ESP Consulting

Frequency Response Auction Trial

Evaluation Report

Prepared for:

nationalgridESO

Issued: 27 July 2020
Status: Final v 1.0
Security: For release to ESO

Prepared by: ESP Consulting
Prinsengracht 846
1017 JM Amsterdam
The Netherlands

Website: www.esp-consulting.co.uk

Registered in Amsterdam
Company number: 53837045

Executive Summary

National Grid Electricity System Operator ("the ESO") contracted ESP Consulting to conduct an initial evaluation of the Phase 2 Frequency Response Auction Trial. The scope of the evaluation included the design of the auction, auction participation and liquidity, the ESO bid submission and the participant offer submissions, auction results, and the EPEXSPOT auction platform and clearing algorithm. Additionally, the Roadmap for the development of the Auction Trial over its remaining duration was reviewed. The evaluation was conducted off-site between March and May 2020. The evaluation activities included a review of publicly available auction results as well as results from the monthly FFR tender, review of publicly available documents on the ESO website, interviews with ESO staff members responsible for supporting the auction, an interview with auction experts at EPEXSPOT, a survey of auction participants, and follow-up interviews with certain survey respondents. This evaluation report, prepared by ESP Consulting, outlines the findings of our analysis and summarises the feedback of auction participants. We also make recommendations for improvements to the current activities of the Auction Trial and for its planned development.

In our opinion, the Phase 2 Auction Trial has had a successful launch. Operations have been robust over the first six months, and the auction clearing algorithm has performed well. Participants are well-engaged with the Auction Trial, and their feedback is generally positive, although provider sentiment varies.

Liquidity in the DLH auction is growing steadily in terms of the number of companies, number of registered units, volumes of response offered, and volumes of response cleared. The DLH service interacts strongly with the monthly FFR tender and most auction participants optimise between the two routes to market. Liquidity in the LFS auction is lower and growth seems to have stalled. The product designs for DLH and LFS, as well as the design of the market, have created a number of barriers to entry to the auction for certain participants.

The ESO's requirements have been fixed at 100 MW for each of the DLH and LFS orders since the launch of the Phase 2 Auction Trial, while their capped bid price is generally constant from week to week. The ESO's bid is therefore static and is not optimised based on the learnings from the outcomes of prior auctions. The objective of "closer-to-real-time" procurement has not been tested by the Auction Trial.

Over recent months, the average cost of DLH in the auction has cleared at a level roughly equal to, or slightly below, the average cost of an equivalent bundle of services in the monthly FFR tender. Participants are concerned by the low auction clearing price outcomes, especially for the DLH product, which they perceive to be a consequence of the low requirements (100 MW) and the low ESO bid prices relative to average tender prices. Clearing price formation for the LFS auction is not competitive because the offered volumes of LFS seldom exceed the ESO's bid volume of 100 MW.

The auction design provides participants with diverse possibilities for the design of their orders. The participants have continually modified and adapted their approaches to the formation of block orders over the course of the Phase 2 Auction Trial. The HELENA clearing algorithm developed by EPEXSPOT meets the functional requirements agreed with the ESO. The algorithm design includes certain optimisation constraints

which have had the effect of rejecting some block orders in clearing despite those orders offering higher surplus than competing, accepted offers.

Auction participants are broadly positive regarding the auction platform and the weekly operational process, although they suggest that the user interface of the auction platform should be improved to better facilitate the submission of offers. The transparency of the auction, in terms of algorithmic matching of orders and comprehensive data publication, gives confidence to providers. Participants are appreciative of the support process for the auction and of the responsiveness of the ESO to queries, but they feel that auction documentation is inadequate.

In our evaluation of the Phase 2 Frequency Response Auction Trial against its success criteria, we note that the auction has afforded the ESO a good opportunity to learn about price formation in pay-as-clear auctions. The ESO can enhance this learning over the remaining duration of the Trial by removing barriers to entry, and flexing their bid prices. We further note that both the ESO and providers have had the opportunity to learn about the necessary operational processes to support an algorithmically-cleared auction for standardised services, and participants have provided quality feedback in this area to both improve the weekly auctions and to support the development of daily auctions. Regarding the ESO's ambition to enhance understanding of closer-to-real-time procurement, this has not yet been achieved. The ESO's auction bid is not reflective of current market conditions.

We make a number of recommendations to mitigate current issues with the Auction Trial and to progress the development of the Trial over its remaining duration.

With respect to the current auction operations, we recommend the ESO to review and clarify its approach to setting bid prices, and to implement an elastic bid curve instead of a bidding a single price for all requirements. We also recommend that the ESO review their fixed requirement of 100 MW per product. The target volume of frequency response to be procured by auction should be reviewed and published each month, and this requirement should be re-optimised before each weekly auction based on an updated forecast of actual frequency response requirements in each EFA period. We advise the ESO to eliminate the 20 MW unit volume cap.

With respect to the future market design, we advise the ESO to study the capability of industry to deliver the end-state frequency response product suite, in order to ensure a stable migration to the new products and to fully optimise industry's capabilities to provide frequency response. The new product suite will require an extension to the functionality of the auction clearing algorithm, such as the capability for providers to submit mutually-exclusive orders. The planned residual auction functionality may be useful for the ESO to satisfy particular requirements, such as the management of geographical constraints, while still adhering to the vision of standardised frequency response products. We suggest that the HELENA clearing algorithm should be enhanced to allow providers to indicate their requirement to link stackable services, such as separate low-frequency and high-frequency response services. We also suggest that some of the constraints on the clearing algorithm should be relaxed to better optimise auction outcomes.

Contents

1. Introduction to this Evaluation

1.1 Background to the Frequency Response Auction Trial

1.1.1 In the GB market, frequency response is procured by National Grid Electricity System Operator ("the ESO"). Historically, commercial procurement has been via long-term tenders or through a monthly pay-as-bid tender. In 2018 the ESO began development of the Frequency Response Auction Trial, which is an exercise to trial the procurement of frequency response with a weekly, pay-as-clear auction for standardised services. Phase 1 of the Trial began in June 2019 with a weekly auction for procurement of frequency response on an in-house platform. Phase 2 of the Trial commenced at the end of November 2019 with the release of a bespoke auction platform and clearing algorithm implemented by EPEXSPOT, who also act as the independent auction administrators for Phase 2. The Auction Trial is partially supported by an award from the Electricity Network Innovation Allowance scheme, who contributed to the development costs of the auction platform and clearing algorithm.

1.1.2 The Auction Trial is expected to demonstrate the impact of a closer-to-real-time approach for procurement of frequency response on market participation, market liquidity, and overall procurement cost. It is believed that month-ahead tendering for balancing services such as frequency response creates a barrier to market participation by non-traditional providers, such as intermittent generators. Such technologies cannot predict their availability over the duration of time covered by the monthly tender cycle, and therefore they cannot confidently offer services into the tender. The rapid pace of change of the GB electricity system has resulted in a significant increase in the number of these non-traditional providers.

1.1.3 The Auction Trial is also expected to demonstrate the benefits of product standardisation on the ESO's internal business process for procurement of frequency response. The services that participants may offer into the monthly FFR tender are not completely standardised. There is a manual process to evaluate these monthly tender offers, which is becoming increasingly unmanageable as the number of providers grows. The Trial therefore supports the development of the ESO's current system and process landscape to enable the stated RIIO-2 ambition of a single platform for procurement of services and a day-ahead market.

1.1.4 Given the above, the success criteria for the Frequency Response Auction Trial are:

- to enhance understanding of how closer to real time procurement can result in reduced barriers to entry and increased market liquidity, compared to the current procurement approach;
- to enhance understanding of how closer to real time procurement can result in more accurate procurement decisions due to increased certainty of requirements;
- to enhance understanding of market behaviour driven by pay-as-clear weekly auctions, compared with longer-term pay-as-bid tenders;
- to support the transition towards day-ahead auctions, through understanding market behaviour and business processes;
- to ensure provider satisfaction with the auction platform, operational processes, and transparency of results; and

- to realise time and cost savings for the ESO, compared to the current procurement approach.

1.1.5 The ESO published its Response and Reserve Roadmap at the beginning of December 2019. The Roadmap updates previous ESO publications relating to the reform of the ancillary services market, and of frequency response services in particular. Among other commitments, the Roadmap outlines the plans of the ESO for the Auction Trial over its remaining duration. The Roadmap commits to increase the volume of frequency response procured on the platform, introduce new frequency response products, and trial day-ahead auctions.

1.2 Evaluation Objectives, Scope, and Approach

1.2.1 ESP Consulting was contracted by the ESO to conduct an initial evaluation of the Phase 2 Frequency Response Auction Trial, including the current operations of the Trial as well as the plan for the development of the Auction Trial over its remaining duration. The objective of the evaluation was to identify the elements of the auction that are working well and the elements that are deficient, and to make actionable recommendations to improve the auction outcomes and enhance the deliverability of the Roadmap milestones.

1.2.2 The scope of our evaluation included the overall design of the market for commercial frequency response; auction participation and liquidity; the ESO auction buy order in terms of prices and volumes; participant behaviours (in terms of sell order submissions); auction results (prices and cleared volumes); and the EPEXSPOT auction platform and clearing algorithm. We considered the current experience of these aspects as well as planned developments. Appendix A elaborates the scope of this evaluation further.

1.2.3 Our evaluation was conducted off-site between March and May 2020. The evaluation activities included:

- engagement with the ESO staff members responsible for supporting the operations of the Auction Trial and the implementation of the Roadmap deliverables;
- an online survey of auction participants regarding their experiences of the Auction Trial, together with follow-up telephone interviews with the survey respondents;
- analysis of the Phase 2 Auction Trial market transparency data (participant offers, ESO bids, and auction outcomes as available on the ESO website) from the go-live in end-November 2019 up to and including EFA Day 29 May 2020;
- analysis of the market transparency data for the monthly tender (“FFR Market Information”) published on the ESO website;
- an interview with auction experts at EPEXSPOT;
- review of the Guidance Documents and Legal Documents supporting the Auction Trial, as available on the ESO website; and
- review of the Response and Reserve Roadmap.

1.2.4 The findings and recommendations in this document were informed by the sources and evidence above.

1.3 Outline of this Evaluation Report

1.3.1 In this evaluation report we outline our findings with respect to the current operations of the Auction Trial and our recommendations for improvement of the Trial and its planned future developments. Our analysis and opinions have been informed by discussions with the ESO and with auction participants, who have made numerous insightful suggestions to improve the auction design and the market for frequency response. We hope that the ESO and providers of frequency response will find our advice useful to progress the development of the Auction Trial.

1.3.2 In **Chapter 2** we present the results of our own analysis of the Auction Trial, together with summaries of participant feedback from the online survey and telephone interviews. We outline our findings with respect to market and auction design, auction participation and liquidity, the auction clearing algorithm, participant and ESO orders, auction price outcomes, and the design of the online auction platform and weekly auction process.

1.3.3 In **Chapter 3** we present our overall evaluation of the Auction Trial and relate our findings back to the success criteria of the Trial.

1.3.4 We present our recommendations in **Chapter 4** and **Chapter 5**. In Chapter 4 we recommend enhancements that the ESO can implement within the current design of the auction in order to remove barriers to entry, encourage greater participation, and improve the overall outcomes of the auction. We believe that these steps would not require further development work by EPEXSPOT nor changes to the operational processes of the auction participants. These recommendations may, however, imply additional development of ESO modelling capabilities or changes to internal ESO business processes. In Chapter 5 we offer suggestions to support the implementation of the milestones in the Roadmap for Response and Reserve, to develop and extend the functionality of the auction clearing algorithm, and to improve the market design for frequency response.

1.3.5 **Appendix A** elaborates the scope of this evaluation. **Appendix B** details the online participant survey. **Appendix C** contrasts, at a very high level, the market design of the monthly tender and the weekly auction. **Appendix D** briefly summarises our understanding of the HELENA algorithm developed by EPEXSPOT for clearing of the Auction Trial. **Appendix E** provides some theoretical background information on pay-as-clear auctions.

2. Observations and Experience of the Auction Trial To-Date

2.1 Overview and Summary of Key Findings

2.1.1 In this chapter, we present the results of our analysis of the operations and results of the Phase 2 Frequency Response Auction Trial over the first six months of activity, from the first auction on 29 November 2019 through the auction of 22 May 2020 (including delivery up to EFA Day 29 May 2020). We also summarise, under each relevant section heading, the consensus view of the participants (or, in some cases, the majority view and dissenting opinions) based on the feedback in the participant survey and follow-up interviews.

2.1.2 In our opinion, the Phase 2 Auction Trial has had a successful launch. Operations have been robust over the first six months. Participants are well-engaged with the Auction Trial, and their feedback is also positive overall, although providers varied widely in their sentiment. All participants were candid in their assessment of the auction and constructive in offering recommendations.

2.1.3 We found that liquidity in the DLH auction is growing steadily in terms of the number of companies, number of registered units, volumes of response offered, and volumes of response cleared. The standardised DLH service is similar to the dynamic services in the monthly FFR tender and there is interaction and substitution between the two routes to market, with most participants first seeking a contract in the monthly tender to secure revenue and mitigate risk. Tender results are therefore a significant driver of auction liquidity. Liquidity in the LFS auction is lower and growth seems to have stalled. There is less interaction between the static auction and FFR tender services due to larger differences in the service terms for static response between the two markets. The product designs for DLH and LFS, as well as the design of the market, have created a number of barriers to entry to the auction for certain participants.

2.1.4 Over recent months, the average cost of DLH in the auction has cleared at a level roughly equal to, or slightly below, the average cost of an equivalent bundle of the “P”, “S”, and “H” services in the monthly tender. Participants are concerned by the low auction clearing price outcomes, especially for the DLH product, which they perceive to be a consequence of the low requirements (100 MW) and the low ESO bid prices relative to average tender prices. Clearing price formation for the LFS auction is not competitive because the offered volumes of LFS almost never exceed the ESO’s bid volume of 100 MW.

2.1.5 The volumes and prices in ESO’s buy order are static and unchanging from week to week. The auction is therefore not “double-blind” because the ESO’s bid is very transparent to market participants. The benefits of “closer-to-real-time” procurement are not proven as the ESO’s bid is not re-optimised based on up-to-date information.

2.1.6 The design of the auction provides a very rich feature set to participants for the design of their orders. The participants have continually modified and adapted their approaches to the formation of block orders over the course of the Phase 2 Auction Trial. The HELENA clearing algorithm developed by EPEXSPOT meets the functional requirements agreed with the ESO. The algorithm design includes certain optimisation constraints which have had the effect of rejecting some block orders in clearing despite those orders offering higher surplus than competing, accepted offers.

2.1.7 Auction participants are broadly positive regarding the auction platform and the weekly operational process, although they suggest that the user interface of the auction platform should be improved to facilitate better the submission of offers. The transparency of the auction, in terms of algorithmic matching of orders and comprehensive data publication, gives confidence to providers. Participants are appreciative of the support process for the auction but feel that documentation is inadequate.

2.2 Auction Participation

2.2.1 Market interest in the Phase 2 Auction Trial has grown modestly but steadily since the end of November 2019, when 7 companies participated in the inaugural auction. Over the first 6 months of the Phase 2 Trial, the number of providers who have participated in at least one weekly auction has increased to 16. The number of units offering frequency response in the Trial has grown commensurately, as illustrated in the graphs below. **Figure 2-1** shows the number of distinct units offering DLH in each auction (the columns, labelled "Active"), as well as the cumulative total, i.e. the number of units that have offered DLH at least once (orange line, labelled "Eligible"). **Figure 2-2** shows similar information for units offering LFS. Note that units that have offered both the DLH and LFS services are included in both totals. The impact of this increased participation on market liquidity and on the volume of MWs of response offered is discussed in Section 2.3 below.

Figure 2-1: *DLH Participation by unit*

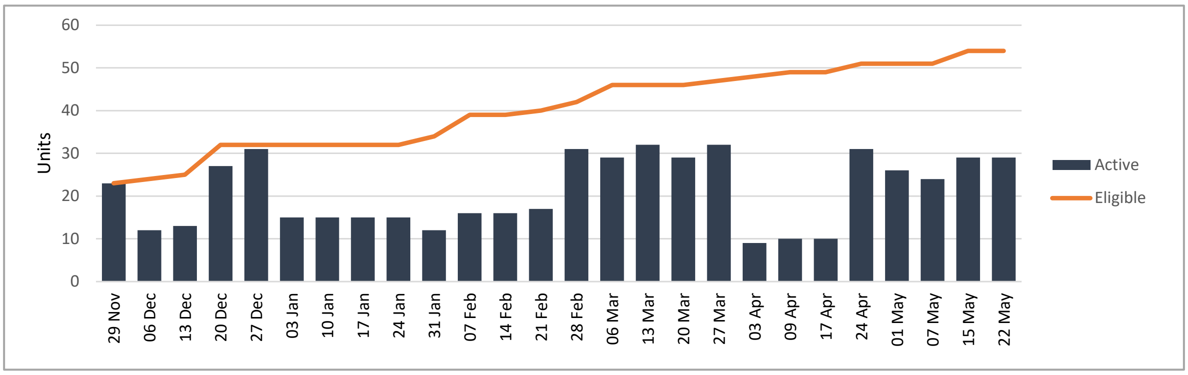
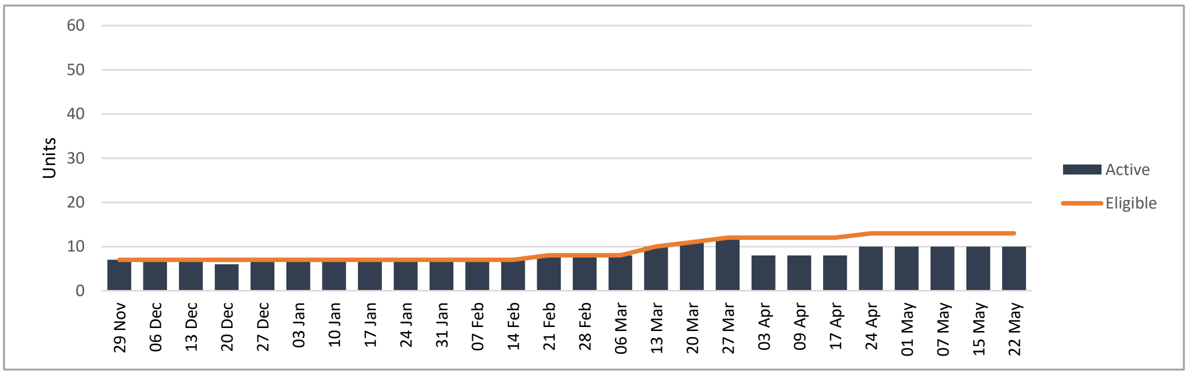


Figure 2-2: *LFS Participation by unit*



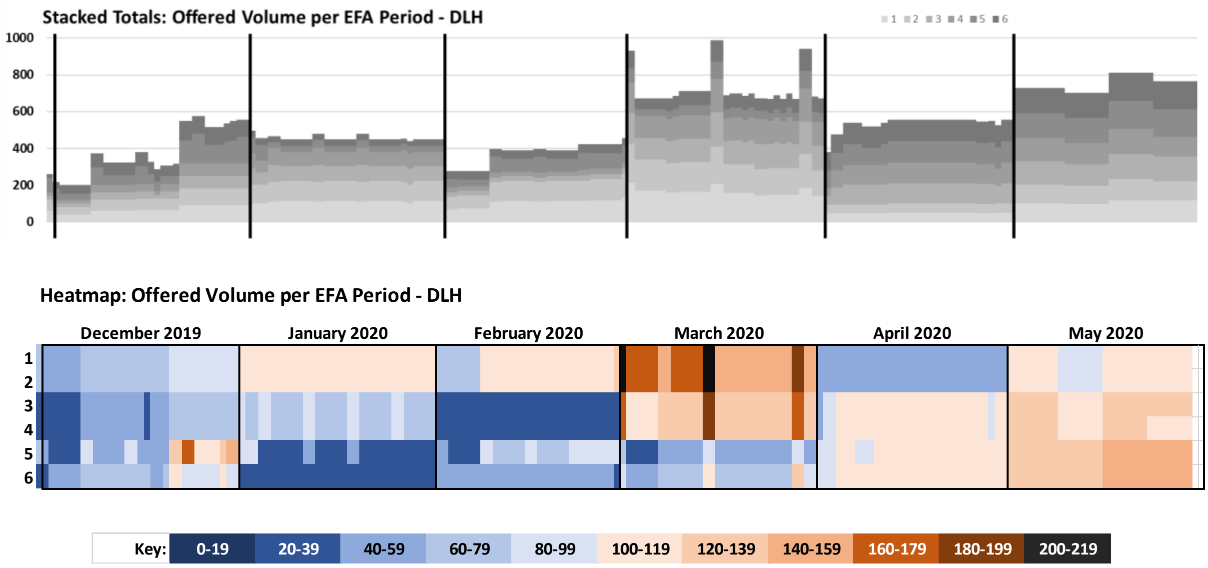
2.2.2 The gap between the "Eligible" units (which have offered the service at least once) and the "Active" units (offering the service in a particular auction) is often significant, especially for the DLH service. In many weekly auctions, fewer than half of Eligible units are participating, and in April this statistic fell to approximately 20%. We understand that, in most cases, the missing units have been successful in the monthly FFR tender. This interaction between the monthly FFR tender and the weekly auctions is an important driver of auction outcomes, and we explore this further in Section 2.5.

2.2.3 The gap between Eligible and Active units is much smaller in the LFS auctions. Switching between the monthly tender and the weekly auction is more difficult for the LFS service than for DLH because the service terms for the LFS auction product are very different from those for the non-dynamic FFR service in the tender. The auction requires a much faster response, and has a different frequency trigger point.

2.3 Auction Liquidity Outcomes

2.3.1 The graphs below show the total capacity of frequency response offered in each EFA period over the first 6 months of operation of the Trial. The “Stacked Totals” graphs show the total offered volumes in each EFA Day (sum of offered volumes in MW/h over the 6 EFA periods). The lightest grey blocks at the bottom of the graph show the volumes in EFA period 1, and the darkest grey blocks at the top show EFA period 6. These same data are presented again in the “Heatmap” graphs, with volumes coloured in blue shades representing less than 100 MW offered in total in the EFA period, and volumes coloured in orange shades representing 100 MW or more. Lightest shades represent volumes close to 100 MW, while the darkest shades of blue and orange represent the most extreme values, small or large.

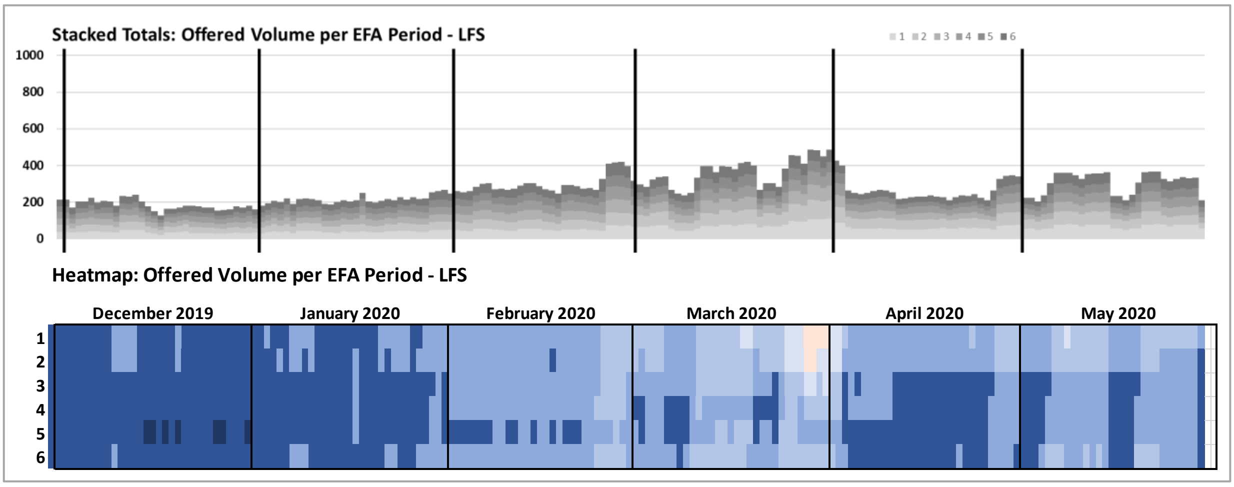
Figure 2-3: *DLH Offered Volume Analysis*



2.3.2 The two graphs above show offered volumes for the DLH product. Offered volumes of DLH have a generally increasing trend over the 6 months of the Trial. March 2020 showed a significant increase over February, but volumes decreased again from March to April. Volumes recovered in May, which is the first month when nearly every EFA period had more than 100 MW offered (with only a few exceptions).

2.3.3 What is striking about the above graphs is the adherence of their behaviour to calendar months. Step changes in offered volumes occur between calendar months, even when the first of the month falls in the middle of the delivery period of a weekly auction. This is significant because it demonstrates that the DLH auction outcomes are closely tied to the cycle of the monthly tender, and thus not instructive of “closer-to-real-time” procurement. We elaborate this point in Section 2.5 below.

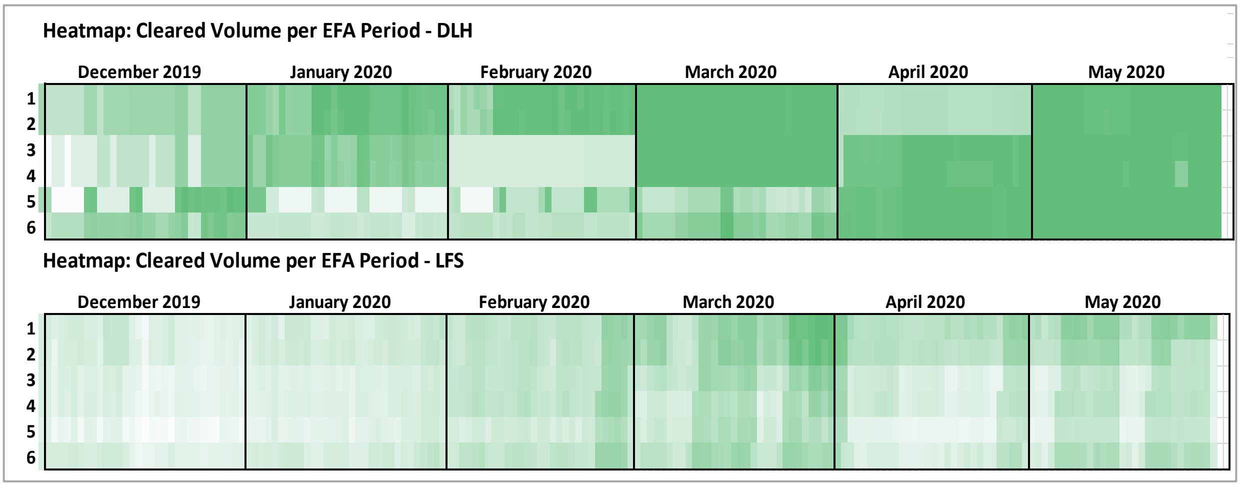
Figure 2-4: LFS Offered Volume Analysis



2.3.4 We now consider the LFS product, whose offered volumes are shown in the graphs above. Liquidity in the LFS product has generally been disappointing, with offered volumes exceeding the bid volume of 100 MW in EFA periods 1 and 2 in only a few days in March. Offered volumes were greatest in late February and in March 2020, and have declined since then. Compared to the DLH product, the liquidity of the LFS product does not seem so closely linked to a cycle of calendar months.

2.3.5 The heatmaps below illustrate the cleared volumes in the DLH (top) and LFS (bottom) auctions. Darkest green indicates 100 MW of frequency response cleared in the EFA period, while lighter shades of green indicate lower cleared volumes. May 2020 was the first month where 100 MW of DLH was cleared in almost all of the EFA periods. The LFS auction has cleared 100 MW in only a small number of EFA periods at the end of March 2020, after which cleared volumes declined in line with offered volumes.

Figure 2-5: *Cleared Volumes*

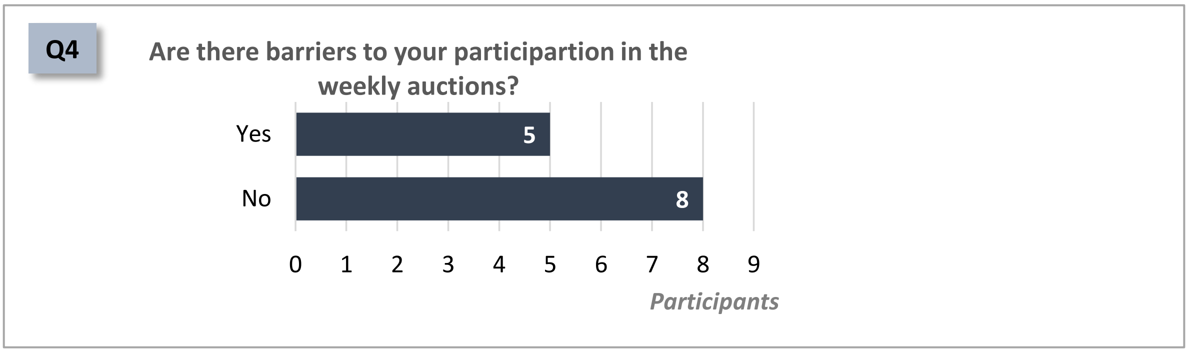


2.4 Barriers to Auction Participation

2.4.1 There are material differences between the monthly tender and weekly auction which may impact the eligibility of a unit to participate in the auction. In our survey and interviews with participants, providers mentioned various barriers to their full participation. These barriers include, for example:

- Auction participation is capped at 20 MW per unit. Units larger than this maximum may participate up to 20 MW, but success in the auction would obviously mean stranded capacity for the portion of the unit above 20 MW. There is no cap on unit size in the tender.
- The standardised design of the DLH auction product requires the offered quantity of low-frequency response to equal the offered quantity of high-frequency response. Units whose capabilities are asymmetric may participate in the auction but may offer only up to the lower of their capabilities of low-frequency or high-frequency response (leaving their remaining capacity stranded). Obviously, units with the capability to deliver only low-frequency response but no high-frequency response (or vice-versa) may not participate in the auction at all. In the tender, units may offer the "P", "S", and "H" services separately or in combination.
- The LFS auction product is specified differently from the non-dynamic tender service. For example, the LFS auction product requires a sub-second response time, while the tender service requires a unit to begin to respond within 10 seconds and to respond fully within 30 seconds. The frequency trigger for response is 49.7 Hz in the tender and 49.6 Hz in the auction. Tender participants who wish to offer LFS in the auction must have their units re-tested (at their own expense) to demonstrate the capability of their units.
- When registering an aggregated unit in the auction, participants must supply detailed information about the subunits (such as MPANs, physical locations, etc.). The ESO does not require this level of detail for participation in the monthly FFR tender. GDPR compliance obligations may therefore restrict by aggregated units that include residential assets from participating in the Auction Trial.

Figure 2-6: Survey Reponses

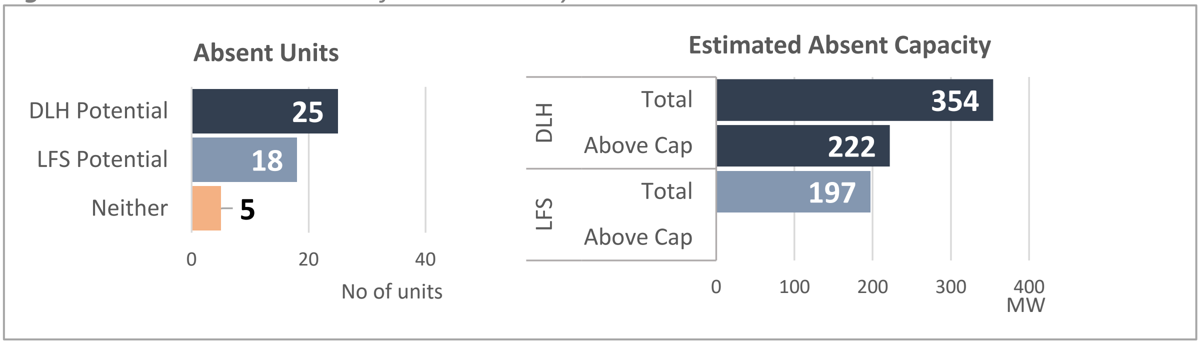


2.4.2 The above list of differences between the tender and auction services is non-exhaustive. There are additional divergences that were not specifically mentioned as barriers by survey respondents, such as differences in settlement terms, differences in contract language with respect to performance monitoring, etc.

2.4.3 When auction participants are confronted with such barriers, they either participate in the auction with only a portion of the assets in their portfolios, or with a portion of the capacity of their assets. Some tender participants find the barriers to be too high to justify participating in the auction at all.

2.4.4 We have analysed the participation in the monthly FFR tender and in the Auction Trial to determine how much additional participation could potentially be expected in the auction, assuming that all barriers are removed and all tender providers are interested in joining the auction. We identified those units that have recently offered frequency response in the monthly FFR tender but have never participated in the auction. Our results here might have some inaccuracies because units are often registered for participation in the auction with a different unit ID than is used in the monthly FFR tender. We have done our best to map FFR tender unit IDs to Auction Trial unit IDs, but to the extent that we have failed to identify units in the tender and auction as being the same, the figures below will be overstated. Nonetheless, we trust that the overall magnitude of the figures will give an indication of potential additional auction liquidity.

Figure 2-7: *Tender units absent from the weekly auctions*

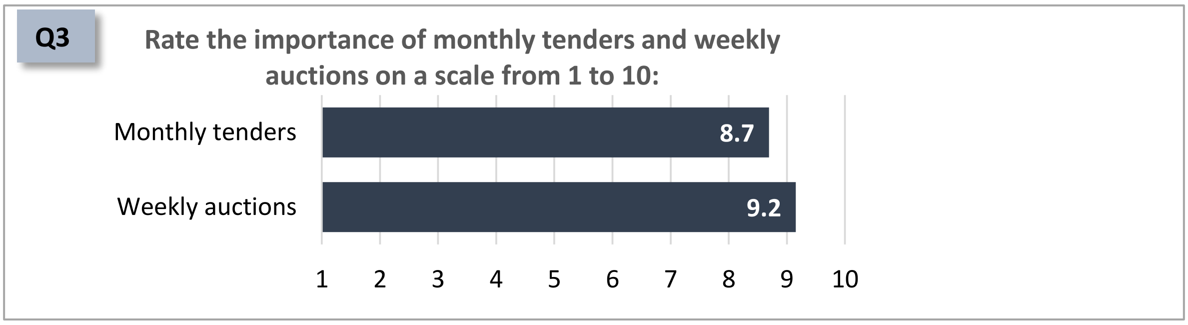


2.4.5 **Figure 2-7** above shows the potential for additional participation in the auction. As of May 2020, we found that over the duration of the Phase 2 Auction Trial (i.e. since end-November 2019), 43 units had recently participated in the monthly FFR tender but had never participated in the auctions. Of these, 25 units provide a dynamic service, with a potential capacity of 354 MW, including 222 MW provided by units larger than 20 MW. An additional 18 units provide 197 MW of static service, but we do not know how much of this is also eligible to participate in the auction, given the requirement for a faster response time for the auction service. Finally, there are 5 dynamic units that do not provide all of the “P”, “S”, and “H” services (labelled “Neither” in the “Absent Units” chart), which we assume will not offer capacity in the auction.

2.5 Interrelated Behaviours of Monthly Tender and Weekly Auction

2.5.1 The above analysis of the auction liquidity and unit participation illustrates the dependency of activity in the auction on the tender results for the same delivery month. This dependency is stronger for the DLH product, because units which supply this service can also supply the dynamic tender service, and therefore these units can optimise their route to market. For the LFS product, the interaction with the tender is weaker because of the larger differences in the service terms for the static service in the auction and the static service in the tender.

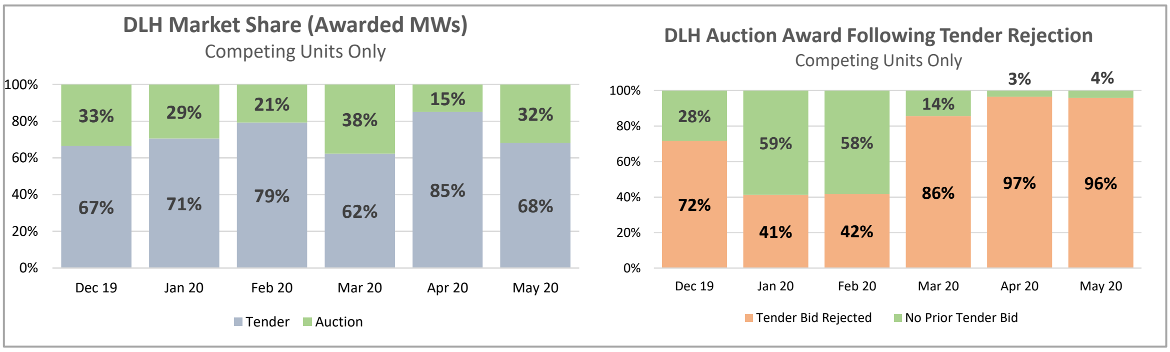
Figure 2-8: Survey Reponses



2.5.2 We have analysed the offer of dynamic service across those units which have participated in both the monthly tender and the weekly auctions between December 2019 and May 2020. To enable comparison with the DLH auction product, tender offers were included in this analysis only when they offered all three dynamic services ("P", "S", and "H") and only with the lowest quantity offered in any one of these (ensuring symmetrical offers). This allowed us to "construct" a DLH-type product for the tender which is akin to the auction product.

2.5.3 The first graph in the figure below illustrates the share of dynamic services procured in the tender and the auction, as a share of all symmetric and dynamic services (i.e. DLH-type services) awarded contracts in each month. The share of DLH dynamic services procured through the auction varies between 15% and 33%. Hence, the majority of DLH capabilities secure contracts through the tender.

Figure 2-9: DLH awards for units participating in both tender and auction



2.5.4 The second graph in the above figure provides an indication of the source and motivation for auction offers amongst the units which have demonstrated capability to access both platforms. As illustrated, a large share of auction offers are actually sourced from rejected offers in the tender. Indeed, in both April and May, close to 95% of auction volumes offered by this subset of units were preceded by rejected offers in the monthly tender. This result suggests that participants who can offer in both platforms often view the tender as the main FFR market place, while the auctions are a residual route to market for units which have failed to secure a monthly contract.

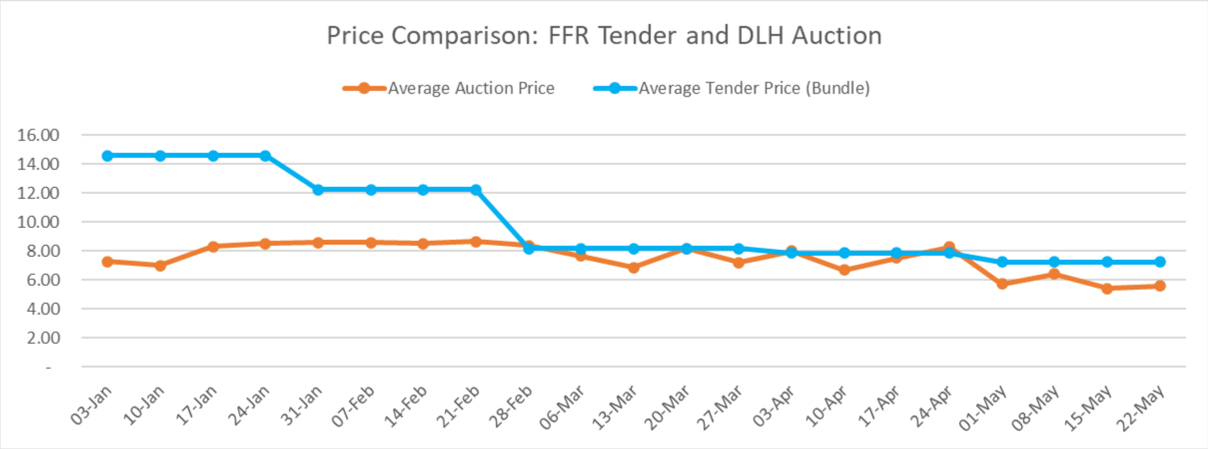
2.5.5 The conclusions of our analysis of the auction and tender data were supported by the responses of the participants in the survey and interviews. While both the monthly tender and the weekly auction are important to participants, the monthly tender is the first opportunity to secure a frequency response contract. A participant who is successful in the tender secures a contract for a whole month and therefore fixes their revenues and reduces risk. The weekly auction is then important as an opportunity to secure a contract for residual unsold volumes.

2.6 Auction Clearing Price Outcomes

2.6.1 The figure below shows:

- the weekly volume-weighted average DLH auction clearing price (i.e. average over all 42 EFA periods in each auction) from January through May 2020; and
- the volume-weighted average tender price (i.e. average over all accepted offers in each tender) for an equivalent bundle of "P", "S", and "H" services. Each monthly tender price is mapped onto several of the weekly auction prices.

Figure 2-10: *Price Comparison*



2.6.2 DLH auction prices outturn, on average, lower than the monthly FFR tender prices for an equivalent bundle of services. Average auction prices have declined in line with the increased auction liquidity, from above £8.00/MW/h in late January and February, to below £6.00/MW/h in late May 2020. Tender prices have declined more quickly, and by late May, were only slightly above the auction prices. Auction participants believe that the auction clearing prices are too low relative to average tender prices, especially given that participants perceive auction revenues to be more uncertain and therefore riskier.

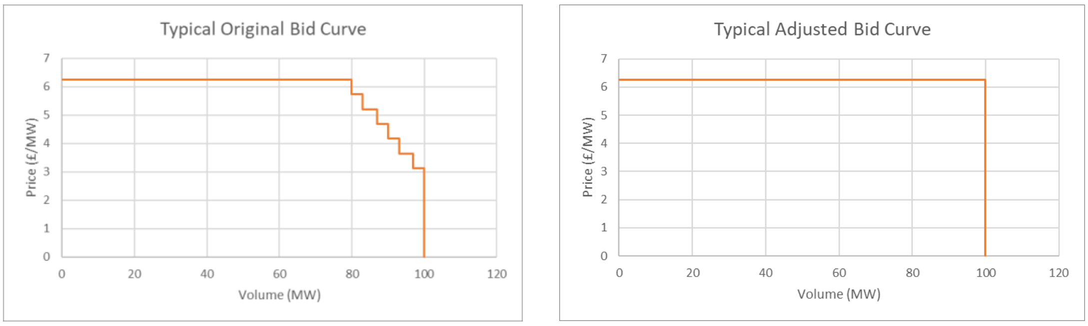
2.6.3 LFS auction clearing prices are higher than average tender prices for the static FFR service. We note that the services are not equivalent and therefore prices are not directly comparable: the auction service requires a much faster speed of response than the tender service, and therefore fewer units can offer the LFS service. There is insufficient competition in the LFS auction for the ESO's 100 MW requirement, so while participants need to offer below the ESO's bid price, they do not need to offer below their competitors to secure volume in the LFS auction.

2.7 ESO Bid Construction

2.7.1 The ESO is the only buyer of frequency response in the auction, and therefore buy orders are submitted only by the ESO. As described in Appendix D, the ESO buy orders take the form of a linear curve specifying an inverse relationship between price and volume: at a higher price, ESO demands a lower volume. The curve is stepwise, so that two consecutive points always have either the same price or the same quantity. A different curve is specified for each product and each EFA period in the auction. The auction clearing prices are capped by the bid prices which the ESO submits into the auction.

2.7.2 At the beginning of Phase 2 of the Auction Trial, the ESO constructed the buy order curves from a series of stepwise pieces. A constant demand from 0 to 80 MW was bid a certain price, and the subsequent levels of demand between 80 MW and 100 MW were bid at successively lower prices. The price at 100 MW was 50% of the price at 80 MW. Starting with the auction of 10 January 2020, the ESO simplified their curve to a single price level for the entire 100 MW volume requirement. This means the bid curve is now entirely inelastic; the demand has no sensitivity to prices.

Figure 2-11: *Bid Curves*

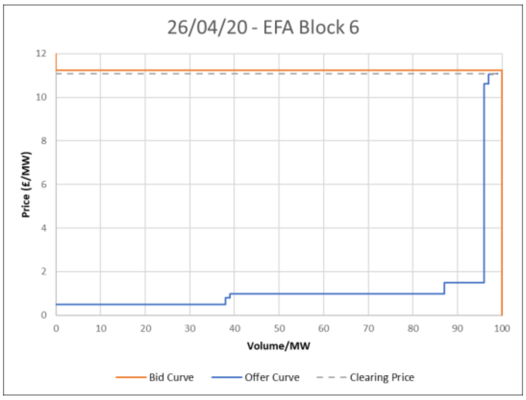


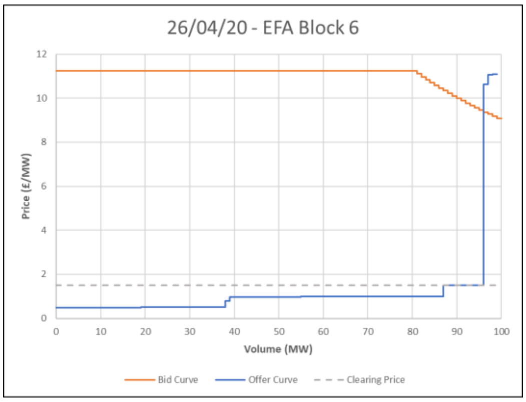
2.7.3 We have analysed the consequences of this change in approach, compared to a counterfactual where the ESO continued to use a stepwise bid curve. To illustrate our analysis with an example, we have selected the offers for DLH in EFA period 6 on 26 April 2020 (Auction of 24 April 2020, EFA period 12). In this EFA period, the final accepted offers have prices which are very close to the ESO's bid price, and therefore the auction has cleared close to the price cap.

2.7.4 We have simulated the application of bid curves with prices declining as a function of the volume procured for the DLH auctions. In our construction, the elastic section of the curve has the following features:

- It begins at 80 MW, in keeping with the inflection point of the original auction bid curves;
- It has a constant slope down to 100 MW; and
- Incremental volumes procured beyond 80 MW have a marginal price of £0, so that the total cost of the bid (i.e. maximum amount of money to be paid by the ESO) is constant, irrespective of the volume (> 80 MW) procured.

Figure 2-12: *Impact of Bid Curves*





2.7.5 In the example above, this alternative bid curve would have resulted in the rejection of the last 3 MW that were accepted in the actual auction. As a result, the simulated auction would procure only 96 MW, and not the 99 MW that were accepted. However, the simulated clearing price is £1.50, compared to the £11.09, which was the clearing price of the actual auction.

2.7.6 Our selected example is admittedly an extreme case. To generalise the impact of the stepwise bid curve, we have applied the same analysis to all EFA periods in the auctions in March, April and May 2020. We adjusted the ESO bid curve as described above, and then rejected any participant block orders with prices higher than the curve (we have therefore neglected the effects of multi-period blocks, linked families, and the merit order constraints, but we do not expect this approximation to materially change our conclusions). This analysis yields the following results for DLH:

Table 2-1: *Bid Curve Analysis*

Auction Date	EFA Periods		Volumes			Volume Weighted Auction Prices			Total Simulated Cost Saving of Sloped Bid Curve
	Number with Different Auction Outcomes	% with Different Auction Outcomes	Actual MWs Procured	MWs Procured with Sloped Bid Curve	% Accepted Volume Reduction	Actual Average Clearing Price	Average Clearing Price with Sloped Bid Curve	% Clearing Price Reduction	
06/03/2020	9	21.4%	3681	3652	0.79%	£ 7.67	£ 7.53	1.8%	£ 2,951.60
13/03/2020	5	11.9%	3818	3804	0.37%	£ 6.88	£ 6.79	1.3%	£ 1,710.32
20/03/2020	17	40.5%	3473	3427	1.32%	£ 8.17	£ 7.15	12.5%	£ 15,470.72
27/03/2020	14	33.3%	3482	3441	1.18%	£ 7.22	£ 5.75	20.4%	£ 21,508.56
03/04/2020	23	54.8%	3273	3232	1.25%	£ 8.01	£ 6.22	22.4%	£ 24,534.48
09/04/2020	11	26.2%	3500	3483	0.49%	£ 6.69	£ 5.86	12.4%	£ 12,047.00
17/04/2020	14	33.3%	3408	3390	0.53%	£ 7.52	£ 6.30	16.3%	£ 17,130.84
24/04/2020	26	61.9%	3574	3512	1.73%	£ 8.29	£ 4.34	47.7%	£ 57,587.96
01/05/2020	12	28.6%	4200	4134	1.57%	£ 5.73	£ 5.61	2.2%	£ 3,592.24
07/05/2020	22	52.4%	4164	4047	2.81%	£ 6.43	£ 5.89	8.3%	£ 11,609.64
15/05/2020	14	33.3%	4200	4186	0.33%	£ 5.42	£ 4.45	17.9%	£ 16,574.40
22/05/2020	14	33.3%	4146	4065	1.95%	£ 5.58	£ 5.11	8.4%	£ 9,389.88
Total	**181**	**35.9%**	**44919**	**44373**	**1.22%**	**£ 6.97**	**£ 5.92**	**15.1%**	**£ 194,107.64**

2.7.7 The results of our simulation show that 35.9% of EFA periods had executed orders with price limits lying above our hypothetical bid curves. Rejecting these orders would result in a 15.1% reduction in procurement costs with only a 1.2% reduction in overall volumes procured, and a consequent cost savings to the ESO of more than £194,000 in total over the 12 auctions in our simulation. This analysis assumes that the participants would not change their offer strategies in response to the ESO's new bid strategy, which obviously would not be the case, and therefore we do not expect that the ESO would have realised anything close to £194,000 in savings had they used a different strategy for their bid. Nonetheless, we believe that the shape and structure of the ESO buy order is an important driver of auction outcomes.

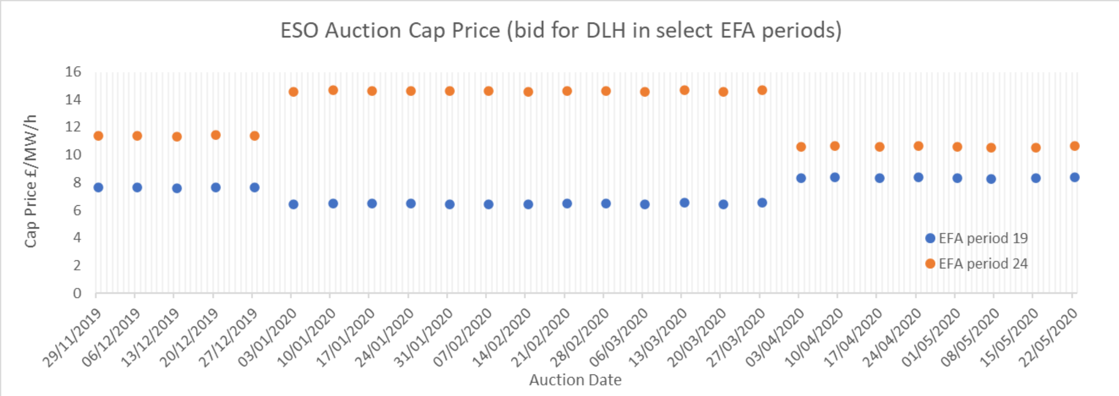
2.7.8 The gradient of the bid curve is an important consideration. Our bid curve has been constructed so that beyond 80 MW of cleared volume, the marginal price[1] of an additional MW of frequency response is £ 0, meaning additional MWs procured above 80 MW would not increase the total procurement cost of the ESO (assuming those MWs are procured at the price limit of the bid curve). Our example should be considered a limiting case: steeper slopes would imply a negative marginal price for incremental volumes of response. We note that this was indeed the case in the auctions from 29 November 2019 to 03 January 2020, in which the actual bid curves submitted by the ESO implied a negative marginal price: at the maximum volume of 100 MW, the bid curve had a price that was 50% of the price bid for 80 MW. These bids implied that the ESO would pay less money in total for cleared volume above 80 MW. We recommend instead that marginal prices should be strictly greater than £ 0, and therefore any bid curves should be less steep than the one used in our example.

2.8 Buy Order Cap Prices

2.8.1 We analysed the cap prices submitted by the ESO as part of their linear orders. The cap prices are different for the DLH and LFS products. Within a single week, the cap prices for DLH show significant variation between the 42 EFA periods, while the cap prices for LFS vary less. More significantly, however, for any given product and EFA period, the bid prices usually exhibit little variation between the weekly auctions and differ by only pennies from week to week. There have been two step-changes in the overall price level, which occurred mid-week (on 01 January 2020 and 01 April 2020) and not on the dates of auctions. By way of illustration, the chart below shows the cap price for DLH for auction period 19 (Tuesday EFA 1) and period 24 (Tuesday EFA 6) in each weekly auction.

[1] A marginal price of £0 for bid volumes above 80 MW results in a constant total cost for total cleared volumes greater than or equal to 80 MW. Suppose the ESO's cap price for volumes up to 80 MW is £9/MW/h, meaning the ESO bids £720 in total for 80 MW of response capacity for one hour. If the marginal cost for volumes above 80 MW is £0, then the bid curve point for 96 MW, for example, would be £720/96 = £7.50.

Figure 2-13: DLH Cap Price in Selected EFA Periods

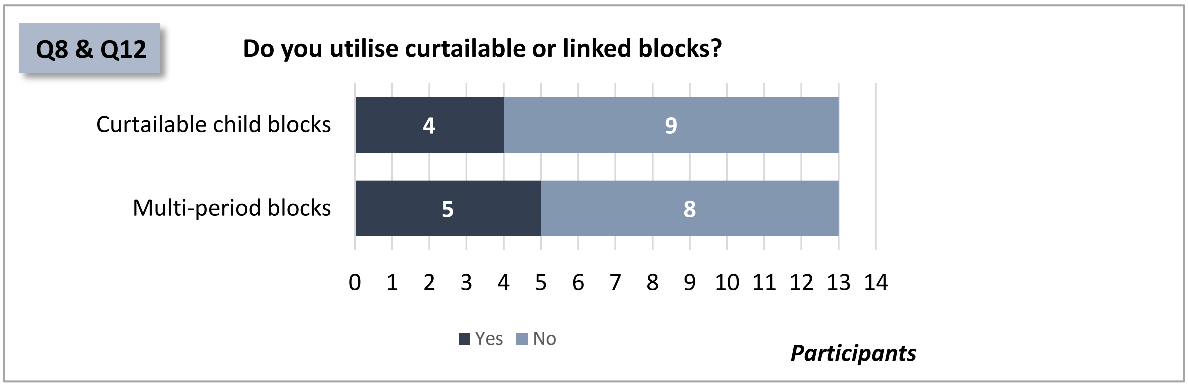


2.8.2 In the survey and interviews, the ESO price cap was an issue of significant concern for many participants, and several participants requested the ESO to share more information on its derivation. Participants noted that the ESO's bid prices do not seem related to market conditions (for example, there has been no general change in the level of the price despite the significant disruptions following covid-19). Participants also observed that in some months the average auction cap price for DLH was below the average FFR monthly tender price for an equivalent bundle of services. We calculate that in February, for example, the average auction cap price over all EFA periods in the month was £10.12/MW/h, while the average tender price in the month (for a bundle of "P", "S", and "H" services) was £13.04/MW/h.

2.8.3 We note that the consistency of the ESO's bid prices, together with the fixed procurement volume of 100 MW, result in an auction buy order that is static from week to week. The ESO's buy order is completely transparent to auction participants, despite the design of the auction being "double blind".

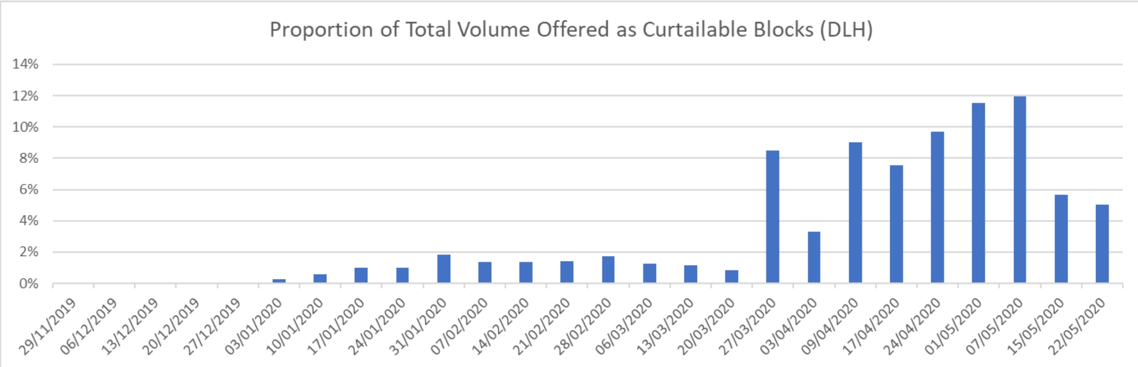
2.9 Participant Offer Construction

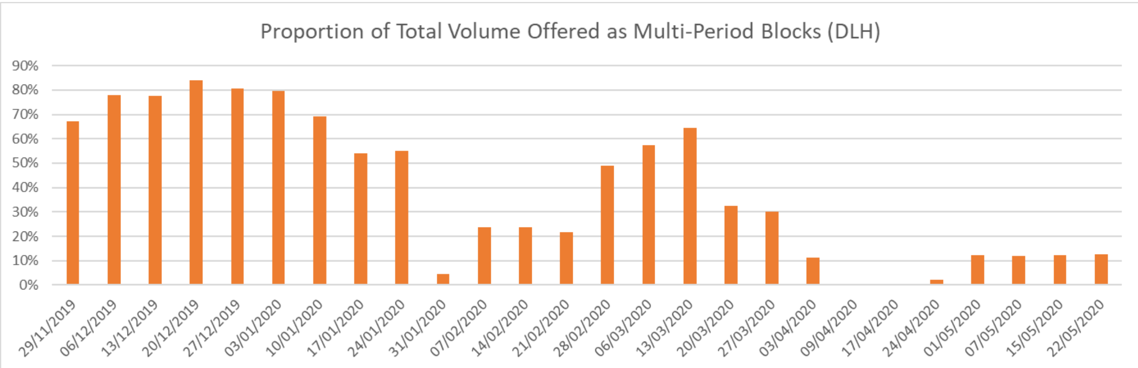
Figure 2-14: Survey Reponses



2.9.1 As detailed in Appendix D below, frequency response providers participate in the auction by submitting block orders to the auction platform. A block order may be for a single EFA period or for multiple, adjacent periods within a single EFA Day (a "multi-period block"). Block orders are either non-curtailable (which must be executed for the full volume or else rejected) or curtailable (which may be executed for part of the offered volume). The charts below show participants' use of these features in the DLH auctions over the first 6 months of the Phase 2 Auction Trial. These charts show the offered volume of curtailable blocks (which we have taken to be the volume of C02 or "child" blocks) and the offered volume of multi-period blocks as a proportion of the total offered volume in each DLH auction.

Figure 2-15: *Curtailable and Multi Period Blocks*





2.9.2 Considering first the curtailable blocks (in blue), we see that none of these were offered in the auctions in November and December 2019. Beginning in January 2020, approximately 1% - 2% of all DLH offered volume was curtailable. The volume of curtailable offers increased substantially from the end of March. The increasing use of curtailable blocks by participants is in line with the advice of the ESO in their paper on Paradoxically Rejected Blocks published in April 2020. Non-curtailable blocks are more likely to be rejected by the clearing algorithm than curtailable blocks because a non-curtailable block must be fully rejected if the offered volume of the block is greater than the remaining ESO demand in the EFA period. In contrast, curtailable blocks may be partially accepted up to the amount of remaining ESO demand.

2.9.3 In the participant survey and the interviews, many participants expressed a preference for non-curtailable blocks despite curtailable blocks being easier to clear. These participants explained that, for technical or market design reasons, their units could not offer frequency response and simultaneously offer another ancillary service or participate in the Balancing Mechanism. If their unit were awarded a frequency response contract in the auction for only a portion of the full capacity of the unit, the remaining unused capacity would be stranded. Participants therefore preferred to be fully rejected in the auction order to leave their unit unencumbered and thus eligible to offer an alternative service.

2.9.4 Considering next the multi-period blocks (in orange), we see that most DLH volume (approximately 70% to 80%) was offered as multi-period blocks at the beginning of the Phase 2 Auction Trial. This proportion has declined substantially as the Trial has progressed, and since the end of March 2020 the proportion of volume offered as multi-period blocks in the DLH auction has been below 15%.

2.9.5 We were surprised to see such high proportions of multi-period blocks offered in the auction. In our opinion, such blocks do not have much utility for auction participants. Typically, we would expect multi-period blocks to be of interest to technologies such as thermal generation that wish to avoid running a stop-start pattern due to high start costs or longer minimum run times. Given that most units participating in the auction are batteries and aggregated demand-side response, we did not expect participants to have a use case for multi-period blocks. In the survey and interviews, we learned that offering multi-period blocks was initially an artifact of the monthly tenders, where participants are allowed only a limited number of rows for submissions of their offers. Participants began the auction by using the same format of offers required for the monthly tender, and only later took advantage of the flexibility of the auction to offer single-period blocks. Nonetheless, some participants continue to use multi-period blocks up to now, and in the survey, they gave commercial or technical reasons for their continued preference to do so.

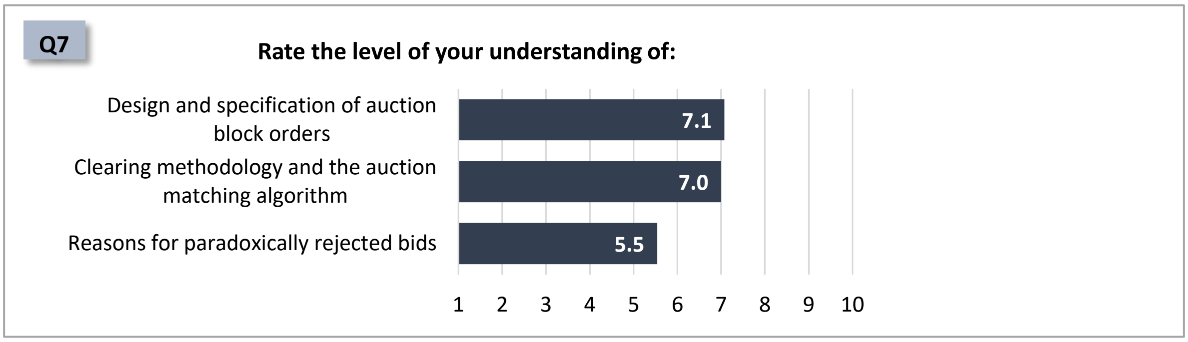
2.9.6 The design of the block order functionality, as detailed in Appendix D below, provides participants with a great deal of flexibility to specify their offers in terms of volumes, price limits, curtailment possibility, etc. There appears to be more scope for creativity than participants find useful. For example:

- Multi-period blocks are defined with a single price limit applying to all EFA periods, but they may have a different volume in each of their constituent EFA periods. In the Trial up to and including the auction of 22 May 2020, we have found no instance of a participant offering a multi-period block with a profiled volume. All multi-period blocks have so far been offered with a constant volume in each EFA period.
- A child block must refer to a parent block defined either on the same EFA period or on an adjacent EFA period within the same EFA Day. Up to and including the auction of 22 May 2020, we have found no instance of a participant defining a child block that refers to a parent block in an adjacent EFA period. All child blocks have had parent blocks defined on the same EFA period as the child.

2.9.7 These examples lead us to comment that perhaps the block order design is more complex than is required by participants for a frequency response auction.

2.10 Auction Design and the EPEXSPOT HELENA Algorithm

Figure 2-16: Survey Reponses



2.10.1 EPEXSPOT developed the HELENA auction clearing algorithm for the Frequency Response Auction Trial according to the design and requirements agreed between EPEXSPOT and the ESO. Our understanding of the functioning of the algorithm, based on our review of the documentation on the ESO website supplemented by further conversations with EPEXSPOT, is summarised in Appendix D below.

2.10.2 Having reviewed the inputs and results of the weekly auctions, it is our opinion that the EPEXSPOT implementation of the HELENA algorithm satisfies the requirements. We did not find any examples of auction results that are inconsistent with the inputs and the stated design of the algorithm.

2.10.3 We note that the application of the merit order constraints to give priority to basic blocks over multi-period blocks and certain other linked families may sometimes result in lower total surplus overall compared to a less constrained optimisation. For example, suppose that in a particular auction the solution with highest total surplus is obtained when a particular multi-period block is executed. However, the multi-period block cannot be executed if it implies the rejection of a basic block in violation of the merit order constraints. In such a case, the multi-period block is rejected, and a suboptimal result (in terms of total surplus) is returned by the algorithm.

2.10.4 In our interviews with participants, some participants raised their dissatisfaction with the merit order constraints. One participant would prefer the auction optimisation to be based on "economic merit" while another indicated that they would prefer to offer multi-period blocks but are discouraged from doing so because such offers are disadvantaged by the merit order constraints.

2.10.5 We understand that the ESO's inclusion of the merit order constraints in their requirements for the auction algorithm design was intended to favour simpler order structures over more complex structures. These constraints were implemented to test the hypothesis that such a design would encourage a "level playing field" among all auction participants by denying more experienced or better resourced participants from gaining advantage by using complex auction strategies, particularly in an environment of limited liquidity and imperfect competition. However, in our opinion, these constraints appear to have had unintended consequences: their application is opaque to auction participants, and the least sophisticated participants are also the least likely to understand when and how their submitted orders will fall foul of the constraints. We conclude that the merit order constraints are restricting the algorithm from finding higher-welfare solutions with no real benefit in terms of auction transparency or equitable outcomes.

2.11 EPEXSPOT Platform, Auction Processes, and Participant Support

2.11.1 We did not directly observe the auction platform and the auction process. Our findings here are based on replies to the survey and our interviews with the auction participants.

Figure 2-17: Survey Reponses

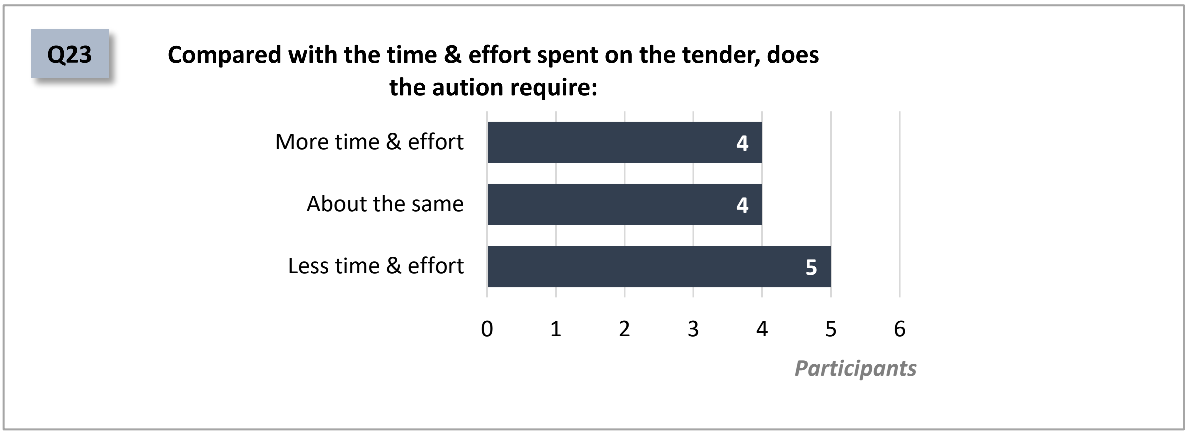


Figure 2-18: Survey Reponses

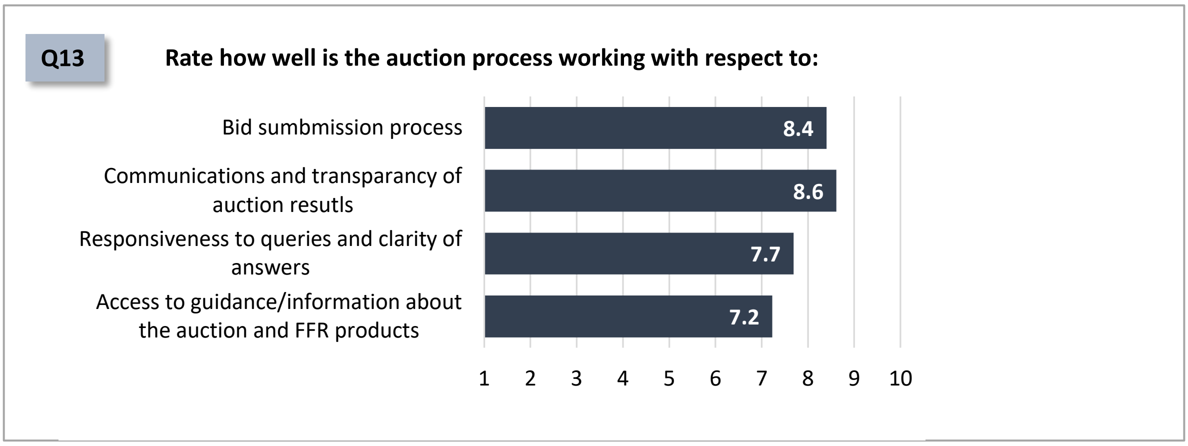
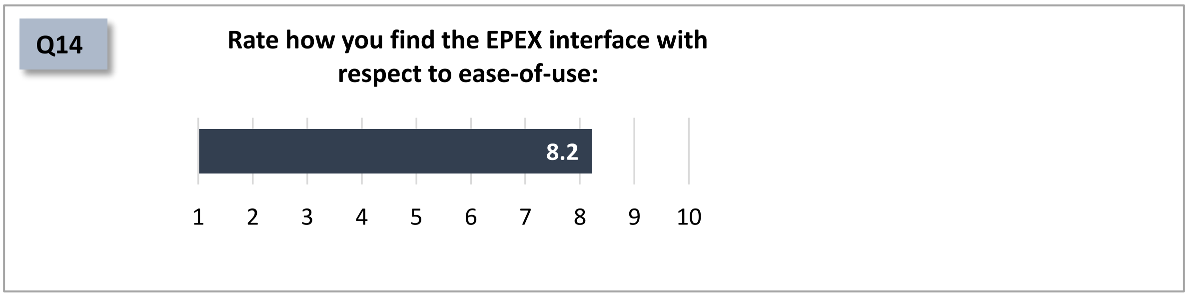


Figure 2-19: Survey Reponses



2.11.2 Overall, participant feedback on the EPEXSPOT CTS++ platform and the weekly auction process is positive, with more providers reporting satisfaction with the platform and process than dissatisfaction. Many participants mentioned the high level of transparency of the auction as a positive factor, both from the point of view of the large amount of information provided after each auction (including the ESO bid and all participant offers), and also from the point of view that providers could be assured that orders were matched objectively and fairly, given that clearing was performed wholly by an algorithm. Participants also appreciated the immediate validation of their orders by the platform at the time their files are uploaded.

2.11.3 Feedback on the auction platform user interface (UI) was mixed. Although most respondents felt that the auction platform was an improvement on the template for the monthly tender, many participants nonetheless found the CTS++ platform UI confusing or difficult to use.

2.11.4 Survey respondents proposed a number of improvements to the CTS++ platform and the auction process, such as:

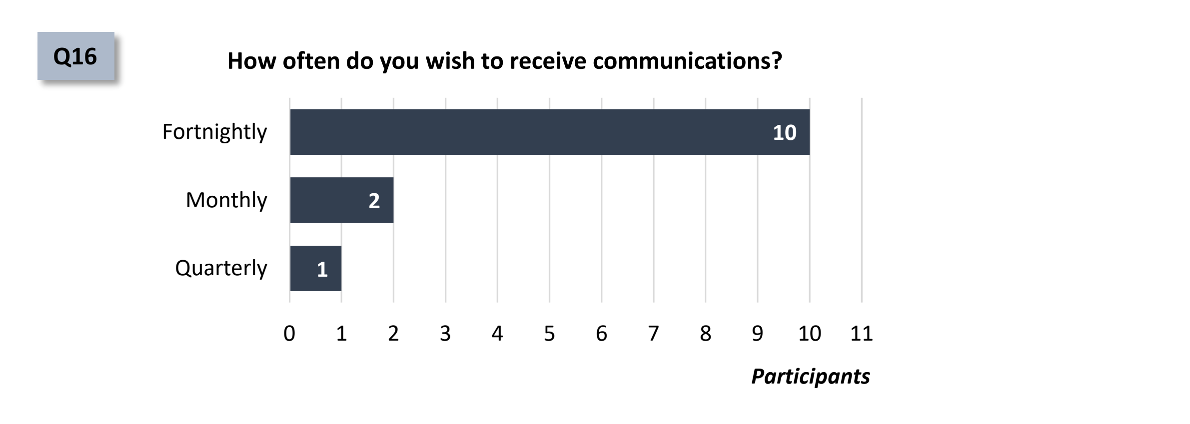
- enhance the EPEXSPOT CTS++ platform UI to make it more "user-friendly", such as highlighting which auction is the current active auction;
- display the weekdays, dates and times associated with the EFA blocks in the UI for validation (EFA blocks are currently labelled only with the numbers 1 to 42), to mitigate the risk of inadvertently selling the incorrect period;
- allow the order submission template to be downloaded directly from the CTS++ platform (in addition to download from the ESO website);
- allow for users to enter and edit orders directly into the UI, in addition to the template upload functionality;
- expose an API for automated machine-to-machine order submission;
- publish all market transparency data on the CTS++ platform (in addition to the ESO website);
- publish the auction results on the CTS++ platform in an .xls or .csv format; and
- publish auction results earlier in the day.

2.11.5 Participants broadly indicated that the time required to prepare for a single auction is less than the time required for a single tender, although over the course of a month the overall effort for the auctions is greater because auctions are four times as frequent. The driver of this additional burden in the auction seemed to be the need to repeat market analysis (e.g. estimation of opportunity costs, etc.), rather than the mechanics of auction submission.

2.11.6 Two survey respondents were not supportive of the auction platform because it further fragmented their interactions with the ESO over yet another platform. These respondents felt that the ESO had introduced too many portals (e.g. the monthly FFR tender submission was via COUPA, etc.) and recommended that the ESO focus on reducing these in order to simplify participant operations.

2.11.7 Nearly all providers whom we interviewed were generally very positive about the ESO's engagement and communication with participants with respect to the weekly auction. Most participants reported that the ESO's responsiveness to queries is timely and helpful. One recently-registered participant commented that the auction registration process was much quicker and smoother than expected. In contrast, an unhappy participant requested better signalling of process changes from the ESO, as they had not read the email stating that the auction would be moved from a bank holiday Friday to the Thursday, and they consequently missed a week's participation.

Figure 2-20: Survey Reponses



2.11.8 A specific exception to the overall high score regarding communication is the quality of documentation. Participants universally reported that auction documentation is poor, especially with respect to documentation explaining the functioning of the clearing algorithm (a great many survey respondents raised this issue in particular). Participants appreciated the recent document "Analysis of Paradoxically Rejected Blocks" published by the ESO to explain the use of the various types of block orders available to providers. The participants requested the ESO to publish more educational documents like this, and suggested topics including:

- an explanation of the principles that govern clearing of the auction, the optimisation of surplus, and the application of constraints such as the merit order rules;
- an explanation of the data available to participants in the market transparency files published on the ESO website;
- an explanation of the validations applied to order submission and of the error codes; and
- a user guide (or "cheat sheet") to the EPEXSPOT CTS++ platform, with step-by-step instructions including screenshots (the existing documentation of the CTS++ platform is branded EPEXSPOT and very technical).

2.11.9 Participants also noted that the existing documentation is difficult to navigate and that specific documents are hard to find on the ESO website.

3. Evaluation

3.1.1 We believe that the Frequency Response Auction Trial has started well. The weekly operational processes such as order submission and auction clearing have proven to be robust. Participant interest, market liquidity, and cleared volumes have increased steadily over the first six months of the Trial (for the DLH product in particular). The auctions have presented a variety of outcomes and afforded a number of opportunities for the ESO to learn, as providers have experimented with different approaches to order formation, and EFA periods with low- or high-liquidity can be contrasted in terms of clearing price formation. Our high-level impressions of the auction, without reference to a specific evaluation framework, are positive. However, in evaluating the Auction Trial against the stated success criteria (see Paragraph 1.1.4), we would rate the success of the Trial as mixed.

3.1.2 One of the success criteria is "to enhance understanding of market behaviour driven by pay-as-clear weekly auctions, compared with longer-term pay-as-bid tenders". We have many relevant observations here: in Section 2.5 we found that participants with a choice between the auction and the tender view the auction as riskier and use it primarily to clean up residual capacity not awarded contracts in the tender, while in Section 2.6 we can draw the tentative conclusion that the pay-as-clear auction results in favourable price outcomes (from the point of view of the ESO) when the bid volume of 100 MW is sufficiently contested. As the Trial continues, we expect the ESO to learn more. However, we believe that the barriers to auction participation discussed in Section 2.4 inhibit understanding of the pay-as-clear design. Some differences between the FFR tender and the Auction Trial (e.g. monthly versus weekly, manual assessment versus clearing algorithm, etc.) are fundamental and cannot be aligned. In contrast, differences in contract language or in the data requirements for the registration of units were discretionary choices in the design of the auction project. The Auction Trial experiment is not designed with a "test" and a "control", and it is therefore difficult to decide which outcomes are consequences of the pay-as-clear design and which outcomes are a result of other factors. We therefore recommend eliminating the 20 MW unit cap in the auction (Section 4.2) to better align the Auction Trial with the FFR tender.

3.1.3 Two of the success criteria relate to "enhancing understanding of closer-to-real-time procurement". From the participant side, some aggregators reported that shorter term procurement horizons facilitate maintaining agreement among the units providing frequency response capacity in their portfolios. We expect that the eventual move to day-ahead auctions will further enhance understanding, as this will facilitate better interactions with the Balancing Mechanism in terms of estimating opportunity costs, as well as opportunities for participation by intermittent generation. From the side of the ESO, the opportunity to enhance understanding of closer-to-real-time procurement has not been realised. The operational business processes that support the procurement of frequency response are tied to longer-time cycles and make no reference to current information or the outcomes of recent weekly auctions. At the very least, we recommend that the ESO regularly rebalance the procurement requirements for frequency response between the monthly FFR tender and the weekly auctions based on observed liquidity in each of the markets, as we advise in Section 4.1.

3.1.4 The final three success criteria relate to business processes. Regarding "support the transition towards day-ahead auctions, through understanding market behaviour and business processes", we believe that this has been achieved. The weekly auction format is a good foundation on which to build the daily auctions, and in our participant interviews we found that the providers have clear ideas of their requirements to make daily auctions successful (Section 5.1). Regarding "ensure provider satisfaction with the auction platform, operational processes, and transparency of results", we would evaluate this as "in progress". We received both positive and negative feedback in this area, but even the most critical of participants could be described as "very engaged", and all the comments from participants were constructive (Section 2.11). Finally, regarding "realise time and cost savings for the ESO, compared to the current procurement approach", we did not review this part of the project and therefore cannot provide an evaluation.

4. Recommendations: Auction Trial Operations

4.1 Optimise the Target Quantity of Response to be Procured in the Auction

4.1.1 The ESO currently reserves a requirement of 100 MW of each of the DLH and LFS products for procurement in the weekly auction. This requirement is deducted from the ESO's total firm requirements for commercially-procured frequency response. The net requirement (i.e. the total requirement less 100 MW of each auction product) is procured in the monthly FFR tender.

4.1.2 Rather than maintaining a constant requirement of 100 MW for each product in all weekly auctions, we recommend instead that each month the ESO should re-optimise their target auction volumes based on the historical experience of auction participation and an analysis of expected future auction liquidity. Such a change would introduce a feedback loop from auction outcomes into the ESO's buy order. For example, based on historical experience and forecast expectations, the ESO may determine that auction requirements of 140 MW of DLH and 80 MW of LFS for the upcoming calendar month would best ensure a competitive auction in line with auction market liquidity. The difference between these volumes and the total requirements for firm, commercially-procured frequency response would then be the requirements for the tender. By aligning the volumes available in the auction with the actual experience of auction participation, we expect that the ESO may learn more about the functioning of a pay-as-clear market and thus the Auction Trial will be better placed to achieve its success criteria.

4.1.3 In the survey and interviews, most market participants recommended that the ESO increase the volume requirement for the DLH product beyond 100 MW.

4.1.4 We suggest that the reserved auction and tender requirements for dynamic and static frequency response should be published monthly along with the FFR tender notice. Because FFR tender requirements are published approximately 6 weeks in advance of the beginning of the delivery month, such a practice would require the ESO to forecast their expectation of auction liquidity (considering, for example, expected new unit registrations over the upcoming weeks as well as other market design changes that the ESO plans to introduce) approximately 6 to 12 weeks in advance of delivery.

4.2 Eliminate the 20 MW Unit Volume Cap

4.2.1 We propose that the unit volume cap of 20 MW, which limits the size of offers into the auction, should be eliminated. From among the companies whom we interviewed, there were four participants who are currently constrained by the 20 MW unit cap, and an additional two participants who are not currently constrained but who have larger assets in development. Additionally, there are companies who do not currently participate in the auction because the 20 MW unit cap is a barrier, as explained in Section 2.4 above. We believe that the unit cap is a market distortion which inhibits the ESO from achieving its objective of learning more about pay-as-clear auction design in the Auction Trial.

4.2.2 Given that, by definition, the excluded units are larger than the units currently participating, we expect that such a change would materially increase auction liquidity. This change also opens up the possibility that a small number of larger units will be awarded most or all of the 100 MW auction requirement per product. In line with our recommendation in Section 4.1 above, we suggest that the elimination of the unit cap should be implemented simultaneously with, or subsequent to, an increase in the target auction requirement above 100 MW (at least for the DLH product).

4.2.3 We do not see much value in increasing the unit cap instead of eliminating it. If the unit cap is increased above the current 20 MW limit, it must at least be set at 50 MW in order to extend eligibility to more units, and currently there are few units in the FFR market with capacity beyond that level.

4.2.4 Of the various recommendations outlined in this chapter, this suggestion to eliminate the unit volume cap is the only one whose implementation is not wholly internal to the ESO. We understand that EPEXSPOT (after being instructed by the ESO) must make a configuration change to the auction platform and perform some regression testing.

4.3 Improve and Clarify the Methodology for the ESO's Bid Price

4.3.1 We recommend that the ESO review their methodology for determining their buy order bid prices, both to make these bid prices more dynamic from week to week and to better reflect market conditions and the actual cost of procuring an alternative service. We suggest that the bid price may reference a forecast or estimate of the cost of the mandatory service over the coming week (considering, for example, forecast BOA prices, the uncertainty of the volume estimates of frequency response requirements, etc.). We advise that the methodology to determine the bid price should be published to the market, but the specific bid prices should not be published (until after auction clearing) in order to maintain the double-blind design of the auction.

4.4 Improve Linear Order Curve Construction

4.4.1 We recommend that the ESO re-introduce an elastic bid curve, with successively lower prices for higher volumes. We expect that this would simulate the effect of additional competition in EFA periods which have low liquidity.

4.4.2 In a pay-as-clear auction with low liquidity there is (by definition) low competition among participants for the ESO's bid volumes. Participants can risk trying to create the opportunity for a higher clearing price by increasing their offer price above what they would dare to submit in a more competitive auction. A step-wise bid curve creates additional uncertainty about the competitiveness of a participant's offer, compared to a single bid price. With a bid curve, the participant cannot estimate precisely the ESO's limit price corresponding to the total offered quantity at that point in the stack, because a participant who submits a sell order is normally uncertain of the exact quantity of lower priced orders from competing suppliers. Participants would therefore generally tend to decrease their offer price to reduce the risk that an order is rejected. This is true even when the ESO's bid prices are known by the market in advance. We provide some further background information to pay-as-clear auctions in Appendix E.

4.4.3 While liquidity in the DLH auctions has increased to the point where most EFA periods have robust competition, the LFS auctions continue to have very low liquidity and thus we expect that an elastic bid curve can better support the concept of pay-as-clear for these auctions. An elastic bid curve will also support competition in the DLH auctions if the ESO increases the DLH auction requirements above 100 MW.

4.4.4 The construction of the bid curve could be parameterised by the following design choices:

- A cap price, defined by some relationship to the bid price methodology (see our recommendation in Section 4.3 above).
- A minimum target volume, which would be the first inflection point of the curve. The bid curve begins with a horizontal section from 0 MW to this point (which previously was chosen as 80 MW). This target volume is bid at the cap price.
- A marginal price for incremental volumes of frequency response beyond the minimum target volume, which would then define the bid price at each point on the curve beyond the first inflection point. The marginal price should be between £ 0 and the cap price.
- A resolution or "step size", which may be 1 MW or greater, and which will determine the number of points between the inflection point and the maximum volume.

4.4.5 In practice, these parameters need not be the same for each product and EFA period. The parameters can also be varied from week to week to simulate competition for the bid volumes further.

4.5 Re-Forecast Response Requirements: "Closer-to-Real-Time" Procurement

4.5.1 One of the success criteria of the Frequency Response Auction Trial is to "enhance understanding of how closer to real time procurement can result in more accurate procurement decisions due to increased certainty of requirements." However, the ESO does not take any advantage of the short auction timescales to update their bid volumes based on up-to-date market or system information. We recommend that the ESO take advantage of the "closer-to-real-time" procurement cycle afforded by the auction trial to re-estimate their requirements for frequency response regularly.

4.5.2 In Section 4.1 we recommend a monthly planning cycle for the portion of total forecast requirements for frequency response that are reserved for procurement in the auction. We further recommend that this planned volume requirement be updated by a revised forecast of requirements at the week-ahead stage.

4.5.3 The week-ahead forecast of the total requirement for frequency response could be based on an updated view of system demand, planned schedules, expected interconnector flows, known outages, and other drivers of response requirements. From this total requirement would be subtracted the frequency response that is already contracted via long-term contracts or the monthly FFR tender (possibly corrected for known technical outages by contracted frequency response providers). The difference between estimated total requirements and contracted response would form the basis for the determination of the remaining firm requirement, which would be the volume bid into the auction. This volume requirement would vary between the 42 EFA periods contested in the weekly auction.

4.5.4 We understand that the ESO is conservative in estimating its frequency response requirements in order to avoid holding excess response in delivery, and therefore we expect that more frequent reforecasting of frequency response requirements would decrease volumes procured in the mandatory market and increase volumes procured in the commercial market. The consequence of more accurate procurement in the commercial market would be lower costs overall for the ESO (as commercial frequency response has recently been cheaper than mandatory response) but increased revenues for commercial frequency response providers. Such an outcome would demonstrate the benefits of "closer-to-real-time" procurement and thus support the success criteria of the Auction Trial project.

5. Recommendations: Roadmap and EPEXSPOT Developments

5.1 Operational Process for Day-ahead Auctions

5.1.1 The ambition to trial day-ahead auctions is a Roadmap milestone.

Figure 5-1: Day-Ahead Participant Interest

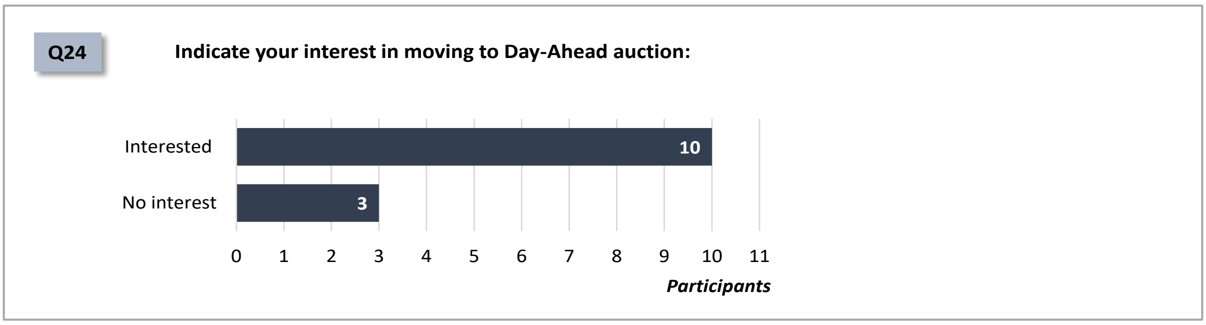
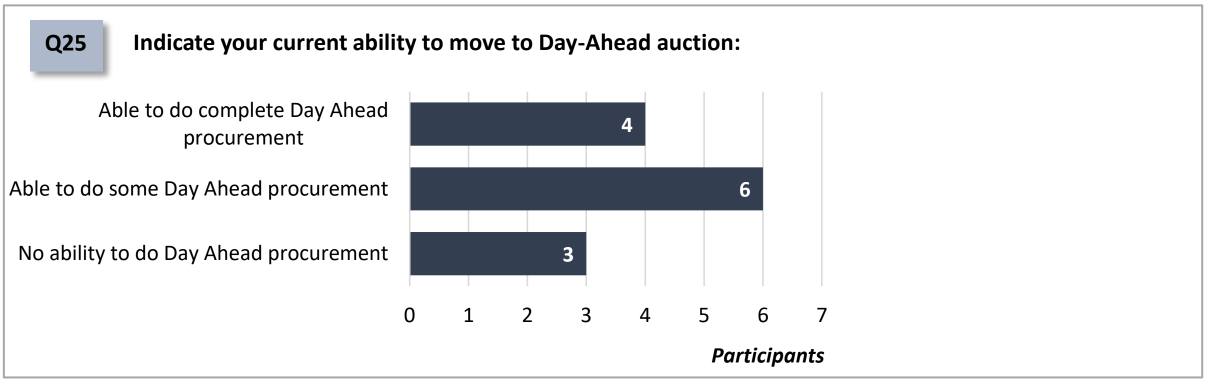


Figure 5-2: Participant Day-Ahead Readiness



5.1.2 Based on the responses to the survey and interviews, most participants are in favour of the proposed move to day-ahead auctions. Participants seem to have a wide range of preparedness: some participants indicated they are capable of moving to day-ahead very quickly, while others indicated that they would require significant preparation and investment. In addition to technical readiness, some participants also mentioned the need to modify internal compliance procedures (i.e. the length of time to get internal approval/ sign-off for auction orders).

5.1.3 Nearly all participants have the capability to integrate auction results (i.e. awarded contracts) into the operational environment on a 24/7 basis, and therefore they recommend that the day-ahead auction should run 365 days/year, with a daily gate closure, clearing, and publication of results. However, many participants do not have a 24/7 commercial capability and therefore advised against being required to submit orders every day. The consensus recommendation is to have an extended gate open period (e.g. rolling 7 days ahead of each auction, with several auctions open for submission simultaneously) so that orders could be submitted in advance (and, in particular, not on weekends or bank holidays). It must be possible to amend or cancel previously submitted orders until gate closure. Participants suggested additional features would be useful, such as the capability to submit the same order in batch for several auctions, or to be able to submit a default order which would be cleared in every auction unless specifically amended or cancelled prior to gate closure.

5.1.4 Most participants stressed the need for further streamlining of the order submission process to reduce the workload associated with the auctions. In particular, there is a requirement for an API interface to enable automated submission of orders to the CTS++ platform.

5.1.5 Many participants highlighted that the timing of the daily auctions would be important, for example in relation to other wholesale auctions such as the day-ahead market coupling auction for electricity. However, there was no agreement (or even strong opinions) on the preferred sequence: should the frequency response auction results be published before gate closure of the market coupling auction, or should be the gate closure of the frequency response auction come after the publication of results for market coupling? This question therefore needs further analysis. Participants agreed that the amount of time between the frequency response auction gate close and the publication of the results should be reduced, compared to the current timetable.

5.1.6 In addition to the participant suggestions noted above, we also mention additional business processes that will need to be considered. The ESO will need to review the deadline for submitting or amending unit registration data in advance of each auction gate open. Also, the ESO will need to define the support model for participants to resolve urgent issues with the ESO and with the auction operator, especially on weekends and bank holidays.

5.2 Market Design of the End-state Frequency Response Product Suite

5.2.1 The ESO published its Response and Reserve Roadmap in December 2019. In this document, the ESO set out its plans for the remainder of the Frequency Response Auction Trial. The ESO also committed to develop a new suite of three dynamic frequency response services (Dynamic Containment, Dynamic Moderation, and Dynamic Regulation) to replace the current portfolio of frequency response products and better ensure the secure operation of a decarbonised, low-inertia, electricity transmission system. We understand that the design and modelling of the new services is ongoing to demonstrate their capability to support system operability under various scenarios. It is foreseen that these services will be procured by auction.

5.2.2 The success of the new product suite will depend not only on its capability to support the operation of a decarbonised, low-inertia, GB electricity system, but also on the development of the associated frequency response market. The ESO will need to procure sufficient volumes of these services at acceptable prices. Long-run outturn market prices must therefore be high enough to incentivise service providers to offer the service in the required quantities, but not so high as to increase overall procurement costs unduly (and ultimately costs to the GB electricity consumer).

5.2.3 Alongside the system modelling that the ESO is currently undertaking to demonstrate how the new services will support the overall operability of the GB system, we recommend that the ESO undertake market modelling and analysis to better understand how the launch of the new products will impact the supply/ demand balance for all commercially-procured frequency response services (including legacy products in the monthly FFR tender and the Auction Trial). For example, such an analysis will enable the ESO to:

- detail an evidence-based initial procurement plan including an estimate, based on expected market interest, of the initial target volumes of each service that can be procured in a competitive auction process;
- analyse the effects of various market design parameters, such as applying initial caps on unit volumes or participant market share, and thus determine if these are desirable;
- estimate the total market size, the market size for each of the three products, and the drivers of substitution between the three new products;
- forecast the expected auction clearing price of the new products, their total additional procurement costs, and the impact on BSUoS of migrating to the new product suite;
- understand the extent to which the new, additional requirements for the new services will cannibalise the supply of existing frequency response services procured in the auction and in the monthly FFR tender, and consequently estimate changes in the cost of these services; and
- develop a plan to scale up procurement volumes over time in line with forecast market growth and gradually to phase out legacy frequency response services.

5.2.4 A market analysis will support not only the development of a comprehensive procurement strategy for the new services, but also the technical design and specification of the services themselves. To the extent that certain design parameters of the new services can be flexed while ensuring that the new services meet system operability requirements, the final service design can be specified in such a way that both system operability and market outcomes (such as total procurement costs) are optimised.

5.3 Residual Auctions

5.3.1 The Roadmap commits to further development of the EPEXSPOT auction matching algorithm, and in particular to the development of residual auctions to optimise procurement between different products. The proposed design for residual auctions uses a value relationship between two distinct products which may be substitutes for each other. As part of its bid curve submission, the ESO would specify minimum volumes for each of the two products, an overall target volume, and a conversion factor to compute equivalence between prices and volumes. The matching algorithm would first clear the minimum volumes of each product, and then take rejected offers for both products into a residual auction which would top up overall volumes with the most favourable remaining offers.

5.3.2 This residual auction functionality was proposed at the beginning of the design phase of the Frequency Response Auction Trial, at a time when the planned suite of frequency response products was very different to the current design specified in the Roadmap. At the time, the development plan for frequency response foresaw high-frequency static (HFS), high-frequency dynamic (HFD), low-frequency static (LFS), and low-frequency dynamic (LFD) products. It was expected, for example, that a minimum required amount of LFD would be cleared in a main auction, with rejected offers of LFD adjusted by the conversion factor and combined with offers of LFS in a residual auction to top up the overall requirement for LF response (including both dynamic and static). Considering the new suite of end-state products outlined in the Roadmap (Dynamic Containment, Dynamic Moderation, and Dynamic Regulation), we believe that the residual auction functionality as defined does not offer much utility to the ESO. We do not expect that the ESO's operational requirements for these new services will be flexible enough to allow significant substitution between them.

5.3.3 However, the residual auction functionality could be repurposed to allow the ESO to satisfy particular requirements while still maintaining a standardised product suite. For example, the ESO could manage geographical constraints by procuring a minimum volume of frequency response in front of the constraint within an overall, total requirement for a general, GB-wide service (i.e. including delivery on both sides of the constraint). Participants could offer either the geographically-limited product or the general product, depending on their capabilities. Other use cases for residual auctions include valuing faster-acting services more highly (in fact, letting the market determine the value of faster-acting services in response to the ESO demand) while still enabling slower services to participate in the auction, or procuring a minimum of transmission-connected response as part of a total amount of overall response including both transmission and distribution connections, etc.

5.4 Market Optimisation and Development of the HELENA Clearing Algorithm

5.4.1 Beyond residual auctions, there are a number of further developments to the clearing algorithm which the ESO could consider to improve the design of the market for frequency response and to better optimise frequency response capacity that is offered by industry in the GB system.

5.4.2 First of all, we note that the merit order constraints are applied in the clearing algorithm to give priority to basic blocks, as explained in paragraph 2.10.3 and in Appendix D. A basic block is either a single-period parent block, or a linked family consisting of a single-period parent block and a single-period child block defined on the same EFA period at the same price. The merit order constraints restrict the higher-priced offers that can be accepted if a basic block is rejected, and this sometimes leads to auction results with lower total surplus than an alternative solution which would violate the merit order constraints but have higher surplus. We recommend that the merit order constraints be relaxed in a future release of the clearing algorithm in order to observe the impact on auction outcomes and provider satisfaction.

5.4.3 Secondly, we note that the DLH product is currently designed as a combined, symmetric ("P=S=H") service requiring suppliers to provide the capacity to deliver equal amounts of both high frequency (HF) and low frequency (LF) response. As we stated in Section 2.4, the DLH product design is a barrier to auction participation for units that have an asymmetric capability for frequency response, such as hydro units which typically prefer to provide only LF service, or wind units which prefer to provide only HF service.

5.4.4 The ESO could define new, separate LF ("P=S") and HF ("H") products to enable the participation of units with asymmetric capabilities. In addition to facilitating greater auction liquidity overall, this change would allow the ESO to procure different amounts of HF and LF, which would clear independently of each other, and at potentially different clearing prices. No change to the auction clearing algorithm would be required: the HELENA algorithm as currently deployed in production is capable of the procurement of HF and LF products separately (as is evidenced by the current procurement of the LFS product).

5.4.5 However, the clearing algorithm as currently specified does not have the capability to "link" together the HF and LF products in order to make the clearing of one conditional on the clearing of the other. An auction participant with a preference to provide a combined service is therefore at risk of being obliged to deliver a one-sided service. We therefore recommend that the ESO raise a change request with EPEXSPOT to enable participants to link an offer of HF and an offer of LF together as a single block (in equal or unequal volumes), so that either both products are accepted in the auction, or both are rejected. It should also remain possible for participants to submit offers for both HF and LF products and have these cleared independently in case a provider is willing to accept a one-sided service.

5.4.6 An immediate use case for this feature would be to decompose the DLH ("P=S=H") auction product into an HF product ("H") and an LF product ("P=S"). Such an enhancement would improve auction liquidity by opening participation to ancillary service suppliers, such as hydro and wind generators, who do not have a symmetric capability of providing frequency response and for whom the monthly FFR tender is now their only route to market. Furthermore, distinct HF and LF products are a better market design. The available market supply of HF and LF services, and thus the supply balance for each service relative to ESO demand, may be different in each case and thus indicate a different market value.

5.4.7 This proposed change to the matching algorithm would also support the eventual efficient procurement of the proposed Dynamic Containment service, as explained in Section 5.2 above. This service is designed to operate post-fault, i.e. either after a significant generation loss or a significant demand loss. The magnitude of generation loss which the ESO needs to secure may be different to the magnitude of demand loss, and therefore the requirements of the ESO for HF and LF services are not symmetric. It would be optimal for the ESO to procure HF and LF services as different auction products against distinct volume and price curves.

5.4.8 The functionality to link LF and HF products could be generalised to allow participants to stack ancillary services in the case that a unit has the technical capability to deliver more than one auction product simultaneously. Participants would have the ability to link together two or more orders defined on the same unit, so that these orders are either all accepted or all rejected. Configuration of the auction products on the platform, together with validations applied to orders at the time of submission, would control that only "legally stackable" products could be linked.

5.4.9 Finally, we note that units offering frequency response may be capable of offering more than one of the three new end-state services. We advise that providers should not be required to select *a priori* which product to offer into a set of simultaneous auctions for different products, because rejected units would then have no way to compete for the other products that they are capable of delivering. This outcome would represent an inefficiency and potential loss of welfare to both the ESO and participants. Instead, we recommend that providers should be able to define mutually-exclusive orders for different (”unstackable”) products. The clearing algorithm should then optimise the procurement of the ESO requirements for all frequency response products across the entire market of units providing response services.

Appendix A Scope of this Evaluation

A.1 In Scope

A.1.1 Our focus in this evaluation has been the current operations and the development plan of the Phase 2 Frequency Response Auction Trial. The scope of our evaluation included:

- the outcomes (e.g. price formation, cleared volumes, provider participation) of the Trial to date, with a view to proposing explanations for the underlying drivers of these outcomes;
- the suitability of the ESO's buy order (e.g. in terms of price levels, etc.) to support the objectives of the Trial as well as overall ESO objectives such as end-consumer value;
- the market design for the frequency response services procured in the auction, with a view to making recommendations where possible to remove barriers to participation and reduce risks for participants and for the ESO;
- the specification of the auction algorithm for the matching of buy- and sell-orders and the optimisation of surplus, to evaluate its suitability in the context of the objectives of the Trial;
- participant engagement and satisfaction with the Auction Trial, including the EPEXSPOT CTS++ platform and the weekly operational auction processes;
- the specification of the remaining deliverables of EPEXSPOT with respect to the Auction Trial algorithm and platform; and
- the Roadmap for Response and Reserve, especially with respect to day-ahead auctions and the onboarding of the end-state frequency response services into the Trial, in order to make design recommendations to improve the effectiveness of the Trial.

A.2 Out of Scope

A.2.1 A number of related avenues of potential investigation were out of scope for this review and were not reviewed by us. These included, for example:

- wider issues of market design for frequency response, such as the interaction between provider capabilities, ESO requirements, and the technical design of frequency response services;
- procurement of other ancillary services, such as standardised reserve services;
- a review of internal ESO quantitative models and methodologies, for example the ESO's internal methodology for determining frequency response requirements;
- analysis of internal ESO systems and business processes, their suitability to support upcoming developments in the Trial, and the design of required changes to the internal system landscape; and
- a comparative review of the operational burdens and costs of conducting the weekly auction and the monthly tender for frequency response.

A.2.2 We did not audit the implementation project of the Auction Trial project from inception through go-live of Phase 2 at the end of November 2019, nor did we review the outcomes and results of Phase 1 of the Trial from June to November 2019.

Appendix B Participant Survey

B.1 Survey Methodology and Response Rates

B.1.1 Frequency response providers were invited to complete an online survey, via a link on the Auction Trial page of the ESO website. The survey questions are reproduced in the table below. A specific invitation was sent to the registered users of the EPEXSPOT Auction Trial platform. The ESO received 16 responses to the online survey, of which 15 had units participating in the Auction Trial, and 1 did not.

B.1.2 The ESO arranged follow-up interviews with 13 survey respondents, all of whom had participating units and were registered users of the platform. Both ESP Consulting and the ESO took part in all the follow-up interviews. These interviews were used to clarify the survey responses of each participant, as well as to explore certain topics in more depth in an unstructured dialogue.

B.1.3 In our review we have considered the responses of all 16 survey respondents as well as the feedback from all 13 interviews. We have summarised this information in the various relevant sections of our document, reporting either a consensus view where all or nearly all respondents shared a similar opinion, or else reporting diverse or dissenting views in the cases where respondents had different experiences of the auction or different recommendations for improvement. The graphics and tables in the report which illustrate the survey opinion include only the responses of the 13 participants whom we interviewed.

B.2 Survey Questions

	Question	Response Options
1	Have you participated in the Phase 2 Frequency Response Auction Trial:	Yes/No
2	If No: Please can you explain why?	Free form
3	Please rate the importance of the weekly auction and the monthly tender, respectively, as a route to market for your frequency response capabilities: - Monthly Tender - Weekly Auction	 1-10 Scale 1-10 Scale
4	Are there barriers to your participation in the weekly auction?	Yes/No
5	If Yes: Please explain what these barriers are.	Free form
6	What, if anything, would make you more inclined towards using the weekly auction in preference to the monthly tenders?	Free form
7	Please indicate the level of your understanding of: - Design and specification of auction block orders - Clearing methodology and the auction matching algoritm - Reasons for paradoxically rejected blocks	 1-10 Scale 1-10 Scale 1-10 Scale
8	Do you utilise curtailable blocks	Yes/No
9	If Yes: Please can you advise what is your purpose for using them?	Free form
10	If No: What are your commercial or technical reasons for preferring non-curtailable blocks?	Free form

	Question	Response Options
11	Do you utilise multi-period blocks (i.e. offer spanning multiple, linked, adjacent EFA periods within the same EFA day)?	Yes/No
12	If Yes: Please can you advise what are your commercial or technical reasons for offering such blocks?	Free form
13	Please rate how well the auction process is working with respect to: - Bid submission process - Communication and transparency of auction results - Responsiveness to queries and clarity of answers - Access to appropriate guidance / information about the auction and frequency response products	 1-10 Scale 1-10 Scale 1-10 Scale 1-10 Scale
14	On a scale from 0-10, how do you find the EPEX auction interface with respect to ease-of-use?	1-10 Scale
15	Via which channels do you prefer to receive ESO communications?	Optins List
16	How frequently would you like to receive communications?	Optins List
17	What content would you like to see in our future communications?	Free form
18	Do you have any question for us?	Free form
21	In our last survey, you mentioned the auction results are not very easy to interpret. Recently we published a document called Analysis of Paradoxically Rejected Blocks to help explain how the algorithm works. Please can you share your thoughts on this document ?	Free form
22	Please can you advise what improvements you would like to see in regards to EPEX auction interface?	Free form
23	Compared with the time and effort you spend participating in the monthly tender, how much time and effort is required to participate in the weekly auction?	1-10 Scale
24	Please indicate your interest in moving to Day Ahead procurement:	Interest/No Interest
25	Please indicate your current ability to move to Day ahead procurement:	Optins List
26	Please use the comments box to provide supporting commentary to the above questions. Answers could include areas such as the benefits that you would see for moving to Day Ahead procurement, and the potential blockers that you would face.	Free form
27	Please can you leave your email address below?	Free form

Appendix C Market Design for Frequency Response

C.1.1 The ESO relies on a number of different approaches for the procurement of frequency response including the monthly FFR tender process, the weekly auction trial, and a "real-time" mandatory service. Additional frequency response is provided by long-term contracts, although these contracts are no longer awarded. Of interest to this report are the monthly FFR tender and weekly auction. The design of these markets is summarised in the following table.

	FFR Tender	Frequency Response Auction Trial
Services Procured	The ESO procures dynamic low-frequency response (including both Primary "P" and Secondary "S" services as defined in the grid code) and dynamic high-frequency response (High or "H"). Participants may offer each of P, S, and H up to their tested quantities. Additionally, non-dynamic low-frequency response is procured.	Two standardised products are procured. The "Dynamic Low and High" (DLH) product, is a bundle of the FFR P, S, and H services where the quantities of each service are equal. The "Low Frequency Static" (LFS) product, corresponds to the non-dynamic FFR service but has a faster response time and lower trigger point.
Frequency and Timings	Tenders are for delivery of frequency response over a calendar month. Participants submit tender offers to the ESO on or before the 1st business day of the month preceding the delivery month. Tender awards are published on the 12th business day. Delivery begins on the first EFA Day of the month.	Auctions are for delivery of frequency response over a week. Each of 42 EFA periods is cleared separately. Gate open for submission of auction orders to the online platform is Thursday morning, with gate closure on Friday morning. Awards are published Friday afternoon with delivery starting at the beginning of the next EFA Day (i.e. Friday 23h GMT).
ESO Volume Requirements	Tender requirements are published monthly, on the 18th business day two months preceding the delivery month. Requirements vary by month and between EFA periods within an EFA Day. In May 2020, for example, requirements were in the region of 350 MW for dynamic response and 150 MW for low-frequency non-dynamic response (in EFA 3-6 only).	In each weekly auction since the beginning of the Phase 2 Auction Trials, the ESO has bid to procure 100 MW of each the DLH and LFS products in each EFA period. These requirements are deducted from the total overall requirement for commercial frequency response.
Award Determination	Tender submissions are evaluated manually by the ESO according to published assessment criteria.	The auction is "double-blind", meaning that both the ESO and market participants submit their confidential orders to the independent auctioneer, EPEXSPOT. The HELENA clearing algorithm matches bids and offers.
Pricing Basis	Tender awards are pay-as-bid for business days, Saturdays, and Sundays during the delivery month.	Auction awards are "pay-as-clear" for each of 42 EFA periods during week.

Appendix D EPEXSPOT HELENA Auction Clearing Algorithm

D.1 Linear Orders (ESO Bids)

D.1.1 Buy orders are submitted only by the ESO. A buy order is a linear demand order, which is a set of price and quantity pairs which define a stepwise curve decreasing with price (i.e. at higher prices, a lower quantity is bid). The ESO submits a different linear curve for each product and EFA period. The current release of the algorithm clears weekly auctions in 42 EFA periods for each of the two product types: DLH and LFS. Therefore, at present, there are 84 linear orders in total for each weekly auction.

D.2 Block Orders (Participant Offers)

D.2.1 Market participants submit block orders into the auction to define their offer (volume and price) for frequency response. A block order refers to one participating unit and one underlying product. Block orders may be single-period (i.e. defined on only one EFA period) or multi-period (i.e. defined on between two and six consecutive EFA periods within a single EFA Day). The EFA periods linked within a multi-period order are either all executed or all rejected by the algorithm. Single-period orders have a price limit and an offer volume. A multi-period order always has a single price limit which applies to all EFA periods in the order, but it may be defined as a profiled block, with different volumes for each EFA period.

D.2.2 A block order is defined as either a parent ("C01") block or a child ("C02") block. A child block has additional restrictions: it must be a single-period order and it must refer to a parent block (either single-period or multi-period) that is defined on the same participating unit and underlying product. The parent block to which the child refers must be defined either on the same EFA period as the child block, or on an adjacent EFA period within the same EFA Day. A parent block can have more than one child block, but at most one child per EFA period. A child block always has exactly one parent block. A parent block together with all the child blocks that refer to it form a "linked family".

D.2.3 A parent block is non-curtailable, which means either the full volume of the order must be executed, or else the order must be rejected. A child block is fully-curtailable, which means it may be partially executed: any portion of the child block's offered volume may be accepted by the algorithm. A child block can only be executed if its parent is also executed.

D.2.4 A basic block is defined as either a single-period parent block, or linked family of a single-period parent block and an associated child block specified in the same EFA period and at the same price limit. There are conditions (explained below) which favour the clearing of basic blocks.

D.3 Order Surplus

D.3.1 The surplus of a participant block order is defined as the difference between the clearing price less the order price, times the accepted volume of the block order. A block order is executed only if it has a surplus greater than or equal to 0. However, in the case of a linked family, the total surplus of the parent block and the accepted child blocks is considered together. A parent block with negative surplus may therefore be "saved" by its child blocks with positive surplus, if the total positive surplus of the child blocks exceeds the negative surplus of the parent blocks. It is possible for a block order to be paradoxically rejected, which means that the order is not executed despite having positive surplus.

D.3.2 Analogous to the definition of surplus for participant block orders, the surplus of an ESO linear order is defined as the order price less the clearing price, times the total accepted volume. The ESO linear orders may not have negative surplus, meaning that the clearing price in an EFA period may not exceed the ESO bid price corresponding to the total accepted volume in that period.

D.4 Optimisation

D.4.1 The HELENA algorithm is a Mixed Integer Linear Program developed by EPEXSPOT to clear the Frequency Response Auction. The algorithm clears each product (DLH or LFS) separately. The algorithm determines the set of executed orders and the clearing price in each EFA period. The objective function of the algorithm maximises total surplus (i.e. the total surplus of all participant block orders plus the total surplus of the ESO linear orders) across the 42 EFA periods while minimising clearing prices.

D.4.2 The optimisation is subject to constraints. First of all, there is a volume constraint: the total executed quantity in each EFA period must not exceed the ESO bid volume corresponding to the clearing price in that period. Secondly, there are the "merit order constraints": a basic block may only be rejected or curtailed if its offer volume exceeds the remaining demand, which is defined as the ESO bid volume at the block's limit price less the total quantity of executed orders in the EFA period with limit prices below the block's limit price. In the event that a basic block is rejected, then the total quantity of the accepted orders in the EFA period with limit prices higher than the basic block's limit price must be strictly less than the basic block quantity. Finally, there are welfare constraints: neither block orders nor linear orders may be paradoxically accepted. A block order with negative surplus may not be executed (with the exception that a parent block's negative surplus can be compensated by the positive surplus of its child blocks). The clearing price in an EFA period may not exceed the ESO bid price corresponding to the total accepted quantity at that price.

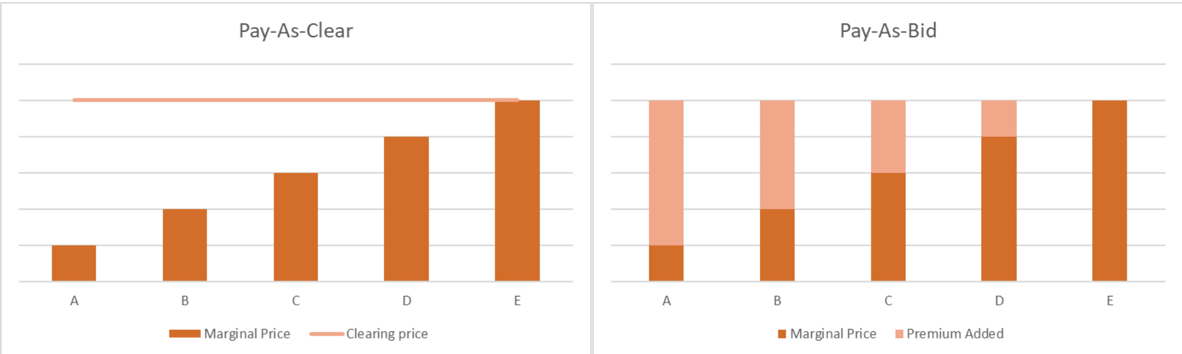
Appendix E Pay-As-Clear Auction Design

E.1.1 One of the major differences between the monthly tenders and the weekly auctions is the approach to defining clearing prices. The monthly tenders follow a "pay-as-bid" approach, in which successful bidders receive the price that they bid. In contrast, the weekly auctions follow a "pay-as-clear" approach, in which successful bidders all receive the same price, which is the clearing price. Typically, the clearing price is the bid price of the most expensive successful bidder.[2]

E.1.2 Under a combination of certain market conditions, both approaches should yield the same outcome. These conditions are:

- Perfect competition;
- Participants having perfect information; and
- The products procured being homogenous.

E.1.3 Under these conditions, all participants would know with perfect foresight what the marginal price of the auction would be and can respond either by bidding in at that level (if it covers their marginal costs) or not bidding at all (if it does not) – it would not matter if the auction pays their bid price or a clearing price.



E.1.4 In such a theoretical scenario, there would be several benefits to pursuing the pay-as-clear approach. Although the auction outcomes are the same, the pay-as-clear approach leads to:

- Greater transparency, as bidders are encouraged to bid their marginal costs or opportunity costs;
- Reduced barriers to entry, as the need to forecast auction results is removed;
- More efficient outcomes, as it reduces the need for bidders to forecast auction outturn prices, thereby reducing the risk that a cheaper unit that could have been accepted puts forward an uncompetitive bid based on an inaccurate price forecast; and
- A single clearing price which creates a signal that can be used for other commercial markets and decisions.

---

[2] For the HELENA algorithm, the definition of clearing price is more complex, because the algorithm optimises across 42 EFA periods and the auction permits multi-period blocks which have a single limit price applied over multiple EFA periods. The clearing prices in the Frequency Response Auction Trial are the minimum prices for which all executed orders have non-negative surplus.

E.1.5 If any of the three conditions above in paragraph E.1.2 are not met, the relative benefits of the pay-as-bid approach start to increase. For example, the early days of the Balancing Mechanism were dominated by a small number of participants who operated a large proportion of the market. This represented a lack of competition and a market power issue which would have been exacerbated under a pay-as-clear approach.

E.1.6 The Frequency Response Auction Trial has several features that suggest that the pay-as-clear approach is correct. The products in each auction are the same and can be assumed to be homogenous. There is a relatively low level of market concentration which helps to promote competition. All participants have access to a complete set of auction data that is published weekly on the ESO website.

E.1.7 To the extent that there is less than perfect competition or less than perfect information, mitigations can be implemented to improve outcomes. For example, we have recommended measures in this document to improve liquidity and encourage greater competition, which should further bolster the pay-as-clear approach. The use of sloped demand curves would further mitigate problems. The sloped bid curves provide an additional source of competition, where bidders have to compete with reduced demand as well as other bidders. This aids in the mitigation of market power. Sloped demand curves also reduce the information advantage that some participants might hold over others, as it becomes harder to forecast clearing prices accurately.