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BUSINESS CASE FOR FLEXIBILITY PROVIDERS

CORNWALL LOCAL ENERGY MARKET

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centrica

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Contents

ACRONYMS

BS	Balancing Service
CLEM	Cornwall Local Energy Market
DNO	Distribution Network Operator
ES	Energy Storage
ESCO	Energy Service Company
LCG	Low Carbon Generation
P2P	Peer-to-Peer
PV	Photovoltaic
RH	Rolling Schedule
WPD	Western Power Distribution

SECTION ONE

INTRODUCTION

In this Section:

- Introduction to the benefits of participating in distributed, local energy markets
- Overview of the Cornwall Local Energy Market platform, including services available for flexibility providers
- Report scope and objectives

BACKGROUND

Distributed, local energy markets – such as the Cornwall Local Energy Market (CLEM) - are expected to be a key contributor to pave the way to a net-zero carbon future. The need for the heat and transport sectors to seek for alternative, low carbon fuels is menacing the cost-effective operation of the electricity system; the uncertainty and seasonal component of renewable energy sources combined with the electrification of the residential heat and transport sectors will detrimentally affect the whole supply chain of the electricity market. The role of local energy markets, in this setting, is to facilitate end-users' access to local, low carbon energy – for example through peer-to-peer (P2P) energy exchanges – but fundamentally to allow network and system operators to actively engage end-users to participate and support system balancing activities by procuring system services directly from them. In this setting, end-users benefit from lower energy bills and can further secure revenue multiple streams from providing their flexibility. On the other hand, network and system operators can benefit from cost-effective (demand side) flexibility to support system operation, in contrast to capital intensive *business as usual* solutions.

Network operators can benefit from end-users` flexibility to reduce / increase their consumption at explicit times so as to cost-effectively manage aggravated peaks of demand and thus maintain network assets within adequate operational limits. Additionally, capital intensive network reinforcements can then be deferred (or fully avoided), both at the distribution and transmission levels, by improving network utilisation levels. Similarly, system operators can also benefit from more cost-effective flexibility services to support their activities associated with balancing demand and supply; by adjusting their consumption levels, end-users can assist balancing demand and supply by providing various frequency regulation products – e.g. reserve and frequency response.

In this context, by offering their flexibility in local energy markets, end-users' can provide a wide range of services and thus be remunerated for the benefits delivered. Indeed, flexibility providers can support the business activities of various market participants and thus secure multiple revenue streams for the value delivered.

THE CORNWALL LOCAL ENERGY MARKET

As the UK pursues its legally binding renewable energy and net-zero carbon targets, the electricity system will face unprecedented challenges associated with intermittent renewable energy outputs and aggravated peaks of demand – due to the potential electrification of the transport and heat sectors; in Cornwall, this will be exacerbated because of the high penetration of renewable generation and insufficient network capacity.

The CLEM project key objective is to develop a local energy market platform - within the geographic area of Cornwall – in order to enable residential consumers and businesses to trade their flexibility with the local network operator (i.e. Western Power Distribution, WPD) and the system operator (i.e. National Grid ESO). This unique market platform will facilitate WPD and National Grid ESO in procuring critical flexibility services that support their business activities in the electricity industry, as well as enabling other market participants to offer their flexibility. Flexibility providers will then receive a payment for the benefits delivered, should their offer be accepted.

In this context, this project will develop a local market platform for flexible demand, generation and energy storage owners to support network and system operators managing supply and demand in a cost-effective way. Flexibility providers can thus support the business activities of the local distribution network and system operators by adjusting their generation / consumption levels, in particular: (i) help the local distribution network operator (DNO) to manage power flow constraints in the network during peaks of demand or excess renewable generation, and (ii) support the system operator to balance system demand and supply by providing frequency regulation products. Therefore, through a multi-service business model, flexibility providers can benefit from reduced revenue volatility and market uncertainty, improved financing and overall value proposition of their flexibility assets. Nevertheless, negotiating the many synergies and conflicts among the multiple services being provided is crucial to optimise and ensure that the portfolio of services selected delivers maximum value.

To conclude, the CLEM project will ultimately enable value optimisation of local renewable generation, support the reduction of carbon emissions and achieve a more efficient decentralised energy system.

RESEARCH SCOPE & OBJECTIVES

This report main objective is to deliver a better understanding of the business opportunities arising with the CLEM (and other similar local energy markets) and support interested users to devise commercial strategies that maximise their value proposition. To achieve this a modelling framework has been developed together with a set of case studies, presented herein, which investigate the value proposition and operational feasibility of a flexibility asset (energy storage, ES, system) in a single and multi-service business model frameworks and considering various deployment solutions: stand-alone or co-located with low carbon generation plants (e.g. solar PV).

Specifically, in contrast to a top-down, whole-system modelling framework - applied to demonstrate the value of flexibility to the electricity system - a bottom-up, stakeholder centric modelling framework has been developed to co-ordinate the provision of multiple services, with the overall objective to support the development of long-term profit-maximisation commercial strategies for flexibility providers. In the context of CLEM, the set of services considered follow a regulatory framework similar to that developed by N-SIDE for the CLEM market clearing algorithm; these include network services to the local DNO, balancing services to the system operator and Intra-day energy price arbitrage opportunities.

The analysis presented in this report aims at informing the development of policy that adequately reward flexibility providers for the diverse sources of value delivered to the electricity system, through local energy markets. This may be of particular interest to energy aggregators, ESCO's, end-users' and overall investors, interested in providing flexibility services.

SECTION TWO

MODELLING APPROACH

In this Section:

- Overview of modelling framework with description of modelling parameters, constraints, input data and overall considerations.
- Analysis and discussion of input data applied to the case studies, namely with respect to: price data, ES modelling parameters and LCG power output profiles.

MODEL OVERVIEW

The developed price-taker model maximises the overall net revenue that flexibility providers could earn over the period of a year, given the set of prices for different services and associated uncertainty levels. Moreover, through a multi-service business model framework, the model allows flexibility providers to further enhance the value proposition of the services offered to different market participants, and thus secure multiple revenue streams.

To achieve this, the model coordinates delivery of multiple applications / services while considering a number of constraints that represent the inter-dependencies among different services' regulatory frameworks, the ES plant operational limits and constraints of the local network infrastructure. When selecting the portfolio of services, the model will ensure the robustness of delivery against potentially different levels of utilisation of stored energy associated with different services. In other words, the model will always ensure real-time deliverability of services that are scheduled ahead of real-time, for example balancing services.

The uncertainty aspect associated with Intra-Day energy prices, is captured through a Rolling Horizon (RH) algorithm, following the approach applied in [1]. Fundamentally, the algorithm is based on a relatively short optimization *time window,* which iteratively (step-by-step) advances through the whole optimization horizon. In other words, ES charge / discharge actions are determined based on the expected energy price in a limited horizon – usually referred to Predictive horizon. A decision with respect to charge / discharge actions is then taken and ES plant is scheduled for the Control horizon (i.e. usually for the next time period / hour). Then the process is re-started for the following time period (i.e. hour), in which new charge / discharge actions can be determined based on more accurate energy price estimations. The whole process is repeated in an iterative approach until the Scheduling horizon is reached (i.e. typically 1 year); Figure 1 shows a conceptual diagram for the operation of a RH algorithm.

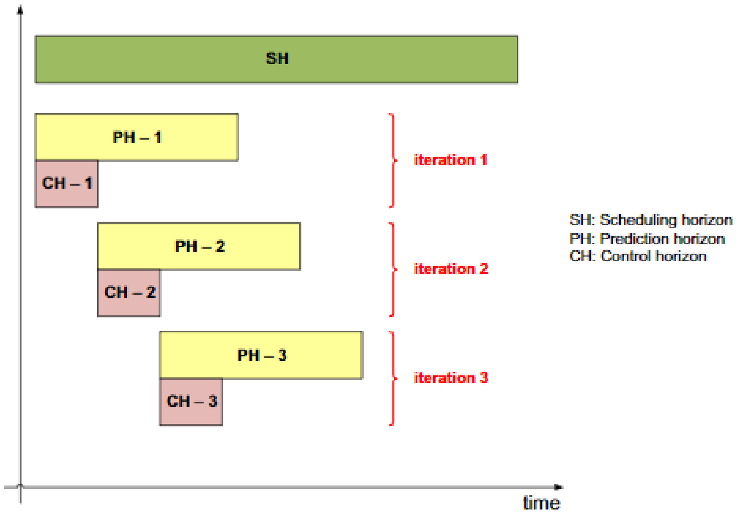

Figure 1: Diagram of concept for Rolling Schedule algorithm [1].

OBJECTIVE FUNCTION

The model objective function maximises net revenue associated with: (i) energy price arbitrage and (ii) balancing services to the system operator. The model also considers provision of DNO services, but this is included in the set of constraints and not in the objective function. Revenues for the DNO service are therefore determined on an Opportunity Cost[1] basis.

In this setting, revenues are determined for every hour, based on the committed ES capacity multiplied by the service price, in particular:

- Energy price arbitrage revenues are determined by the difference between the cost of energy bought and sold, times the given energy prices on an hourly basis. Moreover, considering the RH algorithm, the uncertainty associated with Intra-Day energy prices is captured through a Predictive Horizon in which energy prices are estimated for the next 24 hours, whereas charge / discharge actions are only scheduled for the following time period.

- Committing ES capacity for balancing services assumes an hourly availability payment proportional to the capacity committed to provide the service. In contrast to the Rolling Horizon

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[1] Fundamentally, an Opportunity Cost is usually defined as the loss in revenue / benefit for pursuing a non-optimum strategy. When applied in a business context, it refers to the revenue / benefit a company would have made from its capital or equipment if these assets had been used in a different way.

framework applied to determine energy arbitrage revenues, provision of balancing services is performed taking into account a longer scheduling horizon – following Cornwall Local Energy Market rules, i.e. volumes are committed 1 day in advance (i.e. day-ahead) of real-time utilisation.

DNO service is included in the set of constraints rather than in the objective function. The provision of the services to the local network operator is considered through a set of (charge / discharge) instructions required to maintain the local network within its safety margins; and therefore, revenue for DNO service is determined as the opportunity cost for flexibility providers in providing this service, in contrast to using ES plant power and energy resources for other services.

MODELLING OF ENERGY STORAGE OPERATION

An ES plant has been selected and modelled as the main flexibility source, i.e. through its charge / discharge actions. This way, ES charge and discharge operations are limited by, respectively, maximum charge and discharge capacities (in MW), and by maximum and minimum energy capacity (in MWh).

Energy levels are determined at the end of each period and thus representing a *snapshot* of all the past charge and discharge actions, i.e. at the end of each hour – after all charge / discharge actions are accounted for; and limited by ES plant maximum and minimum energy capacity. ES plant is also modelled in terms of its round-trip efficiency. This way, energy stored at present depends on (i) energy stored at the end of the previous period, (ii) ES plant output at present, and (iii) energy losses driven by the round-trip efficiency.

GENERAL MODELLING CONSTRAINTS

To complement and also understand the mechanisms that optimise the value proposition for ES plants co-located with Low Carbon Generation (LCG), two types of LCG have been considered in the case studies; namely Solar PV and Wind power plants. These were taken into consideration through real power output profiles from actual Wind and Solar PV plants. Fundamentally, the deterministic power output profiles are applied to support ES plant charging actions – when participating in the Cornwall Local Energy Market – and to maximize the value proposition of intermittent Low Carbon Generation.

Provision of DNO service is achieved through a set of constraints applied so as to determine the Opportunity Cost for allocating ES plant power and energy capacity to provide such service. In this setting, and following the Cornwall Local Energy Market framework, a set of (charge / discharge) actions required by the local network operator are revealed one day ahead of delivery. These will thus have an impact on the commercial strategies that the ES plant can pursue in other markets / services; this Opportunity Cost is then used to value the *minimum willingness to be paid* by service providers. Besides these limited number of actions required by the network operator to manage network congestion, the ES plant charge and discharge actions are assumed to have a limited impact on network congestion.

BALANCING SERVICES CONSTRAINTS

Provision of balancing services, to the system operator (National Grid ESO), is achieved in a twofold approach: (i) volumes for service provision are committed one day-ahead of delivery and have an availability fee (in £/MW/h) associated, (ii) on the day of delivery, the system operator has the option to activate (or not) the volumes that were previously contracted – this will depend on the requirement for balancing services at that specific day and hour, and actual frequency deviation. In this context, the model ensures service's deliverability in a robust way by ensuring that ES plant energy and power capacities required to fully deliver the service will be available – i.e. the model will manage ES plant charge / discharge actions so as to ensure the required energy levels to provide the committed volumes to balancing services are adequately maintained for full service deliverability.

In this setting, provision of balancing services is determined one day-ahead of delivery and priced according to its availability fee. Service delivery[2] is ensured by maintaining ES plant energy levels so as to fully deliver the service for 30min, continuously. Moreover, balancing services can require either charge or discharge actions – in order to correct downwards / upwards frequency deviations – and this is ensured by a set of constraints so as to maintain the symmetry of upwards and downwards services at every contracted period. Service provision is also limited to early hours of the morning (6am – 10am) and

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[2] Service delivery refers to the ability to provide a service (i.e. whether levels of energy stored and capacity headroom allow a service – e.g. Firm Frequency Response – to be adequately delivered when it is exercised by the system operator).

afternoon (5pm – 8pm), so as to represent when the service is most required and valued, according to National Grid ESO [2].

INPUT DATA

Prices of relevant services, ES plant modelling parameters and other relevant data to carry out the case studies, are detailed herein. Likewise, a series of modelling, as well as market data, assumptions have been considered in this study which will be detailed in this section.

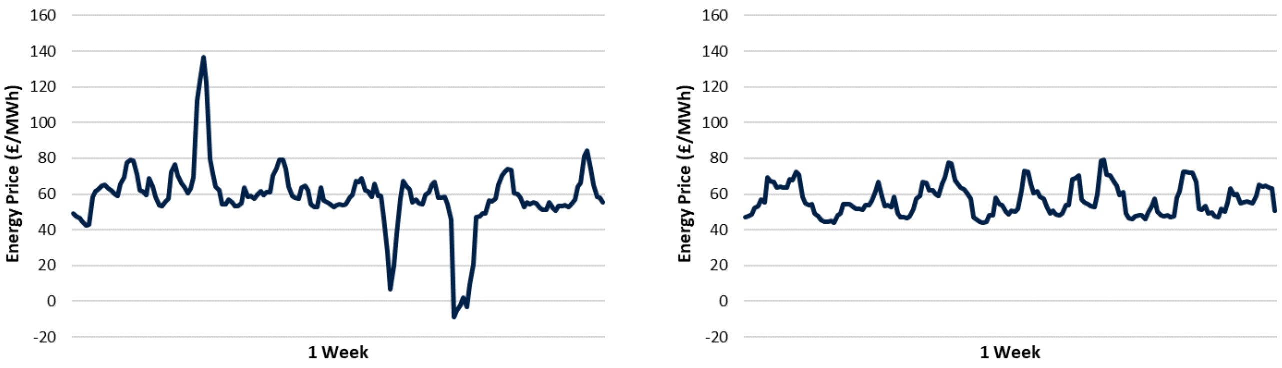
ES plant modelling parameters, with respect to maximum power and energy capacities, as well as round-trip efficiency, applied for the case studies presented next in Section Three, are described below in Table I.

Table I: ES plant modelling parameters.

		Sensitivity analysis
Max. Charging Capacity	1 [MW]	1, 2, 5, 10 [MW]
Max. Discharging Capacity	1 [MW]	1, 2, 5, 10 [MW]
Max. Energy Capacity	1 [MWh]	1, 2, 5, 10 [MW]
Round-trip Efficiency	80%	-

It should be noted that it was assumed that ES plant is technically capable of providing frequency regulation services to the system, and all metering / control equipment is present to ensure service delivery.

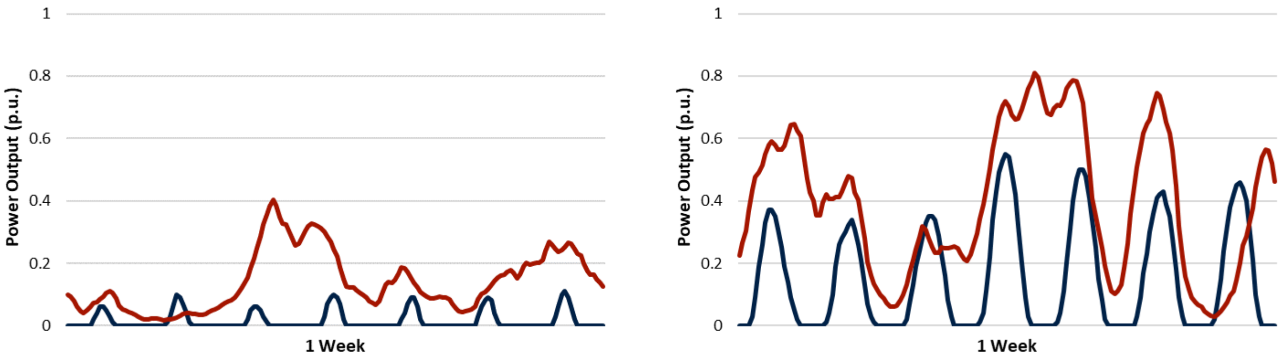
Historic energy price profiles from 2018 [3] were considered in the case studies for energy arbitrage revenue. Usually, these differ according to the season in the year; typical energy prices in winter present a more intermittent pattern with periods during the day in which prices may reach negative values (e.g. due to excess in LCG) and in other periods reaching high, prohibitive levels in terms of its absolute value. In summer, in contrast, energy prices are more *constant* and present a more predictable pattern, nevertheless with lower price differentials. Figure 2 shows for two different weeks in (a) Winter and (b) Summer, the energy prices profiles applied in the case studies.



(a) Winter *(b) Summer*

Figure 2: Energy prices for a week in (a) Winter and (b) Summer.

Following a similar seasonal trend, power output profiles from LCG exhibit contrasting patterns, especially, between Winter and Summer months. Typical summer months lead to higher solar PV outputs, as expected; nonetheless, wind power output can also be higher than in winter and this is because, although winters are associated with more adverse weather conditions and more frequent windy days, wind is usually stronger in the months of March to May, and these have been defined as summer months in this study. Figure 3, shows for the same days of Figure 2, two profiles of wind and solar PV power outputs for (a) Winter and (b) Summer weeks.



(a) Winter *(b) Summer*

Figure 3: Wind and Solar PV plants power outputs in a week in (a) Winter and (b) Summer.

To complement this, Figure 4 shows a histogram with wind power outputs across the whole year but differentiated by summer and winter months. As it can be seen, winter months are characterised by typically more frequent windy days – represented by the orange bars – however in summer wind power outputs can reach higher peaks in power – represented by the blue bars.

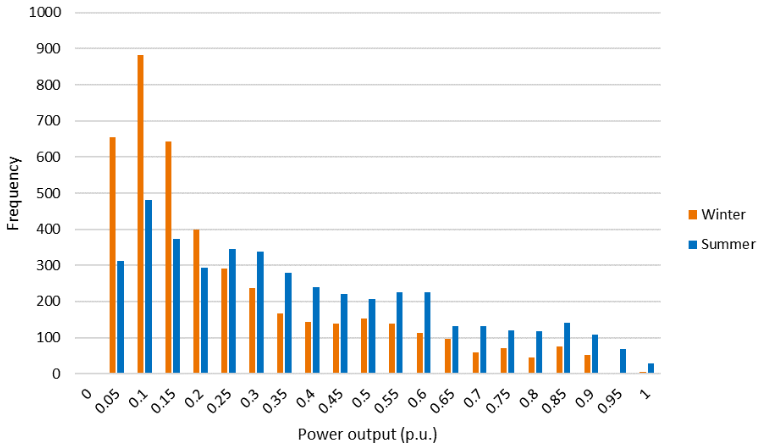


Figure 4: Histogram of wind power output in Summer and Winter months.

Provision of balancing services is, typically, remunerated through an Availability Fee in (£/MW/h) and an Utilisation Fee in (£/MWh) – in the event of being instructed by the system operator to deliver the committed volumes. In this setting, historic market data [2] for similar frequency regulation products (i.e. Firm Frequency Response, FFR) show that Utilisation Fees are typically very low or even 0 (£/MWh), with all the value of providing the service being concentrated in Availability Fees - with typical values oscillating from approximately 2 (£/MW/h) to more than 8 (£/MW/h), as shown in Figure 5. This is fundamentally associated with market participants – with low running costs - pursuing optimum commercial strategies and maximizing the prospect of their offer to be accepted.

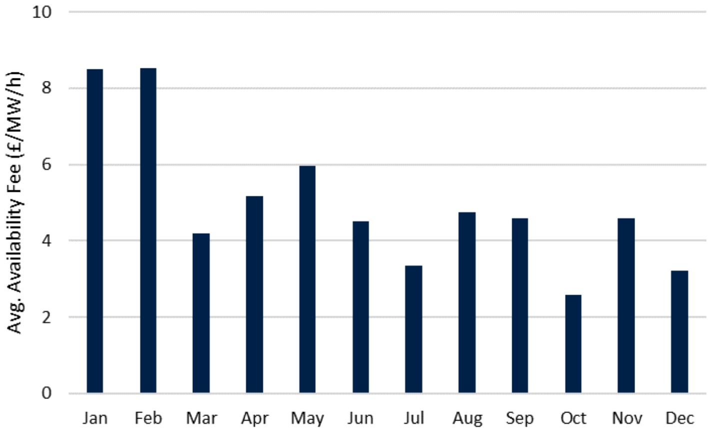


Figure 5: Monthly average availability prices for FFR product from National Grid ESO..

In this setting, and given the probabilistic nature of delivery instructions, the revenues for provision of balancing services will be determined taking into consideration historic market data for Availability Fees for FFR service. Nevertheless, it should be noted that when instructed to deliver balancing services – either upwards or downwards actions – the ES plant will deviate from its scheduled operation. In other words, after service delivery the ES plant will be required to recover to its scheduled energy levels, whether by charging or discharging additional energy in the Intra-Day energy market. Furthermore, taking into consideration that ES plant can be instructed to deliver balancing services multiple times per day – note that provision of balancing services, in principle, is viable at any period of the day – and thus the *recovery window* has been defined in the case studies as the time periods comprised between two delivery instructions. In other words, the ES plant can recover its energy levels after being instructed to deliver the committed volumes and just before another delivery instruction may occurs from the system operator. This will clearly have an impact on the business proposition for provision of balancing services and will be analysed in Section Three.

SECTION THREE

BUSINESS CASE FOR PROVISION OF FLEXIBILITY SERVICES

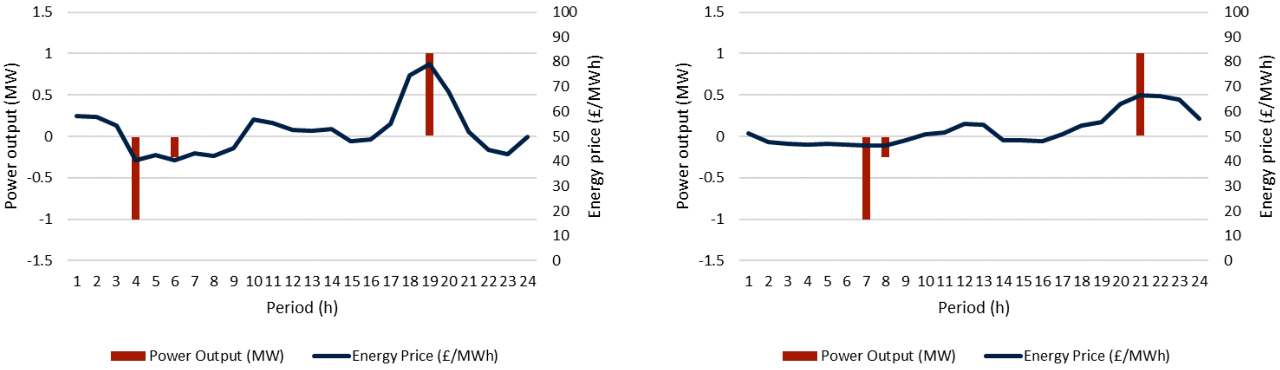
In this Section:

- ES plants can efficiently co-ordinate provision of multiple services and thus secure multiple revenue streams.
- Different market and system conditions will impact the optimum portfolio of services to be contracted across; Winter months are more beneficial for energy arbitrage opportunities and provision of DNO service, whereas summer months are more beneficial for provision of balancing services.
- Limiting ES plant operation to manage local network congestion for the DNO has a considerable impact on its value proposition and should therefore be remunerated accordingly

Seizing Arbitrage Opportunities in the Energy Market

ES plants can maximise stakeholders’ revenues in the energy market by arbitraging across time and thus taking advantage of energy price differences, i.e. by charging the ES plant during low price periods and discharging during periods with higher prices. On a typical day, for example, ES would charge in early morning, during periods with lowest energy prices, and discharge (typically) in the evening, when the prices are highest. This would result in a net profit, discounted by the round-trip efficiency of the ES plant.

Figure 6 shows, for a day in (a) Winter and (b) in Summer, the charge and discharge actions for maximum energy arbitrage revenue. Note that charging actions (i.e. negative power outputs) occur at the lowest priced periods and discharging actions (i.e. positive power outputs) occur at the peak priced periods.



(a) Winter

(b) Summer

Figure 6: ES plant charge and discharge actions, and Intra-Day energy prices in a day in (a) Winter and (b) Summer.

Fundamentally, by taking advantage of price differentials ES plants can benefit from arbitrage opportunities in the Intra-Day energy market. Figure 7, shows for a typical year, the potential revenue for an ES plant when seizing arbitrage opportunities in the Intra-Day energy market, differentiated per month.

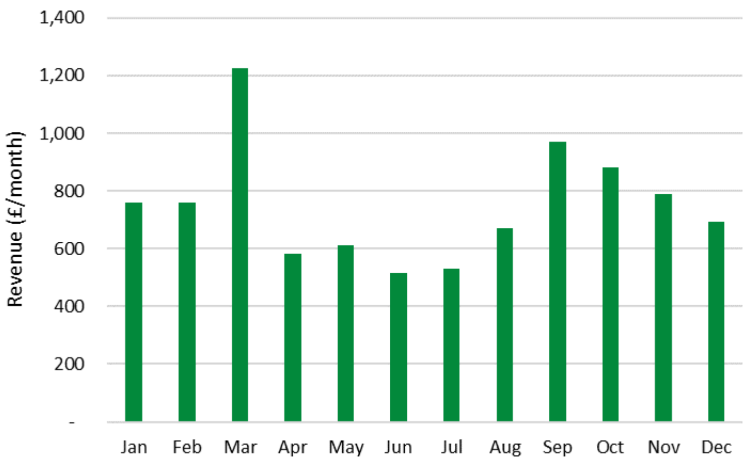


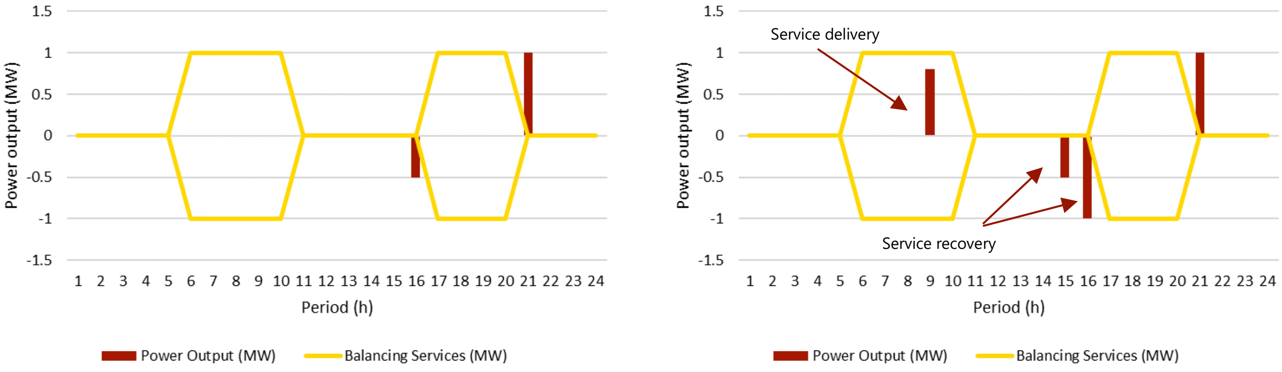
Figure 7: Intra-Day energy arbitrage revenues per month.

Note that the value proposition for energy arbitrage varies (significantly) across the year, and this is because of the characteristic patterns that energy prices exhibit in different seasons of the year, i.e. in summer and winter months.

PROVISION OF BALANCING SERVICES

It has been shown that ES plants can benefit from seizing arbitrage opportunities in the Intra-Day energy market. Nevertheless, their associated flexibility can also be applied to provide various system balancing services, for instance different types of frequency response applications and short-term operating reserve.

Provision of balancing services is typically a twofold process: (i) availability volumes are committed ahead of delivery – one day-ahead in the case studies presented herein - while ensuring that sufficient power and energy / headroom capacity are available for adequate service delivery and (ii) utilisation of committed volumes is subject to the ES plant being instructed by the system operator to deliver the full (or part) of the volumes committed, and thus assist in correcting deviations in system frequency. Figure 8, shows for the same day, ES plant (a) scheduled operation with committed volumes for balancing services, and (b) a simulation of a real-time delivery of committed volumes with respective recovery period.



(a) Scheduled Operation *(b) Real-time Operation*

Figure 8: ES plant (a) scheduled operation and (b) simulation of a delivery instruction and recovery period.

Note that, if instructed to deliver balancing services in real-time, ES plant will deviate from its scheduled operation – since energy levels will be affected with delivery of balancing services. In this setting, the model assumes that after a delivery instruction ES plant will need to recover to its scheduled energy levels and this can be done within the next hours before the next window for provision of balancing services.

ES plant can thus further enhance its value proposition by coordinating provision of balancing services, while managing its energy levels and seizing arbitrage opportunities in the Intra-Day energy market. Figure 9 shows the combined revenue streams from energy arbitrage and balancing services provision.

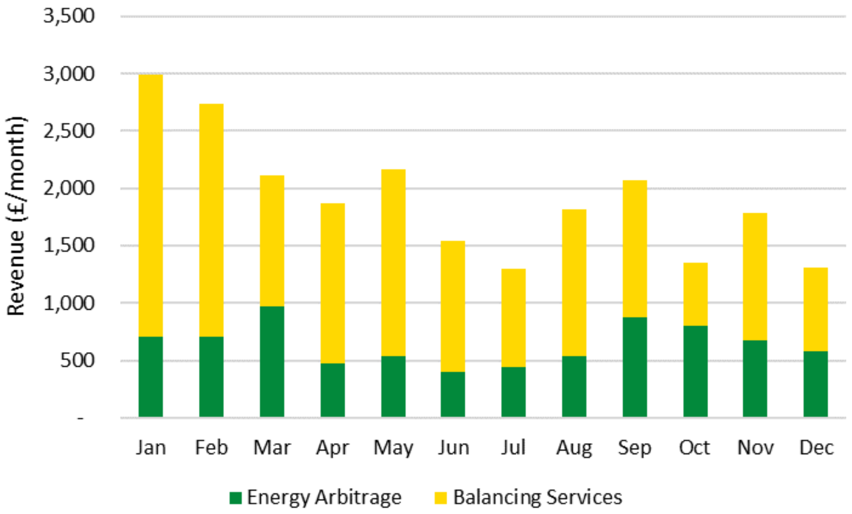
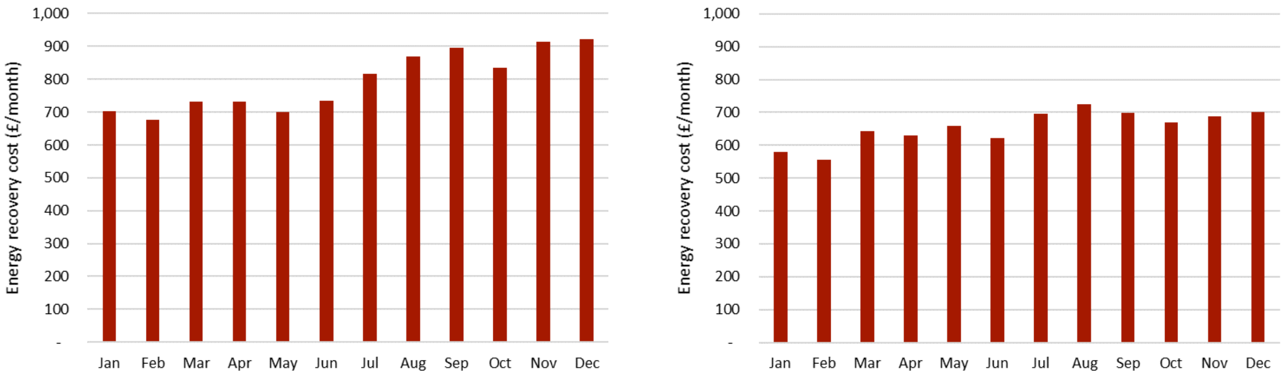


Figure 9: Balancing services and energy arbitrage revenues per month.

It should be noted that the higher from provision of balancing services in the months of January and February are associated with the increased availability prices in those months, and not because of higher committed volumes. Indeed, in the months of May, August and September provision of balancing services is maximised.

Real-time utilisation of balancing services will depend on real-time system frequency deviations and therefore with the possibility of being instructed to provide upwards (i.e. discharge actions) or downwards (i.e. charge actions) by the ES plant. These will have a different impact on the business case for provision of balancing services: (i) provision of upwards balancing services will require ES plant to charge the energy delivered and thus have an additional incurred cost, in contrast, (ii) provision of downwards balancing services will require ES plant to discharge the additional energy – so as to recover its scheduled energy level and thus maintain sufficient headroom capacity – and this will potentially further enhance the revenues associated with provision of balancing services.

These additional costs / revenues will also depend on the time of service delivery – i.e. during the morning (6am to 10am) or afternoon BS window (5pm to 8pm) – and also on the Intra-Day energy price. Figure 10 shows the expected cost associated with recovering ES plant energy levels after delivering upwards service (i.e. discharging actions) at full committed volumes, (a) in the morning BW window, and (b) in the afternoon BS window.



(a) Morning BS window

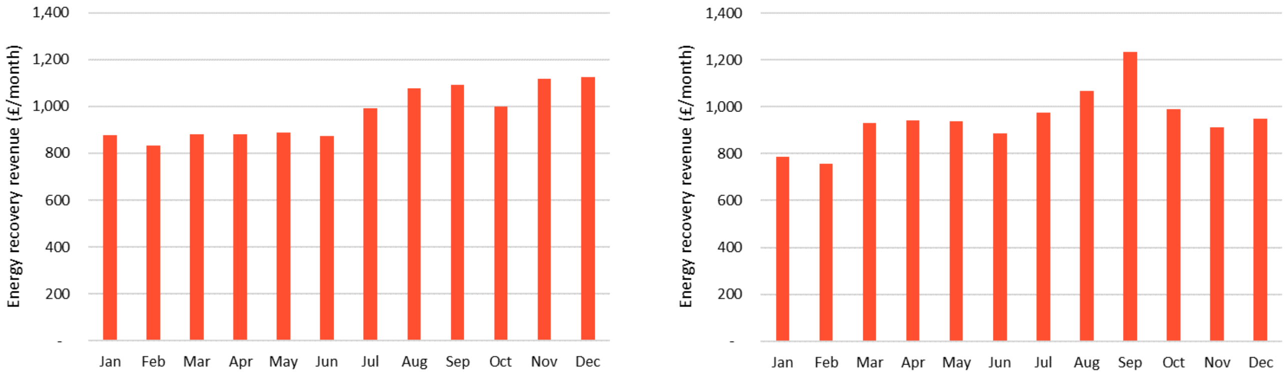
(b) Afternoon BS window

Figure 10: Revenues associated with recovery after delivering upwards service (i.e. discharge actions) in (a) morning and (b) afternoon BS window.

Note the higher costs associated with delivery of upwards balancing service in the morning window, comparatively to delivering the same volumes but in the afternoon window; this is due to two aspects, although related: (i) Intra-Day energy prices are typically higher in value between 10am and 5pm (i.e.

recovery window for provision of balancing services in the morning) when compared to Intra-Day energy prices between 8pm and 6am, and (ii) the recovery window for post-service delivery in the afternoon is longer in time comparatively to the recovery window for post-service delivery in the morning, in other words, the ES plant has more time to select the optimum energy prices after delivering balancing services in the afternoon.

Correspondingly, Figure 11 shows the expected revenue associated with recovering ES plant energy levels after delivering downwards service (i.e. charging actions) at full committed volumes, (a) in the morning BS window, and (b) in the afternoon BS window.



(a) Morning BS window

(b) Afternoon BS window

Figure 11: Revenues associated with recovery after delivering downwards service (i.e. discharge actions) in (a) morning and (b) afternoon BS window.

Fundamentally, the results show that delivery of downwards service is significantly more attractive comparatively to upwards service; the revenues associated with the additional stored energy are considerably higher in absolute value than when providing upwards service. This is essentially due to higher peaks in energy price, and particularly during winter months. Note that to recover its scheduled energy levels after delivering downwards service the ES plant will select the maximum (possible) Intra-Day energy price to do so, whereas after delivering upwards service the ES plant will select the minimum Intra-Day energy price.

PROVISION OF SERVICES TO THE DISTRIBUTION NETWORK OPERATOR

Distributed ES plants can also apply their flexibility potential to support the local DNO to manage network congestion, i.e. provide peak demand shaving service. This is achieved, in principle, by minimising the power flow in the primary substation, and fundamentally by preventing charging actions from the ES plant and potentially require the plant to discharge during peak demand periods.

In this setting, by limiting ES plant flexibility to charge / discharge at optimum price periods – or fundamentally by limiting its operation in order to provide a service to the DNO – there is an opportunity cost associated with these actions. In other words, the ES plant should be remunerated for the service being provided since this effectively undermines ES value proposition on other markets / services. Moreover, DNOs will benefit with such a service (i.e. peak demand shaving) given that network reinforcements can then be deferred (or even avoided).

Figure 12 shows the opportunity cost for providing DNO service – i.e. by constraining ES plant operation to discharge during peak demand periods or limit its charging actions – simultaneously with the other 2 revenue streams from provision of balancing services and seizing arbitrage opportunities in the energy market.

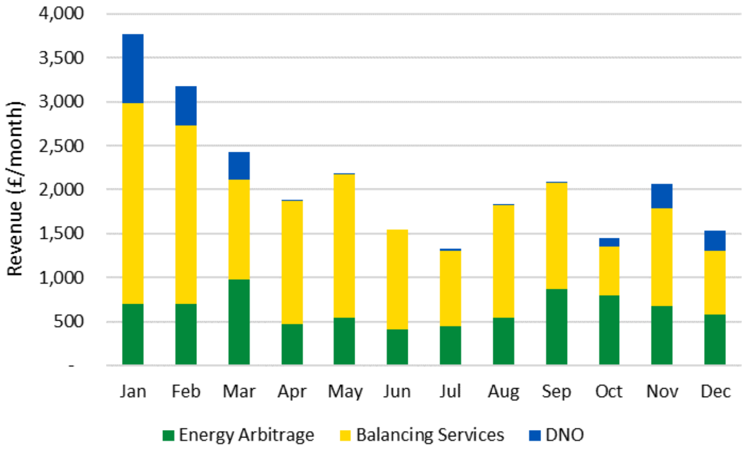


Figure 12: Opportunity cost revenues, per month, for provision of DNO service combined with revenue streams from energy arbitrage and provision of balancing services.

A key aspect presented in Figure 12 is associated with the optimum commercial strategies for ES plants across different market and system conditions. Note that during Summer months, requirements to provide DNO service are not as critical as during Winter months – typically when network is more congested. This suggests that to pursue the optimum commercial strategies, ES stakeholders should consider provision of other (better remunerating) services during summer months, for instance provision of balancing services.

MULTI-SERVICE BUSINESS MODEL

Figure 13 shows the revenue streams (in £ per annum) associated with the optimum portfolio of services to support the local DNO to manage network congestions, provide balancing services to the System Operator and also seize arbitrage opportunities in the Intra-Day energy market. This demonstrates how multiple ES applications to provide services to various market participants can be efficiently co-ordinated during longer-term periods.

Provision of balancing services correspond to contracts auctioned ahead of delivery, i.e. one day-ahead. The model will then co-optimise energy arbitrage revenues at the moment of bidding for balancing services at the beginning of the day using the forward price time series. In contrast to energy and balancing market, DNO service is assumed to be compulsory and, if properly remunerated, it creates an extra revenue stream as shown in Figure 13.

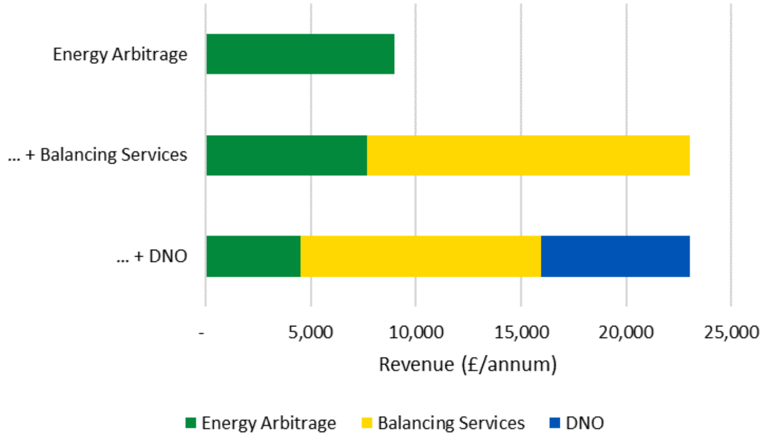


Figure 13: Multi-Service business model revenues for an ES plant.

It is important to note that, as other services are considered in the Business Model and contracted, revenue streams from other contracted services are affected. This is evident in Figure 13 by inspecting (for example) the revenue stream associated with energy arbitrage; as other services are added, for instance balancing services, ES plant power and energy resources are then co-optimised to provide both services and although the overall revenue will improve, individual revenue streams are potentially undermined.

SECTION FOUR

MULTI-SERVICE BUSINESS MODELS FOR ENERGY STORAGE & LOW CARBON GENERATION

In this Section:

- ES value proposition can significantly benefit from being co-located with a low carbon generation plant, particularly with solar PV.
- Co-locating an ES with a wind plant is more beneficial for ES plants with large energy capacities, specifically when the ration between power and energy capacity is superior to 5h.
- The value proposition for co-locating an ES plant with solar PV is maximum in winter months, rather than summer, and this is because of typical patterns of energy prices in winter with more pronounced price differentials than in summer.
- LCG can further benefit from the flexibility offered by ES plants and unlock their potential to provide balancing services.

ES plants are often co-located with intermittent (i.e. low capacity value) generation so as to provide the required flexibility to: (i) improve the business case for low carbon generation (LCG) with volatile outputs and (ii) enhance the capability to participate in other markets, for example in the balancing market by providing frequency regulation products. In this context, the business case for ES plants co-located with a LCG plant is investigated next, namely when co-located with a Wind power plant or a Solar PV plant.

BATTERY ENERGY STORAGE CO-LOCATED WITH WIND PLANT

The intrinsic flexibility associated with charge / discharge actions from the ES plant allows the set (i.e. ES + wind plant) to maximise their combined revenue by selecting the peak priced periods to sell the wind energy to the market; rather than selling it when wind is blowing, and thus subject to non-optimum energy prices. This will hold in the eventuality of wind power output to be comparatively smaller (with respect to total energy output) to the ES plant energy storing capacity – i.e. once the ES plant maximum energy level is reached, wind energy can no longer be stored with the objective to wait for optimum energy prices and thus wind energy is curtailed (commonly known as a *saturation* effect).

Figure 14 shows this particular effect, for both (a) Winter and (b) Summer months, in which adding an ES plant may actually reduce the revenue obtained if wind energy would be directly sold to the market – albeit in a deterministic way[3]. The reason for this, as described, is due to the fact that ES plant energy capacity is insufficient to store all the wind energy produced; and moreover, it is assumed that all the wind energy that cannot be stored by the ES plant is therefore lost (i.e. curtailed). It should also be noted that this effect is more notorious in strong wind conditions, characterised by high wind power outputs such as the case as summer months – as seen in Figure 4.

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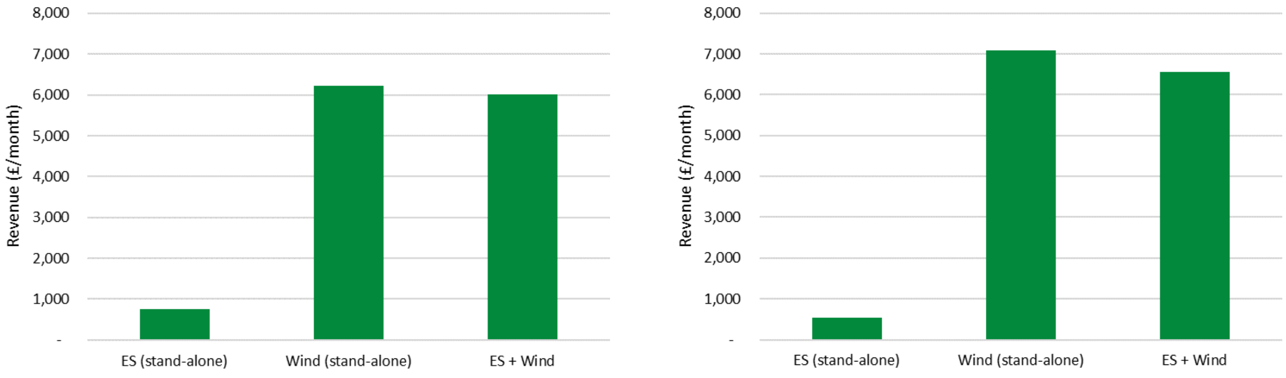
[3] In this case it is assumed that the wind power output is effectively known in advance and any fluctuation / deviations from the expected output ignored. Essentially, a best-case scenario with respect to revenues.



(a) Winter

(b) Summer

Figure 14: Intra-Day energy arbitrage revenues for ES plant (only), Wind plant (only) and ES & Wind plant in (a) Winter and (b) Summer.

Note that, although the maximum wind power output is lower than the ES maximum charging capacity (i.e. 1 MW), in case the wind plant is generating at (for example) just half of its capacity (i.e. 0.5 MW), after a few of hours the ES plant will reach its maximum energy level of 1 MWh. This will limit and constrain the commercial strategies pursued by stakeholders.

To support this, Figure 15 shows the revenue obtained when the wind plant is co-located with different ES plant power and energy capacities. Namely, the sensitivity analysis shows the potential revenue achieved on the Intra-Day energy market, for a month in Winter, with 1, 2, 5,10 MW and 1 MWh, and 1, 2, 5, 10 MWh and 1 MW ES plant – i.e. taking into consideration the ration between ES plant power and energy capacities, these represent respectively 0.1, 0.2, 0.5, 1, 2, 5 and 10h of storing capacity.

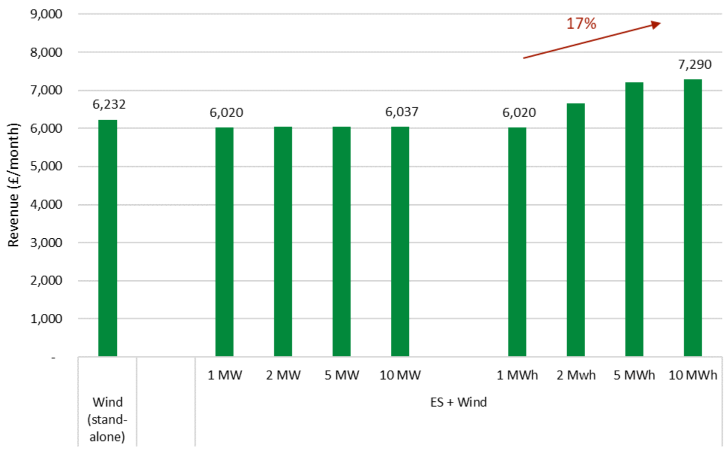


Figure 15: Intra-Day energy arbitrage revenues for ES plant across different power and energy capacities in a month in Winter.

Similarly, Figure 16 shows a similar analysis for a wind plant co-located with an ES plant with different power and energy capacities, namely with 1, 2, 5, 10 MW and 1 MWh, and 1, 2, 5, 10 MWh and 1 MW ES plant.

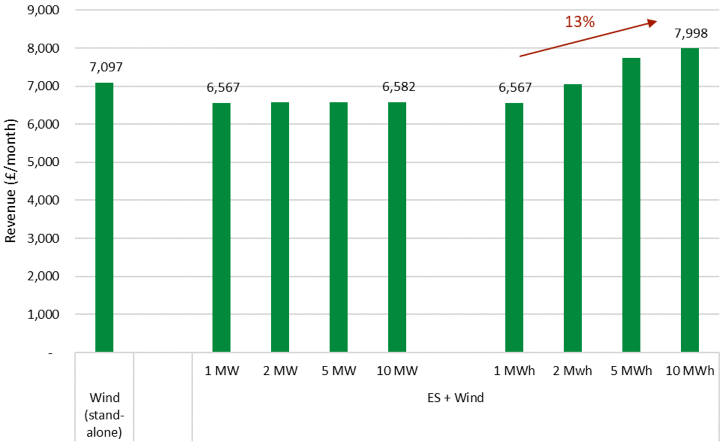
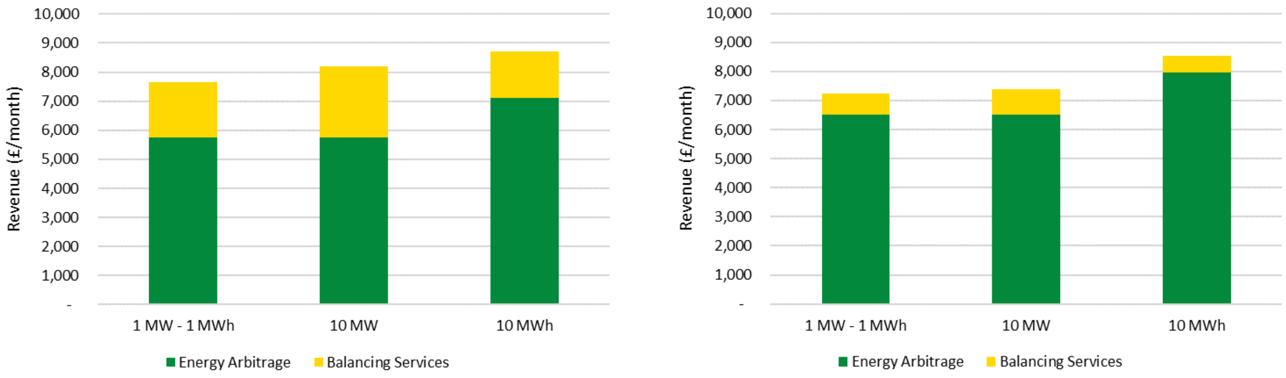


Figure 16: Intra-Day energy arbitrage revenues for ES plant across different power and energy capacities in a month in Summer.

In addition to supporting ES plant revenues in the energy market, LCG can also benefit from the flexibility associated with (controllable) charge / discharge actions. In other words, by co-ordinating operation of ES and Wind plants, operators of (intermittent) LCG plants can then participate in other markets, such the balancing market – which would not be possible given the uncontrollability aspect of intermittent renewable energy sources – and thus secure further revenue streams by providing balancing services.

In this setting, Figure 17 shows the combined revenue streams of ES and Wind plant associated with balancing services and energy arbitrage in a month in (a) Winter and (b) in Summer, across three different ES plant energy and power capacities, respectively 1 [MW] - 1 [MWh], 10 [MW] - 1 [MWh] and 1 [MW] - 10 [MWh].



(a) Winter *(b) Summer*

Figure 17: Intra-Day energy arbitrage and balancing service revenues for ES & wind plant in (a) Winter and (b) Summer, and considering different power and energy capacities.

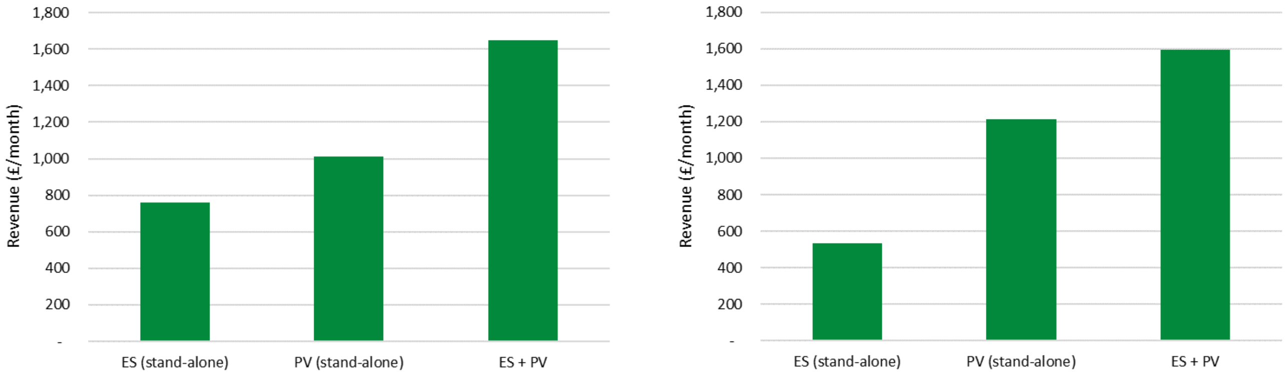
Note that, as expected, increasing ES plant charge / discharge (power) capacity allows for higher revenues for provision of balancing services. In contrast, an increased ES plant energy capacity allows for higher revenues associated with seizing arbitrage opportunities in the energy market. This is because, provision of balancing services is often associated with intense but short power deliveries, in other words, higher requirements for power availability than for energy storing capacity. On the other hand, as demonstrated in Figure 15 and Figure 16, increasing ES plant energy capacity allows for more wind energy to be stored and later sold at optimum energy prices in the Intra-Day energy market.

Battery Energy Storage Co-Located with Solar PV Plant

As demonstrated in Section Two, power output profiles for wind and solar PV plants are significantly different and therefore will have a different impact on the value proposition for co-locating ES plants with a LCG plant. Therefore, the business case for ES plant co-located with a Solar PV plant is investigated next.

Similarly to the case in which ES is co-located with a wind plant, the intrinsic flexibility associated with charge / discharge actions from the ES plant allow the set (ES plant + solar PV plant) to maximise their combined revenue by selecting the peak-priced periods to sell the energy to the market. However, since power outputs from solar PV plants are limited to a few hours in the day (i.e. high radiance hours), the ES plant energy capacity is capable to store the majority of solar energy output and thus the saturation effect seen in Figure 14 (with a wind plant) is thus eliminated.

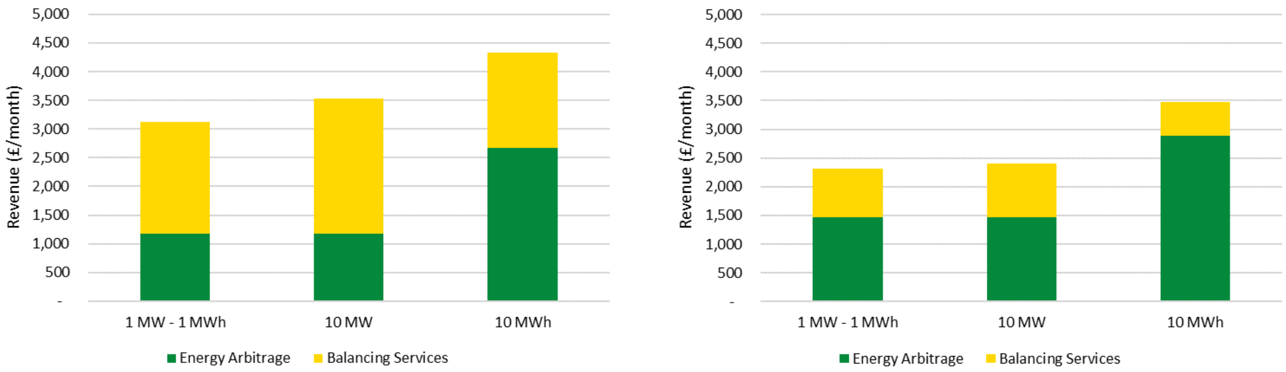
Figure 18 shows, for both (a) Winter and (b) Summer months, the revenue obtained by an ES plant (only), solar PV plant (only) – i.e. considering that all energy produced is promptly sold at the current market price – and finally the total revenue for the set ES + solar PV plant.



(a) Winter *(b) Summer*

Figure 18: Intra-Day energy arbitrage revenues for ES plant (only), solar PV plant (only) and ES & solar PV plant in (a) Winter and (b) Summer months.

Note that, in contrast to the case in which ES is co-located with a wind plant, the value proposition with a solar PV plant differs from winter and summer months. It can be seen that the increase in revenue in winter is significantly higher than in summer, and this is because of typical energy price patterns in summer and winter months; note that in winter there is a significant increase in value by storing and later selling the energy to the market at peak priced periods, however energy prices in summer are usually lower in absolute value and also with lower price differentials, and therefore the increase in value is not so pronounced.



(a) Winter *(b) Summer*

Figure 19: Intra-Day energy arbitrage and balancing service revenues for ES & Solar PV plant in (a) Winter and (b) Summer, and when considering different power and energy capacities.

SECTION FIVE

CONCLUSION

In this Section:

- Through a multi-service business model, ES stakeholders can reduce their exposure to uncertainty and volatility in the Intra-Day energy market, while improving the value proposition of ES plants.
- The potential electrification of the heat and transport sectors is expected to further enhance the benefits that flexibility providers can deliver to distribution, but also, transmission network operators.
- ES plants can further enhance the value proposition of LCG by maximising the combined revenues in the Intra-Day energy market, but fundamentally by unlocking the potential to participate in other markets / services – for instance balancing services.
- There is a range of other technology options – e.g. demand side flexibility - that can also be applied to support system and network operators in their business activities, as well as complement ES plants and further enhance the flexibility offered.

ES plants can deliver benefits to several sectors in the electricity industry, including generation, transmission and distribution, while providing services to support real-time balancing of demand and supply, network congestion management and reduce the need for investment in system reinforcement.

In this context, the developed model was applied to assess and analyse the value proposition of ES plants in providing multiple services and derive adequate commercial strategies that co-optimise various services / applications for managing distribution network congestion and providing services in energy and balancing services markets.

The developed model demonstrates that significant revenue streams will be associated with the provision of balancing services. Such preference is not only driven by the higher prices of balancing services, but also by market conditions associated with other (alternative) services. It has been demonstrated that provision of balancing services can improve the value proposition of ES plants, particularly if energy prices' differentials (i.e. energy market conditions) are not favourable; besides, ES stakeholders can also reduce revenue volatility and uncertainty in such market conditions. Fundamentally, by providing other concurrent services while seizing energy price arbitrage opportunities in the Intra-Day energy market, ES stakeholders can reduce their exposure to uncertainty and revenue volatility.

In addition, both upwards and downwards balancing services – i.e. respectively, discharge and charge actions - can be co-ordinated and provided concurrently while managing ES plant energy and power resources to provide other services. Provision of balancing services leads to a steady operation of storage driven by the need to offer fixed daily availability profiles of balancing services – i.e. symmetrical volumes for upwards and downwards products. Such steady operation of ES plant can be co-ordinated with other markets, energy arbitrage and DNO service in a cost-effective way.

DNO service (i.e. peak demand shaving) at the primary substation can help to defer network reinforcements and so materialise potentially significant savings in capital cost associated with DNO infrastructure. As demonstrated, by providing DNO service, ES plant is fundamentally limited to participate in other (higher remunerative) services and therefore there's a significant opportunity cost associated with it. Nonetheless, it should be emphasized that the potential cost savings for the DNO are expected to significantly increase as the UK moves to a net-zero carbon economy; the potential electrification of the heat and transport sectors will require considerable reinforcements of the distribution network, and potentially at the transmission level too thus benefiting the transmission network operator as well.

The integration of flexibility assets with LCG (such as wind or solar PV plants integrated with an ES plant) can enhance the value proposition for both assets. Fundamentally, co-locating an ES plant with intermittent LCG can maximise the revenues obtained through the energy market, and this is because ES plants can store the relatively low cost and low carbon energy from renewable generation and then select optimum market conditions (i.e. highest energy prices) to maximise stakeholder's revenues. Nevertheless, the relative size of the ES plant – particularly with respect to its energy capacity – in comparison to the LCG plant, may limit the overall value proposition of the set (ES plant + LCG). The results have shown that in order to take full advantage of the ES plant flexibility, its ration between energy and power capacities should be superior to 5h, especially when co-located with a wind power plant.

Furthermore, by combining the flexibility of an ES plant with intermittent LCG can unlock the potential for renewable generation to participate in other markets / services – such as balancing services. It has been demonstrated that ES plant can co-ordinate provision of balancing services – both upwards and downwards products – when co-located with a wind or solar PV plant and thus enhance their combined value proposition.

In addition to ES technologies, there is a range of other potentially available technology options that could contribute to real-time system balancing, support the security of supply and mitigate investment in infrastructure reinforcement. Different levels of generation flexibility, interconnection and demand side flexibility, and even electric vehicles with V2G (vehicle-to-grid) capabilities, can also be applied to support system and network operators in their business activities and also enhance the business case for flexibility providers. Particularly when participating in the Cornwall Local Energy Market (CLEM). Moreover, some of these solutions can be complementary to ES plants and further enhance the flexibility offered.

This work and developed modelling framework will support the mission of the CLEM project that will address the "split benefits" challenge and provide insights associated with the development of appropriate market mechanisms to ensure that investors in ES and other flexibility assets are adequately rewarded for the delivery of diverse sources of value in distributed electricity markets.

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