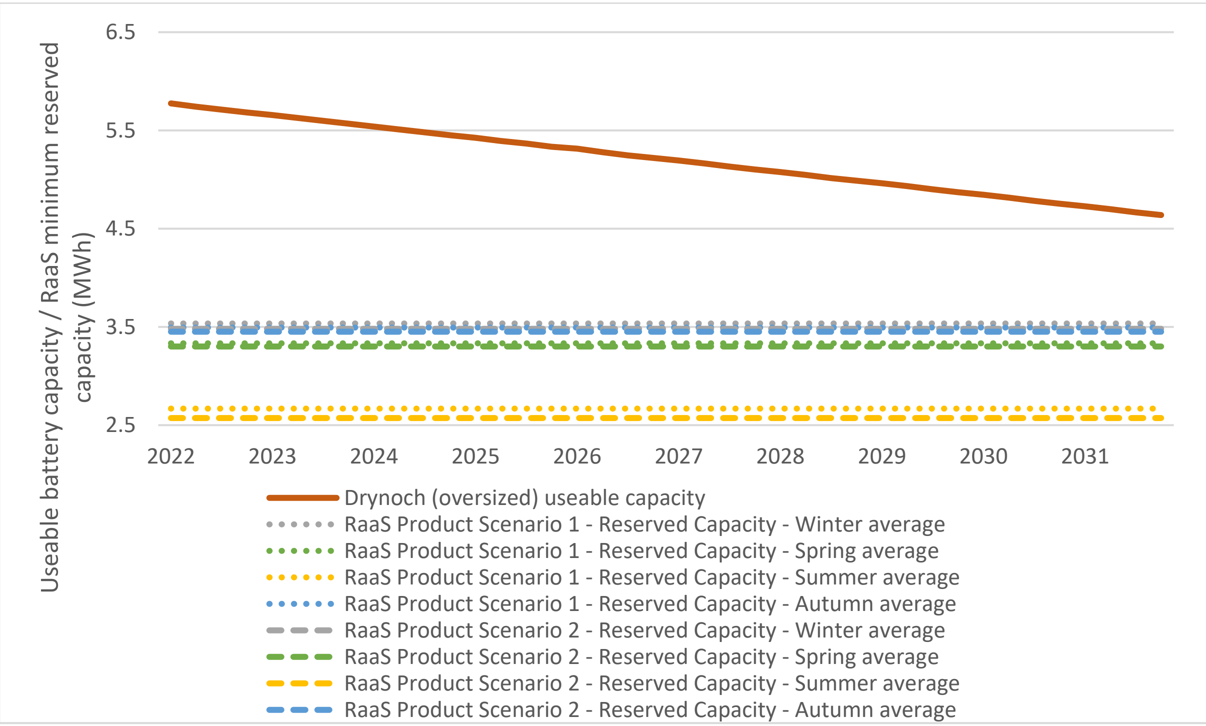
This is also a result of the fact that the battery is able to hold the required reserved capacity for the RaaS service and still have a sufficient margin to optimise in other markets for a greater number of years into the future. In this case RaaS Product Scenarios 1 and 2 do not see margins fall away to the same extent over the modelling horizon. Instead, margins start very close to those of RaaS Product Scenario 3, with the gap increasing to around £10/kW/year by the end of the period. This compares to a gap of around £30/kW/year in the pilot scheme Drynoch scenario.

Figure 14: Overall margin (£/kW) comparison for RaaS Product Scenarios - Drynoch oversized battery



For completeness, Figure 15 shows the useable capacity of the oversized Drynoch battery over time compared to the average RaaS requirement under scenarios 1 and 2, illustrating that there is much greater capacity above the level required by the RaaS services**.** With the oversized Drynoch battery the total capacity was always sufficient to meet the maximum reserved capacity for both RaaS scenarios 1 and 2, which is not the case for the pilot scheme Drynoch battery shown in Figure 12.

Figure 15: Average reserved capacity and headroom battery capacity for RaaS Product Scenarios - Drynoch oversized battery



5.1.4 Overall margin for a generic RaaS-providing battery

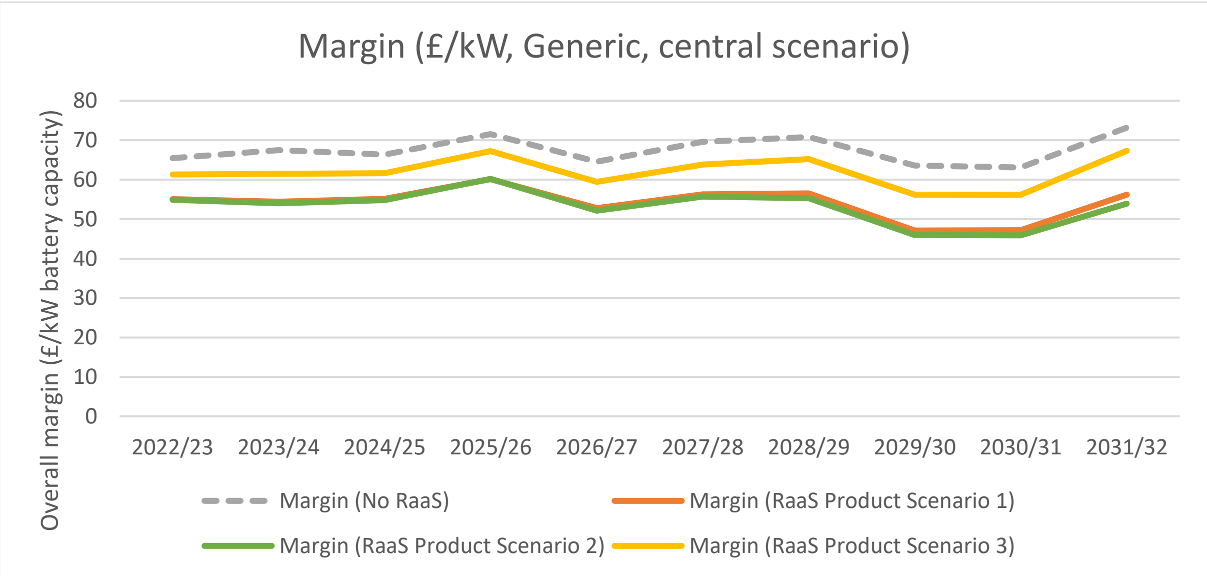
The scenario for a 'generic' RaaS-providing battery is intended to show the impact of RaaS services on battery margins without the specific limitations at the Drynoch site. As such, this scenario does not include a network constraint - the network capacity for both import and export available to the battery is assumed to be equivalent to the capacity of the battery. The power capacity of the battery is 2.5MW and the energy capacity 3.5 MWh. These values are based on assumptions considered in the original battery sizing analysis reported in E2a.1 'Site Selection'.

For this generic battery, the required RaaS service has been scaled by an assumed change in peak load – this is 1.8MVA at the Drynoch site and assumed to be 1MVA at the generic site. As such, the RaaS requirement is 56% of that at the Drynoch site.

As the modelling has shown, the generic battery always has sufficient capacity to fully provide the maximum requirement of RaaS Product Scenarios 1 and 2, when factoring in degradation.

Figure 16 shows the overall margin for the generic RaaS battery. Margins are between £55-65/kW/year for RaaS Product Scenario 3, and approximately £10/kW/year lower for RaaS Product Scenarios 1 and 2. In a similar pattern to the Drynoch battery, the margins from other flexibility services with no RaaS service provision gives a margin approximately £5/kW/year higher than RaaS Product Scenario 3.

Figure 16: Overall margin (£/kW) comparison for RaaS Product Scenarios, generic RaaS battery



The key differences that drive the higher margins for this battery are:

- **Network charges** – the 'generic' East Midlands site considered for this analysis attracts considerably lower distribution charges (DUoS) and attracts transmission credits rather than charges (TNUoS)
    - The East Midlands was selected as it has median transmission charges when considering the different DNO regions
    - DUoS charges are approximately half of those for the Drynoch site (~£45,000/year charge for the generic site, ~£90,000/year charge for the Drynoch site)
    - The generic site attracts TNUoS credits of approximately £3,000-£7,000/year, first through the embedded export tariff, and then through capacity-based credits from

2024. Meanwhile, the Drynoch is not credited, and is charged approximately £16,000/year from April 2025 (there is a small credit of £3,000 in 2024-25)
    - It is assumed that distribution-connected sites, including the batteries under consideration in this report, will pay wider TNUoS charges (equivalent to transmission-connected generators) from 2024, as a result of Ofgem's ongoing Network Access and Forward Looking Charges Significant Code Review
- **Network constraint** – the generic site is assumed to not be constrained by network capacity, unlike Drynoch. This allows the battery to use its full power capacity, whereas the Drynoch battery assessments are constrained in both export and (particularly) import capability

5.1.5 Overall margin under different pricing scenarios

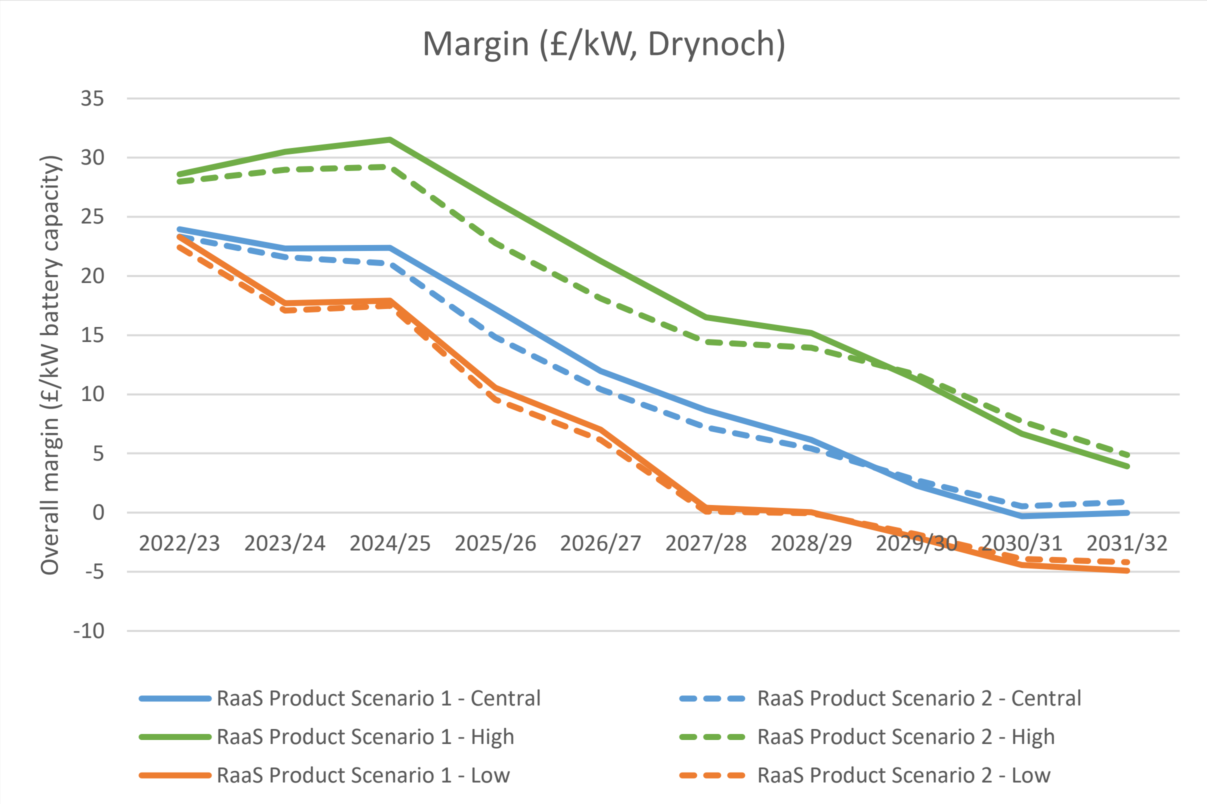
All of the RaaS Product Design Scenarios and Site Scenarios were run with central, high and low wholesale pricing scenarios. The varying inputs into these scenarios are described in Section 4. At a high level, the scenarios impact wholesale prices and volatility, BM prices, and frequency response prices. Capacity Market prices and network charges are not affected.

Figure 17 shows the impact of the different wholesale pricing scenarios on the results for the Drynoch battery, for RaaS Product Scenarios 1 and 2. This shows that through each wholesale pricing scenario, RaaS Product Scenarios 1 (solid lines) and 2 (dashed lines) remain relatively similar.

The difference between the RaaS Product Scenarios is slightly more pronounced in the higher wholesale pricing scenarios, likely due to the fact that larger opportunities are missed when RaaS Product Scenario 2 restricts battery options at the start of the evening peak period (end of EFA block 5).

The battery has a negative margin in the low wholesale pricing scenarios towards the end of the modelling horizon. The issues resulting in these reducing margins for the Drynoch battery are described in section 5.1.2 above. In the low wholesale pricing scenario, this is compounded by fewer wholesale arbitrage or BM opportunities. As a result, there are limited revenue opportunities for the battery, while its major costs (network charges) remain – the majority of these charges are levied on a capacity basis, rather than a volumetric charge.

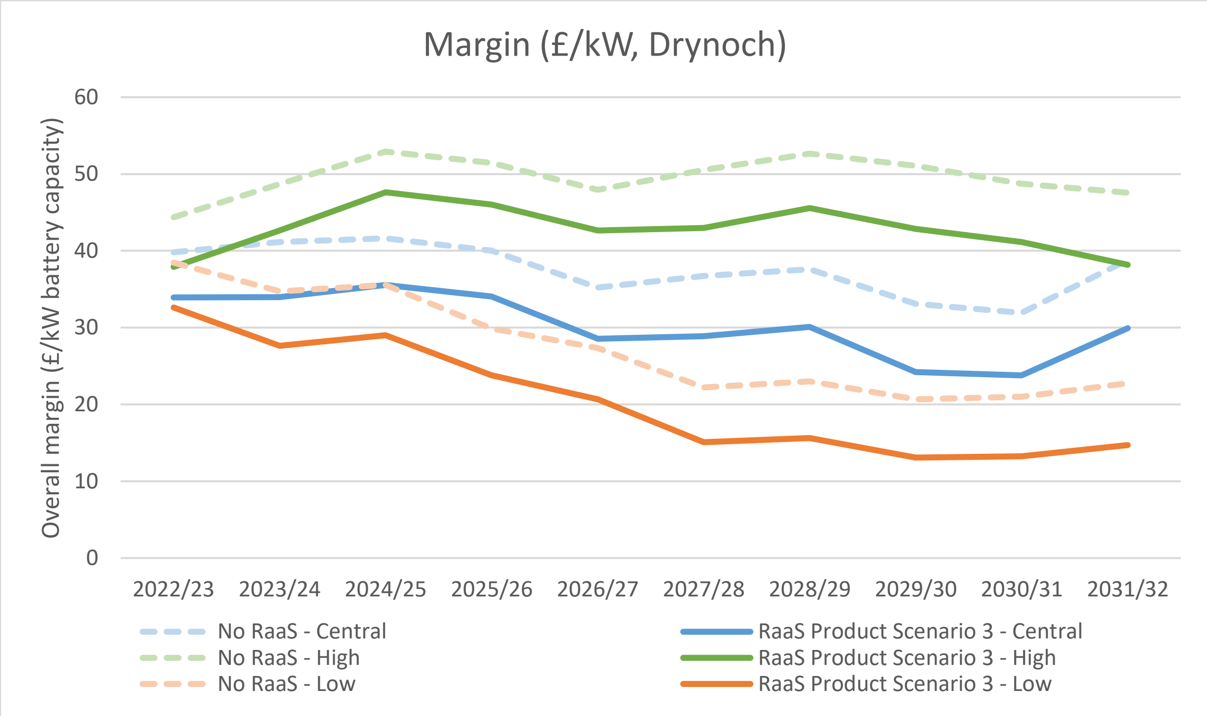
Figure 17: Overall margin (£/kW) RaaS Product Scenarios 1 and 2, pricing scenario comparison



The results for RaaS Product Scenario 3 (solid lines) with the Drynoch battery, alongside the results for this battery with no participation in RaaS (dashed lines), are shown in Figure 18. This shows a similar pattern of differing margins between wholesale pricing scenarios, with the low wholesale scenarios having margins ~£5-10/kW/year lower than the equivalent central wholesale scenarios, and the high wholesale scenarios having margins ~£10-15/kW/year higher than the central wholesale scenarios.

It also shows that the difference between RaaS Product Scenario 3 and the baseline scenario with no RaaS participation remains similar in each wholesale pricing scenario, at £5-10/kW/year.

Figure 18: Overall margin (£/kW) RaaS Product Scenario 3 and baseline (no RaaS), pricing scenario comparison



5.1.6 Revenue breakdown for Drynoch battery

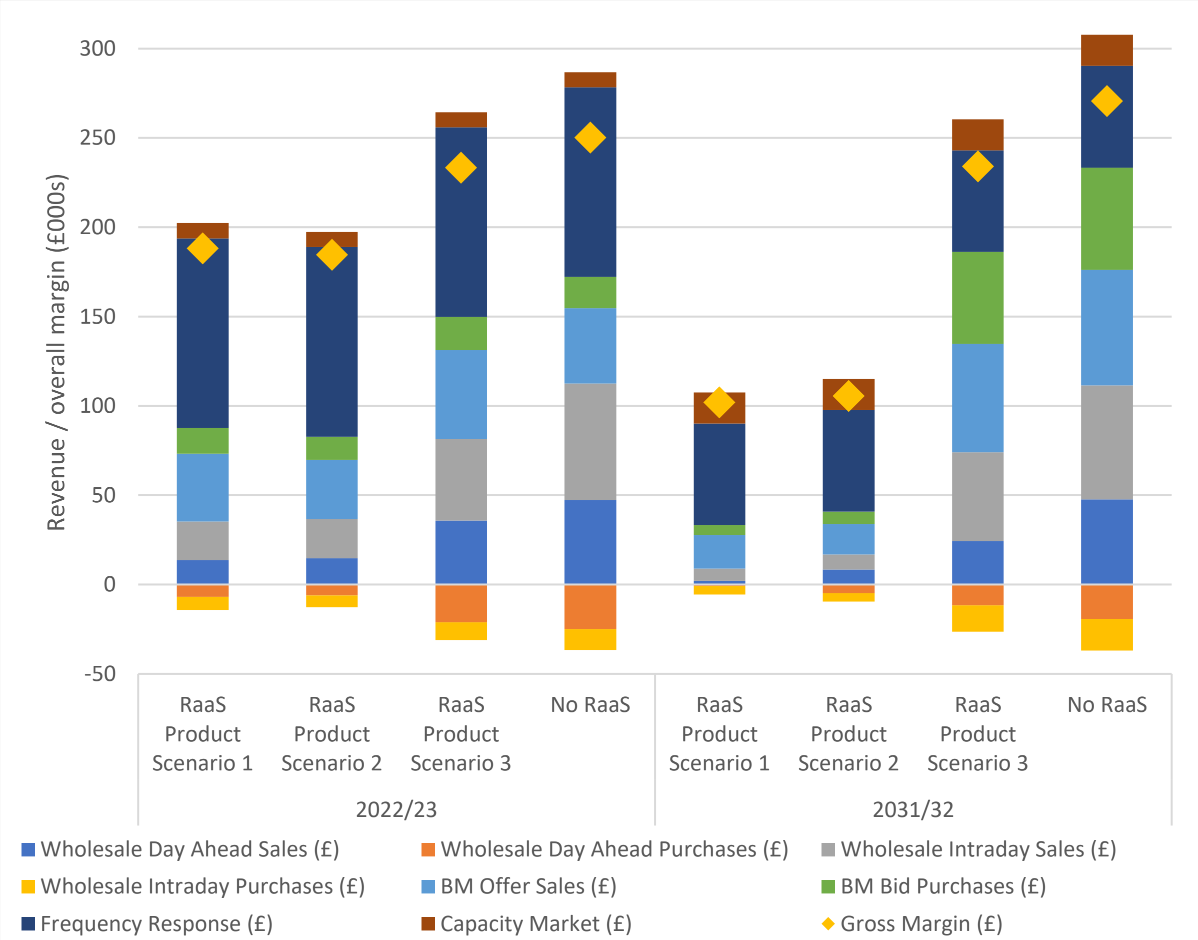
Figure 19 shows a breakdown of revenue for the first and last years of the model runs for the Drynoch battery, alongside the gross margin (revenues net of wholesale costs, network costs excluded).

For RaaS Product Scenarios 1 and 2, there is a high dependency on frequency response prices at both the start and end of the period, with ~55% of gross margin coming from these services. This is higher than we would typically see for a battery asset, reflecting both the RaaS service and network constraints restricting opportunities in the wholesale markets and BM, as these would otherwise provide the majority of the revenue for battery assets (this can be seen in the scenarios with no RaaS).

There is a greater level of headroom for optimisation in the flexibility markets available under RaaS Product Scenario 3. This leads to a similar proportion of revenue coming from each service as in the baseline scenario with no participation in RaaS. While the overall distribution is the same (~45% revenue from frequency response, ~25% from BM, ~25% from wholesale and ~5% from the Capacity Market), overall revenues are restricted by a large proportion of the battery capacity being reserved for resilience events.

In the final year of the modelled period, the impact of battery degradation and the relatively high requirements for reserved capacity of RaaS Product Scenarios 1 and 2 is clear – in these scenarios wholesale and BM opportunities are severely restricted. ~55% of revenues still come from frequency response, despite this being a much smaller revenue by this point (due to degradation and reduced headroom above the RaaS minimum reserved capacity, as well as frequency response prices dropping), while the stable Capacity Market revenue makes up 17% of total revenue by that point. In contrast, the Drynoch battery providing RaaS Product Scenario 3 is able to make up the majority of the revenue lost in frequency response through increased opportunities in the wholesale market and particularly in the BM due to the available revenues in these markets, increasing with greater price volatility as the proportion of renewable capacity on the system.

Figure 19: Revenue breakdown for the Drynoch battery, forecast years 1 and 10, central wholesale price scenario



5.1.7 Battery degradation

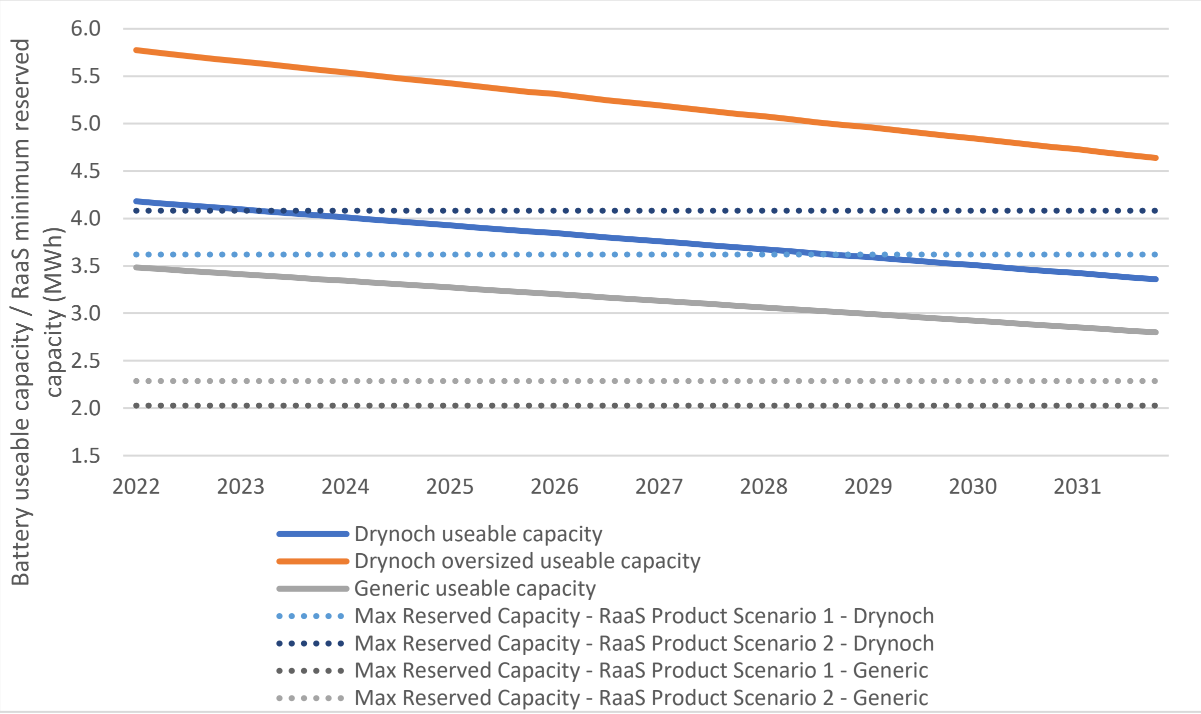
A linear 2% reduction in battery capacity per year was applied across all scenarios to represent degradation. This assumption is in line with the RaaS FEED report. The output, alongside interaction with the minimum and maximum RaaS minimum reserved capacity requirements under different scenarios, is shown in Figure 20.

This indicates that the battery capacity of the 'oversized' Drynoch battery (starting at 5.8 MWh) is always large enough to meet the entire requirement of RaaS Product Scenarios 1 and 2 (RaaS Product Design Scenario 3 is not shown as the maximum requirement is less meaningful – it is higher but only required for one EFA block during the year).

The pilot scheme Drynoch battery (starting at 4.2 MWh) is insufficiently sized to meet the modelled peak RaaS requirements for RaaS Product Scenario 2 from year 3 (early 2024) due to degradation assumptions, and similarly is not capable of meeting all of the requirement for RaaS Product Scenario 1 (with requirements based on average demand over a full day, rather than individual EFAs) from 2029 (although it is always big enough to meet the minimum requirement for both scenarios).

The generic battery always meets all requirements for RaaS Product Scenarios 1 and 2 – this is related to the fact that the starting headroom capacity of the generic battery is 83% of the Drynoch battery, and the RaaS minimum reserved capacity for the generic site is 56% of that at the Drynoch site.

Figure 20: Battery degradation and indicative RaaS minimum reserved capacity figures



5.1.8 Impact of modified import and export limits for Drynoch

Three assumptions to evaluate sensitivity associated with network constraints at Drynoch have been modelled, as referenced in section 4.

Network Constraint A used for the majority of runs was a fixed import limit of 1.98MW and a fixed export limit of 3.02MW (the power factor was assumed to be 1, so the limits described earlier in MVA are directly translated into MW limits here).

Network Constraint B was then applied as a fixed import limit of 0.72MW and a fixed export limit of 4.28MW. Given both Drynoch battery sizes under consideration have a power capacity of 4.2MW, the export would not be constrained under Network Constraint B (whereas Network Constraint A would equate to an export limit of 72% of battery capacity). The import capability of the battery under Network Constraint B is limited to 17% of the battery's capacity (compared to a 47% limit under Network Constraint A).

Network Constraint C then applied a fixed import limit of 1.5MW (35% of Drynoch battery capacity) and a fixed export limit of 2.5MW (60% of Drynoch battery capacity).

These alternative network constraints were modelled for the pilot scheme Drynoch battery with the central wholesale pricing scenario only, to assess the impact of the change. The overall margin results are shown in Figure 21, with Network Constraints B & C shown in dashes.

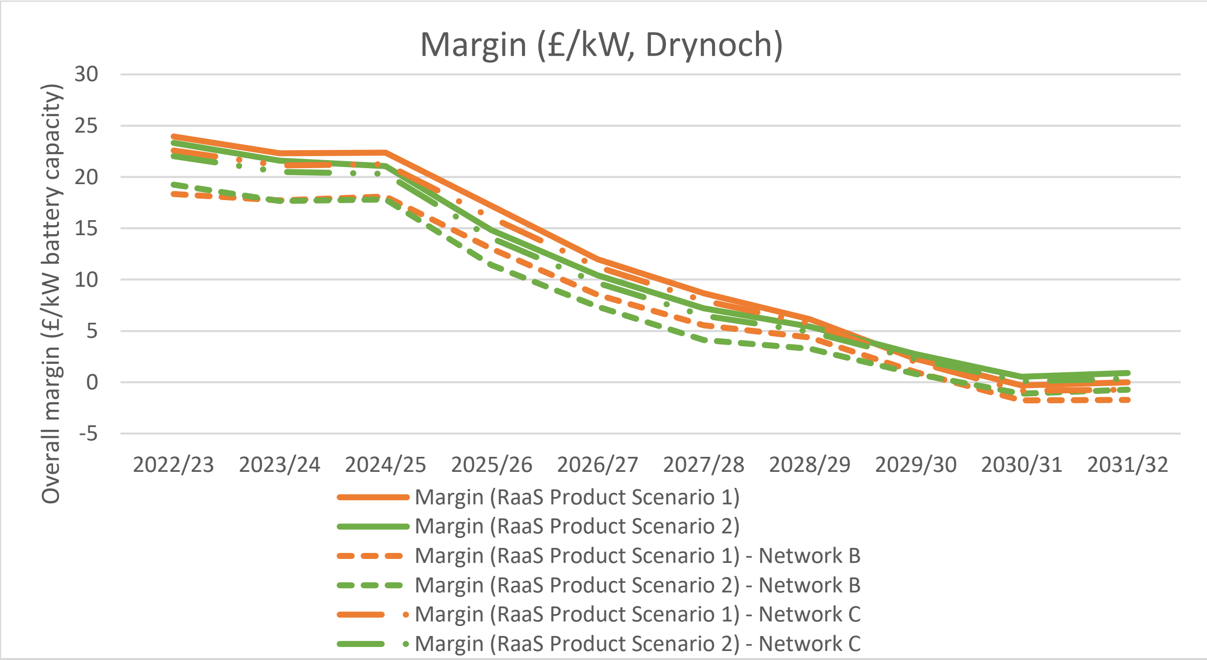
The results show a lower margin for all RaaS Product Scenarios under both Network Constraints B and C, including for the baseline case (no RaaS participation). This is most notable for Network Constraint B, which is as expected given the tight limit on import power capacity.

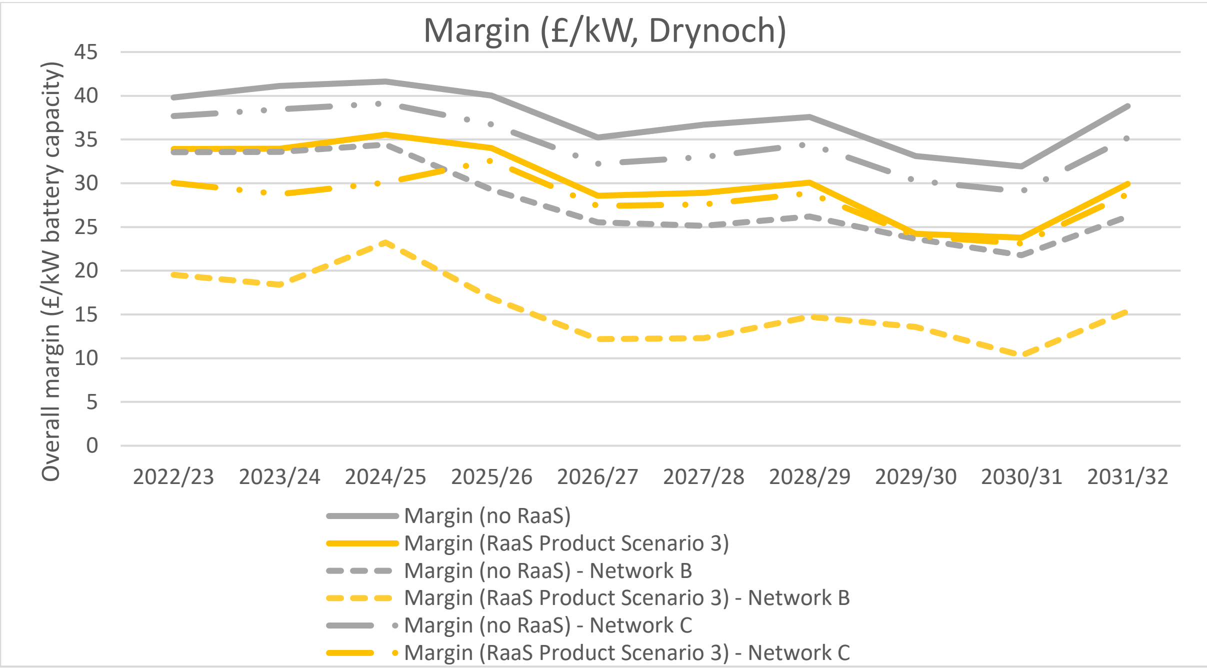
Larger reductions in margin are seen in the scenarios where there is more battery headroom to optimise in flexibility markets, as would be expected given the importance of the power capacity in taking advantage of flexibility opportunities.

Network Constraint B returns the lowest margins, on average £3/kW lower than Network Constraint A for RaaS Product Scenarios 1 and 2, and £15/kW lower for RaaS Product Scenario 3.

Network Constraint C returns margins much closer to those of Network Constraint A, but still consistently lower. The difference is less than £1/kW on average for RaaS Product Scenarios 1 and 2. For RaaS Product Scenario 3, the difference is £2/kW on average, and where there is no RaaS product, the difference is £3/kW on average.

Figure 21: Overall margin (£/kW) for all RaaS Product Scenarios and different network constraints at Drynoch





6 Analysis of flexibility optimisation results

6.1 Implications for RaaS commercial design

This modelling analysis and the associated risk around potential revenue streams have implications for the design of the RaaS product, as described below. These observations will be carried forward into future project work within WP4 ‘Operational Optimisation’ and WP5 ‘Business Model’.

- Under **Product Design Scenario 1**, RaaS requirements are set out with the lowest granularity, overlooking variations in demand over the course of a day, and with volumes determined at the point of contract.
    - Contractually agreeing the RaaS requirements in advance potentially offers greater certainty regarding prices (costs/incomes) to the DNO and RaaS Service Provider, however this may also be dependent on the payment structure for RaaS (e.g. availability and/or utilisation payments).
    - The limited granularity reduces the analysis required to establish RaaS requirements (inc. minimum reserved capacity).
    - Under this scenario the overall RaaS minimum reserved capacity is highest, which also means that this option has the lowest amount of headroom available for participation in other flexibility markets, equating to lower revenues from those markets.
    - The low level of activity in the flexibility markets also reduces the rate of degradation of the battery asset, as it is used less.
    - The lower ability for assets to earn flexibility market revenues could lead to higher RaaS service fees being submitted through the tender process.
- Under **Product Design Scenario 2**, RaaS requirements are set out with a similar structure to scenario 1, however with 4-hour EFA block granularity, with volumes determined at the point of contract.
    - Contractually agreeing the RaaS requirement in advance potentially offers greater certainty regarding prices (costs/incomes) to the DNO and RaaS Service Provider, however this may also be dependent on the payment structure for RaaS (e.g. availability and/or utilisation payments).
    - The enhanced granularity better tailors requirements to typical demand profiles.
    - This scenario requires a lower overall RaaS minimum reserved capacity compared to scenario 1, which allows greater headroom for optimisation in other flexibility markets. However, at certain times (e.g. EFA block 5 which runs from 15:00 to 19:00 and EFA block 3 which runs from 07:00 to 11:00) the RaaS requirement is higher than scenario 1. As these are ‘peak’ periods, the asset loses out on some flexibility revenues during these times.
    - The RaaS requirements under this scenario are more variable as they are set on a more granular 4-hour EFA block basis, which allows greater headroom for optimisation in other flexibility markets.

- Under **Product Design Scenario 3**, RaaS requirements are more dynamic, with requirements not determined at point of contract and instead issued at some point in time ahead of an operational day.
    - The key aspect of this product design scenario is that it could result in a more precise alignment of minimum required capacity to actual demand on the day in question.
    - The granularity of forecast in half hourly time periods also tends to allow greater headroom to be available for participation in other flexibility markets beyond the RaaS service, supporting increased revenues from those markets.
    - On the basis that this scenario could lead to higher revenues from other flexibility markets, this option could lead to lower RaaS service fees being submitted by investors through the tender process.
    - This option would, however, require an enhanced level of administration (including time and resource requirements) from both the DNO and RaaS Service Provider, as it will introduce a requirement to forecast, notify and analyse requirements in short timeframes ahead of the operational day. This may also include a requirement to develop an appropriate communications route for providing these notification signals.
    - Timings for notification of RaaS requirements should take account of timings for notification periods associated with other flexibility markets, to align well with the associated scheduling activities – e.g. the day-ahead markets for reserve and response (timings of these to be confirmed in the 2021 and 2022) and the timing of the day-ahead auction for wholesale markets (9:50GMT).

The preferred scenario is likely to differ between both DNOs and RaaS Service Providers, and is also likely to change through time, e.g. as forecasting capabilities develop. Further assessment by each DNO would be needed to evaluate the balance of benefits against complexity of defining RaaS requirements.

6.2 Implications for battery sizing

The analysis finds that the ‘oversized’ battery (5.8 MWh) at the Drynoch site will meet the minimum reserved capacity for a greater number of years than the pilot scheme Drynoch battery modelled. This becomes a greater consideration later in the 10 year modelling period applied within this optimisation analysis, as the pilot scheme battery degrades to the point that the RaaS service can no longer be fully provided towards the end of the 10 year period.

To ensure appropriate battery sizing by a RaaS investor, this point must be considered with reference to the potential contract duration for RaaS, including the potential for annual ‘rolling renewals’ beyond the initial contract period. The detailed analysis relating to this point would include an assessment of the capital costs of the oversized battery, and the implications for RaaS pricing to ensure an attractive offer to the DNO whilst ensuring the battery is commercially viable.

6.3 Implications and learnings for investors and DNOs

6.3.1 DNOs

A key consideration for DNOs relates to the balance between the benefits of a RaaS solution and potential costs. The analysis presented within this report illustrates the range of factors that would need to be considered by a RaaS Service Provider with regard to revenue stacking across other markets. Different potential RaaS Service Providers may have different capabilities, and different costs, for providing different minimum reserved capacities for RaaS. DNOs therefore need to consider the fact that a service which doesn't meet full requirements for RaaS at a given location may still represent an improvement in service to customers, and so where this may be more cost effective than procuring the full requirements, this option should still be considered. A recommendation here is for DNOs to consider including a number of options in the tender process (essentially reflecting different durations for the provision of a RaaS service during an outage) and inviting quotes for each. It is acknowledged that a DNO's engagement with the local community to understand their preferences and expectations would also be of value to inform the decisions made by a DNO for the implementation of RaaS at specific locations.

6.3.2 Impact of investor risk assessment on flexibility optimisation

Different investor profiles and types will have different attitudes to risk. This may influence the choice of other flexibility markets to be participated in by a RaaS Service Provider with regards to the characteristics of the different revenue stream, thereby changing the preferred revenue streams to be used in the battery optimisation model. To provide examples:

- The frequency response revenue stream is reasonably stable and relatively low risk
  - Prices have been reasonably stable and predictable, and there is a well-established need for the service
  - There are, however, risks around the structure of the service, such as moving to shorter-term procurement which may increase volatility in prices
  - There are also market-based risks associated with the projected rise in battery capacity in GB (batteries are the primary provider of frequency response services)
- Wholesale market and BM revenues are much more volatile, and therefore perceived as higher risk
  - Prices vary considerably over the long-term and short-term
    - Various price drivers are difficult to predict, including global commodity prices, weather, carbon pricing and electricity demand
  - There may be greater risk of losing revenues compared to other flexibility services that offer a longer term revenue stream, as revenues can often not be secured with as much certainty in advance, but also an opportunity for higher prices (e.g. when there is system scarcity)
  - There is a risk of limited utilisation within the BM, given the locational nature of the BM requirements, and risk that National Grid ESO does not accept the asset for dispatch at any point in time
- The Capacity Market is a stable revenue and therefore relatively low risk, with prices known in advance
  - There are some risks associated with over clearing prices in auction being too low
  - There's a low likelihood of non-delivery of CM if RaaS is called at the same time due to the low probability of both Capacity Market stress events and RaaS events, with associated lower probability of a coincidence of these events
  - New-build assets can secure 15-year agreements

The RaaS product is assumed to be low risk as it is expected to provide a steady revenue stream. Assets are unlikely to be utilised often for a RaaS event (up to a few times per year), which will protect the asset from excessive degradation. Additionally, whilst the timing of RaaS events is uncertain, the 'available energy' requirement during a RaaS is known in advance, with this particularly so for RaaS Product Scenarios 1 and 2 where the requirements are determined at point of contract, whereas to the requirements for RaaS Product Scenario 3 will be issued on a more dynamic basis. However, it is acknowledged that this may also be dependent on the payment structure for RaaS (e.g. availability and/or utilisation payments).

To provide the context for consideration of different investor profiles, an overview of the current key types of investor in energy services is provided below.

Corporate Lenders – focus on 'universal' banking offering – long and short term lending, deposits and cash management and hedging

- Capital of ~£75-£150mn per project, with 2 to 6 large deals per year
- Examples: BNP Paribas, Santander, Barclays, Société Generale, NatWest

Project Finance Banks – more specialist community which includes corporate lenders but also further additions from the international banking community – particularly, Northern European and Japanese banks

- Smaller capital typically than corporate lender. 5+ deals a year with longer term duration
- Typically more expensive than corporate lending, mainly as a result of tenure rather than risk
- Examples: Barclays Project Finance division, RBS, Santander, Mitsubishi, Mitsui

Mezzanine Lenders – providers of subordinated loans but not taking an equity stake in the project

- Limited number of active players as the high level of senior debt gearing squeezes these out and the costs of finance are prohibitive relative to senior debt. Other actors (state banks and export credit agencies) have been able to fill gaps more cost-effectively during the 'credit crunch'

Venture Capital Funds – raise money from wide range of sources including high net worth, pension funds, insurance all with high risk appetite

- Target new technology/markets and early stage companies
- Investment horizon 4-7 years
- Examples: Eneco Ventures, Greencoat Capital, Siemens Energy Ventures

Private Equity – target opportunities for upside (the potential increase in value of an investment)

- Interest in mature technologies (pre-IPO, or under-performing companies)
- Investment horizon 3-5 years
- Examples: Energy utilities, traditional wind and solar developers (RES, Lightsource, Infinis), flexibility developers (Zenobe, Harmony Energy)

Infrastructure Funds – funds drawn from institutional investors and pension funds. Target infrastructure (a durable and tangible assets, long term and stable cash flows)

- Low-medium risk appetite
- Investment horizon 7-10 years
- Examples: ISquared Capital, Bluefield, Infrared Capital, Gresham House, Gore Street

Pension Funds – in search of inflation linked returns, with increased interest in energy since the 2008 financial crisis

- Have typically preferred operational assets to avoid construction risk. Comfortable with long duration assets
- Examples: Foresight, Aviva Investment, PIP

Export Credit Agencies – public agencies and entities that provide government-backed loans, guarantees and insurance to corporations from their home country that seek to do business overseas in developing countries and emerging markets

- Examples: UK Export Finance (part of UKTI), EKF (Denmark), Atradius (Netherlands)

State Banks – publicly owned and /or funded financial institutions that are able to fund their activities at a lower cost to commercial banks and hence deliver cheaper financing to borrowers

- Usually offer senior debt where there is a 'gap' in funding from private sources, but can offer equity or mezzanine finance. Either national or international in nature, they typically have prescribed mandates that cover limited technologies, sectors and geography
- Examples: Green Investment Bank (now Green Investment Group), KfW (Germany), European Investment Bank (EU wide)

Community Energy Groups – typically focused on low-carbon assets for shared use and wider social benefits

- High returns are typically not a high priority for these investors, and so risk profiles may vary
- Examples: small independent groups, Co-operative societies, with supporting organisations for shared knowledge, experience and guidance

6.4 Risks to modelling analysis

The main risks to the modelling outputs relate to the future development and evolution of flexibility markets. In addition to the risks identified in this report, further considerations are set out in more detail in E5.2 'Investor Risk Evaluation' and its accompanying Investor Risk Register, which identifies and provides mitigation measures for 73 potential risks across all stages of the provision of a RaaS service from tendering to operation.

For example, while a frequency response revenue stream is modelled within this analysis, the service is transitioning away from its current state as Firm Frequency Response to Dynamic Containment (which is currently in a trial phase). The market dynamics and future rules surrounding these services is not known, therefore in the current frequency response price forecasts, a view is taken on the fundamental drivers of the continuing need for frequency response services. The modelling also assumes the service will continue to be stackable with other services (such as RaaS) in its future form.

There are also risks around network charging, for example linked to the outcomes of Ofgem's ongoing Access SCR. Changes here may impact the business case for all flexibility market participants. The outcome of this review, and associated timeframes for implementation, are currently uncertain. The modelling work presented here takes this into account by reducing distribution charges or credits by half in 2024, however it is acknowledged that the actual impacts are likely to be highly locational.

6.5 Impact of results on deliverable E5.3 Investor Business Case

This work feeds directly into the E5.3 'Investor Business Case' work, which will also draw in scheme costs and potential income from RaaS to evaluate the cost benefit balance from a RaaS investor perspective The key outputs of this analysis are:

- Forecasts for revenue and gross margin achievable from participation in other flexibility services (beyond the provision of RaaS) under the three battery scenarios considered - this will feed into work to determine the potential tender pricing of the RaaS product design.
- Considerations regarding the positive and negative aspects of the RaaS Product Scenarios considered within this analysis.

7 Conclusions and summary of results

The key conclusions from this report are:

- There are clear and beneficial opportunities for RaaS Service Providers to also stack revenues in other flexibility services, in addition to providing a DNO RaaS service. The scope to participate in other markets will depend on the level of headroom available to the battery, which itself will depend on both the battery specification and the final design of the RaaS service.
- Assets offering RaaS services will receive lower revenues from participating in flexibility markets than those not offering a RaaS service, as some battery capacity is reserved for the RaaS service and therefore not used in other markets. Further work within the project will incorporate the potential revenues from participation in the RaaS service into the business cases for an investor in a RaaS battery asset.
- The revenues available to RaaS Service Providers from other flexibility markets will also depend on the RaaS Product Design Scenario used. Three scenarios were assessed for this report, with margins for the Drynoch pilot scheme (from other flexibility markets only) ranging from £24/kW to £34/kW in the first year. Margins were higher for RaaS Product Design Scenario 3, which is the most dynamic of the Product Design Scenarios, providing greater granularity of RaaS requirements specification.
- There are a number of factors that could influence participation in RaaS, with considerations around its pricing and the Product Design Scenario developed:
    - The RaaS service will likely provide a more reliable / steady revenue stream compared to revenues from other flexibility markets. This may make it more attractive to some types of investors.
    - The RaaS service may have a lower impact on battery degradation because the asset would be expected to cycle (charge and discharge) less, compared to participating in other flexibility markets. This is not captured in the modelling, but in practice would extend the life of the asset or increase the headroom available to operate in flexibility markets.
    - Approaches that use a more dynamic notification of requirements would require greater levels of analysis and forecasting capability, and a more refined communications process, for both the DNO and RaaS Service Provider, however would increase the scope for revenue stacking from other markets, and therefore potentially reduce the associated RaaS fee.

The analysis presented within this report illustrates the range of factors that would need to be considered by a RaaS Service Provider with regard to revenue stacking across other flexibility markets, to inform the business case for investment in a RaaS asset. Different potential RaaS Service Providers may have different capabilities, and different costs, for providing different minimum reserved capacities for RaaS. Similarly, a key consideration for DNOs relates to the balance between the benefits of a RaaS solution and potential costs. DNOs therefore need to consider the fact that a service which does not meet full (ideal) requirements for RaaS at a given location may still represent an improvement in service to customers, and so where this may be more cost effective than procuring the full requirements, this option should still be considered.

A recommendation here is for DNOs to consider including a number of options in the tender process (essentially reflecting different durations for the provision of a RaaS service during an outage) and inviting quotes for each. It is acknowledged that a DNO's engagement with the local community to understand their preferences and expectations would also be of value to inform the decisions made by a DNO for the implementation of RaaS at specific locations.

The next steps for the project are to use this analysis to inform the design of the RaaS service, both for the trial site and for the future roll out of RaaS, and evaluate the appropriate pricing level for the service through the investor business case analysis to be undertaken in WP5 'Business Model'.

Tables Table 5 to Table 7 below summarise the average margin (on a £/kW of total battery capacity basis) achievable from participation in other flexibility markets (beyond RaaS) for each of the scenarios modelled, including different battery systems, RaaS Product Design Scenarios, Wholesale Pricing scenarios and Network Constraint scenarios.

Table 5 – Overview of modelling results – Drynoch battery

Wholesale Pricing Scenario	Network Constraint Scenario	RaaS Product Scenarios			Baseline
		Scenario 1 average margin (£/kW)	Scenario 2 average margin (£/kW)	Scenario 3 average margin (£/kW)	No RaaS average margin (£/kW)
Central	Network Constraint A	11.5	10.8	30.3	37.6
High	Network Constraint A	19.2	18.0	42.8	49.6
Low	Network Constraint A	6.5	6.3	20.5	27.6
Central	Network Constraint B	8.3	8.0	15.7	27.9
Central	Network Constraint C	10.6	10.1	28.1	34.6

Table 6 – Overview of modelling results – Drynoch 'oversized' battery

Wholesale Pricing Scenario	Network Constraint Scenario	RaaS Product Design Scenarios			Baseline
		Scenario 1 average margin (£/kW)	Scenario 2 average margin (£/kW)	Scenario 3 average margin (£/kW)	No RaaS average margin (£/kW)
Central	Network Constraint A	31.4	31.0	38.5	47.3
High	Network Constraint A	45.4	44.8	52.8	61.5
Low	Network Constraint A	20.8	20.7	26.7	35.6

Table 7 – Overview of modelling results – 'generic' East Midlands battery

Wholesale Pricing Scenario	Network Constraint Scenario	RaaS Product Design Scenarios			Baseline
		Scenario 1 average margin (£/kW)	Scenario 2 average margin (£/kW)	Scenario 3 average margin (£/kW)	No RaaS average margin (£/kW)
Central	Network Constraint A	54.1	53.3	62.0	67.6
High	Network Constraint A	72.6	71.4	79.4	84.2
Low	Network Constraint A	39.0	38.5	46.8	52.6

Appendix 1: Constant modelling parameters across all runs

Parameter	Value	Comment
Run start date	01/04/2022	Assumed operational date of batteries. Warranties and generation licences also assumed to commence on this date
Run length	10 years	
Site connection	High voltage	Assumed for generic site, impacts distribution charges
DUoS reform	-50% from 2024	Ofgem's Network Access and Forward Looking Charges Significant Code Review ("Access SCR") assumed to reduce DUoS charges from 2024
TNUoS reform	In 2024	Access SCR expected to charge distributed generators as if they were transmission connected from 2024
Maximum allowed cycles per day (and average per quarter)	1.5	In line with standard warranties. RaaS products mean battery cycling is much lower regardless
Import efficiency	88%	Round—trip efficiency accounted for by restricting import efficiency
Minimum wholesale dispatch profit	£25/MWh	Minimum profit value which would need to be achieved above the trading costs for the battery to operate. CI estimates have been used
Minimum day ahead to intraday wholesale dispatch profit	£40/MWh	This is the minimum profit value which would need to be achieved for the day-ahead position to be sold back and sold on an intraday basis
Day ahead to intraday risk adjustment factor	50%	This is the volume of the asset which would operate if position sold and bought back. This acts as a risk mitigation approach; the lower the percentage, the less risk taken
Intraday to BM risk adjustment factor	50%	This is the minimum profit value which would need to be achieved for the intraday position to be sold back and sold on a BM basis
BM utilisation	50%	This is the assumed utilisation of the asset in the BM
Minimum BM dispatch profit	£50/MWh	This is the minimum BM price required for the asset to participate

Appendix 2: Capacity Market assumptions

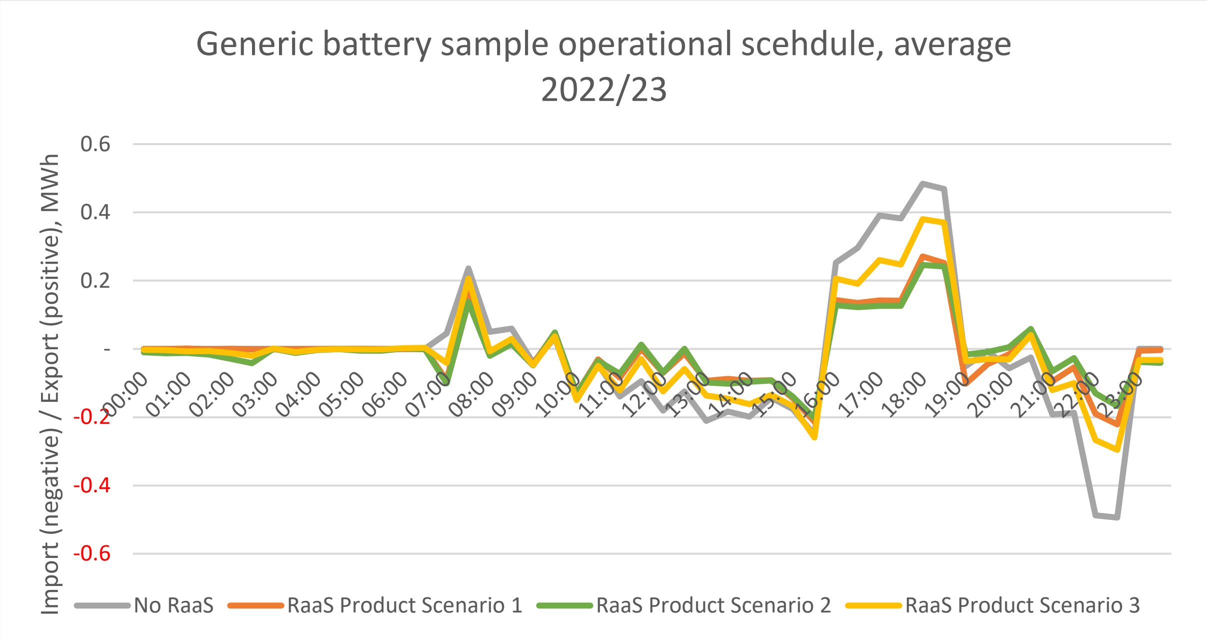
Assets assumed to access agreements in T-1 auctions until a 15-year agreement can be reached in a T-4 auction (first delivery year 2025/26). Based on in-house Cornwall Insight forecasts.

Batteries of 1.4 hour duration assumed to have 1 hour derating factor.

Battery capacity used for CM payment, not network capacity.

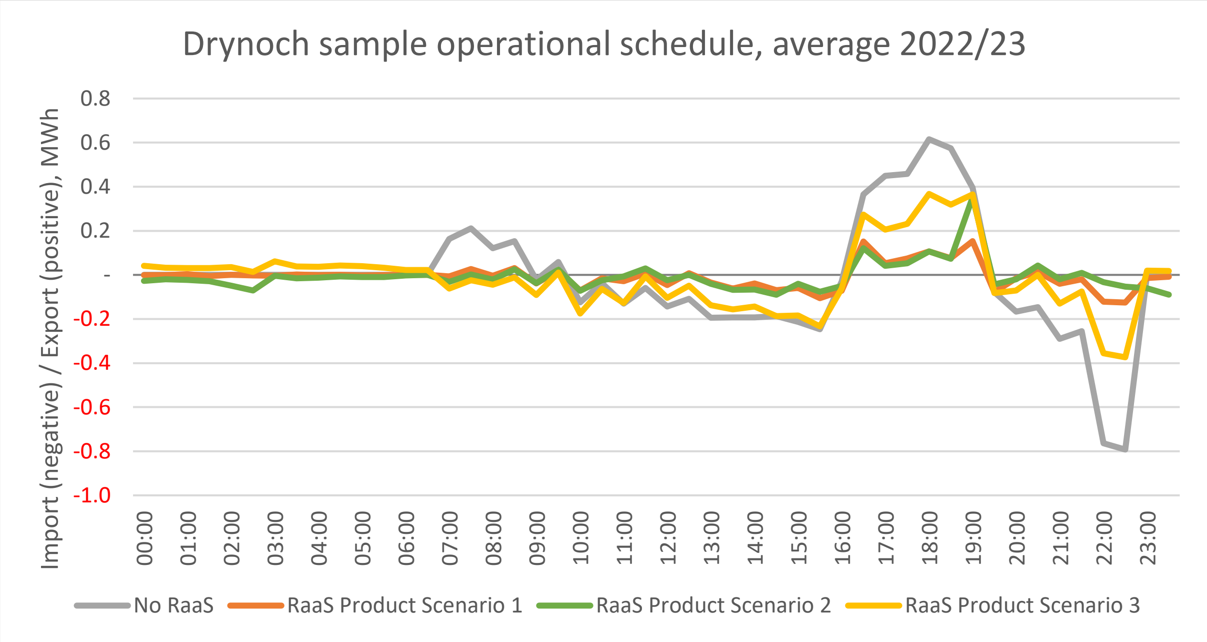
Appendix 3: Example output of an operational schedule for a generic RaaS providing battery

Figure 22: Generic battery operational schedule – average 2022/23



Appendix 4: Example output of an operational schedule for the Drynoch pilot scheme

Figure 23: Drynoch battery operational schedule – average 2022/23



Appendix 5: Commentary on our wholesale price scenarios

At the heart of our analysis are scenarios developed to highlight uncertainties around the future evolution of the market.

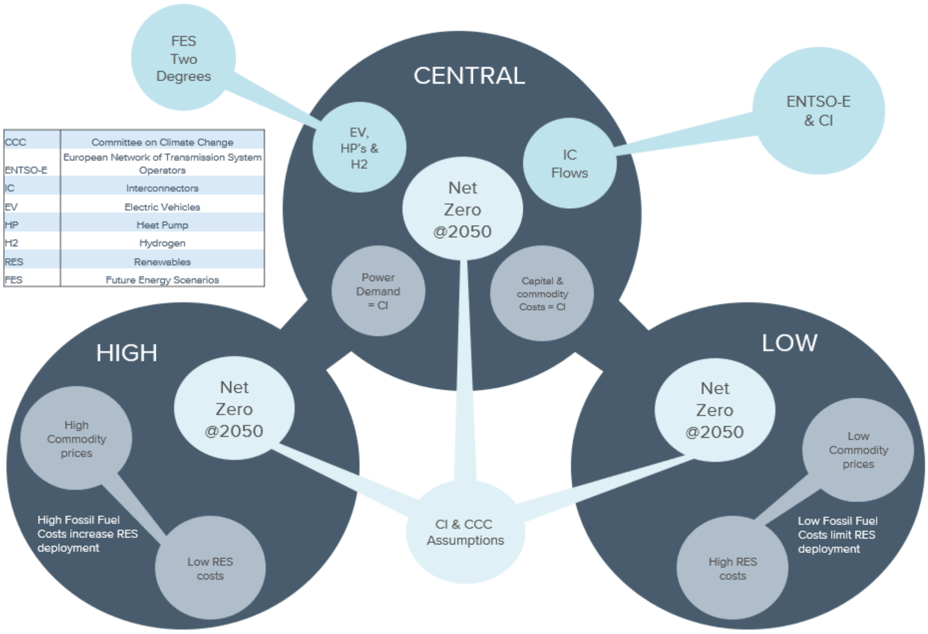
Cornwall Insight have developed three scenarios to frame our views of the future of the electricity market. Each scenario reaches Net Zero in 2050 to reflect the ambition of the UK government and ensures the electricity market is planned towards the current Capacity Market framework of meeting the Loss of Load Expectation of 3 hours per year.

The Cornwall Insight Central scenario is our expected view of commodity prices and the capital cost of different technologies.

The High scenario provides a view of high commodity prices and low costs for variable renewables technologies The Low scenario provides a view of low commodity costs and lower costs for firm low-carbon capacity such as BECCS, nuclear and CCUS.

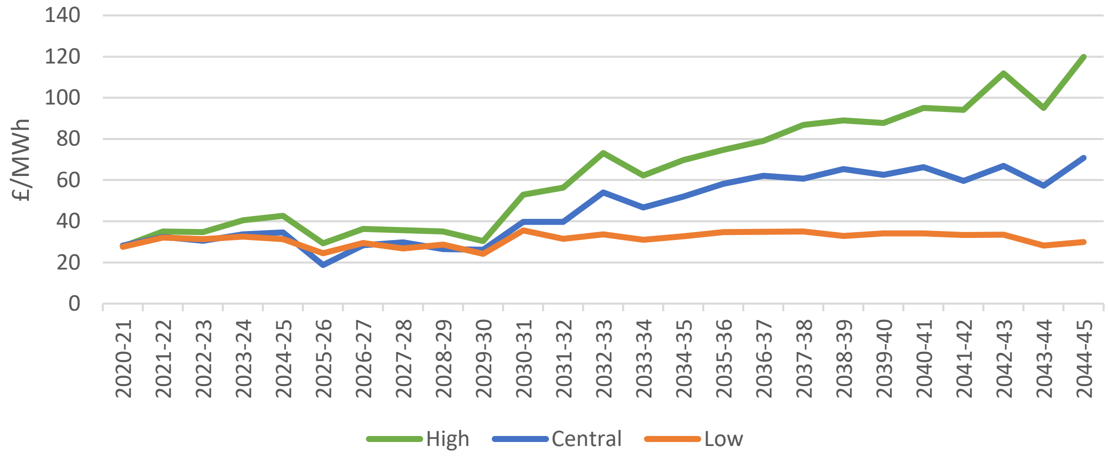
For wider European assumptions, we have used the scenario most closely representing the ambition to reach Net Zero carbon targets. For 2030 we have assumed Member States reach their 2030 renewable capacity goal as laid out in each National Energy Climate Plan.

Figure 24 - Wholesale pricing scenario framework



CCC	Committee on Climate Change
ENTSO-E	European Network of Transmission System Operators
IC	Interconnectors
EV	Electric Vehicles
HP	Heat Pump
H2	Hydrogen
RES	Renewables
FES	Future Energy Scenarios

Figure 25: Cornwall Insight BPC power curves used for wholesale scenarios



Wholesale prices are affected by the generation mix, demand, and a range of other factors. The BPC average prices vary as follows:

- Prices rebound in 2021 as demand increases because of a recovery in economic activity following the COIVID-19 pandemic.
- Prices rise to 2024, but after the deployment of offshore wind and new interconnectors in the second half of the decade prices flatline for the rest of the 2020s. After 2030 prices rise again as electrification and hydrogen penetrates further into the economy and demand increases.
- In the Central Scenario the average price between 2020-21 and 2029-30 is £29.9/MWh falling to a minimum of £18.7/MWh in 2025-26. Between 2030 and 2045 the average price is £57.4/MWh.
- In the Low Scenario the average price between 2020-21 and 2029-2030 is £29.4/MWh falling to a minimum of £24.2/MWh in 2029-30. Between 2030 and 2045 the average price is £33.0/MWh – prices after 2030 are lower than the other scenarios due to lower volatility and greater reliance on baseload BECCS and CCUS.
- In the High Scenario the average price between 2020-21 and 2029-2030 is £35.2/MWh falling to a minimum of £29.3/MWh in 2025-26. Between 2030 and 2045 the average price is £83.2/MWh – greater volatility and higher commodity prices drive prices higher than the central scenario after 2030

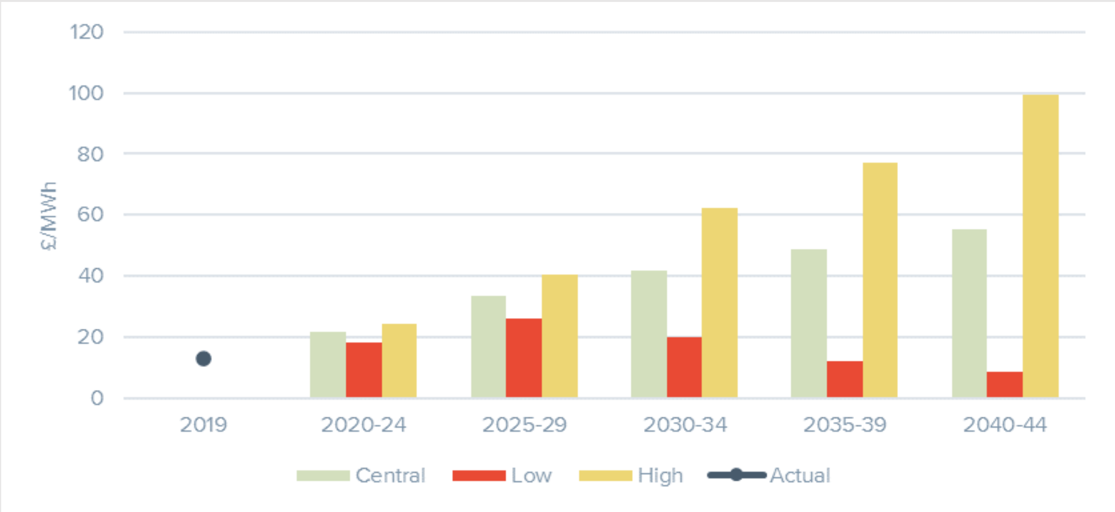
The volatility in prices also changes between wholesale scenarios, masked by the annual averages shown above. Figure 26 shows the volatility measured as a standard deviation of hourly prices for each period. For 2019 this measure was valued at £13/MWh.

The volatility then develops across different wholesale scenarios:

- Between 2020 and 2024 there is an increase in volatility in all wholesale pricing scenarios between £18.1/MWh in the Low scenario and £24.1/MWh in the High scenario. This is driven by a rise in renewables deployment
- The High wholesale scenario has a greater standard deviation because of high variable renewables, and low load factors for peaking capacity driving significant spikes and troughs in wholesale power prices
    - The High wholesale scenario sees volatility increase to £54.8/MWh between 2035 and 2039 and £114.1/MWh between 2040 and 2044

- In the Low wholesale scenario volatility is dampened as the scenario has a higher contribution from synchronous generators such as bioenergy with carbon capture and storage (BECCS) and gas turbines.

Figure 26: Cornwall Insight BPC hourly wholesale price standard deviation



Appendix 6: Further detail of our Frequency Response modelling approach

The Cornwall Insight Frequency Response model is based on the following approach using market fundamentals and covers the following elements.

Demand

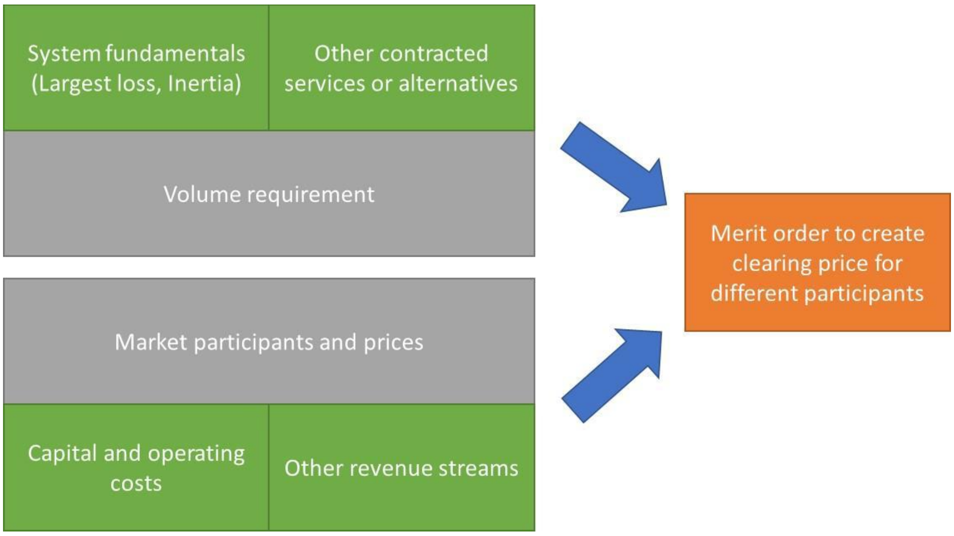
- Based on National Grid ESO requirements for services according to levels of inertia, largest loss on the system and peak demand

Supply

- Technologies suitable by product, considering other balancing services opportunities
- Capex, Opex and alternative revenue streams (Capacity Market, Embedded benefits)
- Short run marginal cost for existing plants
- Long run marginal cost for new entrants

Using the above information, it is possible to create bid calculation for each participant in the market. From this, a merit order is created which stacks successful participants to determine the optimum clearly price for the frequency response service. A visual of the modelling methodology is shown in Figure 28.

Figure 27: Cornwall Frequency Response Model



Source: Cornwall Insight