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ANALYSIS OF REFORM OPTIONS FOR STATUS QUO ELECTRICITY BALANCING ARRANGEMENTS

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1 Introduction

As part of the Review of Electricity Market Arrangements (REMA) programme, policymakers in DESNZ are considering a number of aspects of the current electricity market design. One important area relates to whether to implement locational pricing in the GB wholesale market. The second REMA consultation from DESNZ recently ruled out a move to locational marginal pricing (LMP) but DESNZ is continuing to consider a move to a zonal wholesale market, as well as looking at other stand-alone changes, including whether to move to a central dispatch regime (while maintaining a single national price).

The suggested benefits of a move to some form of locational pricing in broad terms relate to investment and operational efficiency:

- *Investment efficiency* – the efficiency benefit occurs if the locational signal in a locational market triggers more efficient siting decisions by investors relative to the current TNUoS arrangements, reducing the need to invest in network reinforcement.

- Operational efficiency – the efficiency benefit occurs if a single national price leads to inefficient planned dispatch of generating capacity, interconnectors, and sources of demand, which cannot be adjusted efficiently by ESO in the Balancing Mechanism. In comparison, perfectly efficient dispatch is assumed to be possible under LMP.

DESNZ carried out a study that showed benefits from moving to a zonal market, in particular related to operational efficiency. Ofgem published an assessment of locational pricing options by FTI which suggested that greater dispatch efficiency could be material under both zonal and nodal pricing. FTI's calculations also suggested that the operational efficiency benefits represent a substantial share of the total benefits (around 60%, or up to £14bn for LMP).[1] Although FTI's analysis focused more on LMP, FTI also assessed the case for a zonal market concluding that it would bring benefits albeit smaller in magnitude.

DESNZ and Ofgem both concluded that implementing locational pricing could produce significant benefits for society compared to the current arrangements. However, importantly, they also recognised that there are potential improvements that can be made to the current arrangements and that these need to be considered as part of a more realistic counterfactual for any assessment of locational pricing.

While FTI's work demonstrated that optimising the location of investment and optimising dispatch of domestic and international sources of supply could lead to substantial consumer and system benefits, FTI did not assess why the assumed perfectly efficient dispatch under LMP could not be achieved with reform in a national market.

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[1] https://www.frontier-economics.com/media/itvbt2rw/the-benefits-of-locational-marginal-pricing-in-the-gb-electricity-system.pdf page 3 showing 58% of system benefits are attributable to optimised dispatch.

Ofgem and DESNZ have signalled the need for more work to assess how much operational benefits of locational pricing could be achieved through incremental market reforms. On the basis of the scale of operational benefits identified by FTI, this is clearly an important stream of work.

Scottish Power has commissioned Frontier Economics to identify and assess options for incremental reforms to the current arrangements that could improve operational efficiency without implementing locational pricing. Even though LMP has been recently been ruled out for GB by DESNZ, and any operational efficiency benefits would likely be smaller in a zonal market, for the purposes of this report we qualitatively assess potential national market reforms relative to the theoretical benefits of LMP. This report also includes analysis by LCP Delta related to current interconnector redispatch.

The purpose of this report is therefore to:

- identify existing inefficiencies in the current balancing arrangements in GB;
- identify potential reforms to address them; and
- consider the extent to which these reforms could achieve efficient dispatch in a national market.

This report is structured as follows:

- In Section 2 we provide an overview of the current Balancing Mechanism arrangements

- In Section 3 we explain the efficiency standard that we consider for the purpose of this report and set out each of the areas of potential operational inefficiency that we have identified with the current arrangements

- In Section 4 we set out the reform options that we have identified to address the issues we have identified and provide a brief assessment of these reform options.

- Finally in Section 5 we explore how different reform options could be developed in coordination to address the broad set of operational efficiency challenges presented by the current status quo arrangements.

2 Status quo balancing arrangements

In this section we provide a brief overview of the balancing arrangements in GB, including the Balancing Mechanism. This is not a comprehensive description of all aspects of balancing. However, it should provide the broad context for the specific efficiency issues we discuss in the next section. We finish this section making a broad comparison between the working of the existing GB arrangements, and those that would be likely to be needed in an LMP market.

2.1 Overview of supply and demand balancing in GB

In GB, bilateral trading in electricity wholesale markets takes place from years ahead of delivery until gate closure (i.e. one hour ahead of delivery) and relates to energy (MWhs) delivered anywhere on the electricity grid in a half hour imbalance settlement period (ISP). Generators, traders, retailers and large consumers contract to buy and sell electricity, with contracts reflecting market participants' expectations of the national electricity supply and demand positions for the relevant ISP. Market participants are incentivised to ensure that supply and demand matches their contracted positions on a 30 minute basis because they are charged "imbalance prices" on any deviations.

However, demand and supply must be continually balanced on a second by second basis at each location on the grid, and the electricity grid has limited capacity. There is therefore a need for ESO to act as 'residual balancer' to ensure security of supply.[2] In broad terms, ESO is responsible for:

- ***Energy balancing***, which involves addressing deviations in the national supply and demand balance. This could be due to deviations between contractual and physical positions of market participants that occur close to real-time,[3] or due to a need to resolve sub-30 minute variations in supply and demand.

- ***Locational or "system" balancing***, which involves addressing congestion on the network that arises where there is insufficient network capacity to accommodate the pattern of locational supply and demand resulting from national wholesale trading. The ESO acts to "redispatch" market participants to ensure that the final pattern of supply and demand respects the physical transmission constraints of the system. In this role of resolving *locational constraints,* ESO will turn down generators (or increase demand) in

[2] In addition, licence obligations (i.e. The Grid Code, https://www.nationalgrideso.com/document/287271/download) mean ESO has to act economically and efficiently, and there are a range of measures to assess whether ESO is meeting these obligations.

[3] Many sources of electricity demand cannot be actively controlled in real time and there remains uncertainty about the volume of electricity that generators will deliver to the grid until very close to real time, in particular from variable renewables such as wind and solar.

areas of excess supply, and turn up generators (or reduce demand) in areas of excess demand.

To fulfil its balancing obligation, ESO uses a range of tools, with the key one being the centralised Balancing Mechanism (BM). This operates after gate closure and is described in more detail below. However, not all of ESO's balancing decisions and actions in relation to a given ISP take place through the BM or after gate closure. For example:

- ESO trades with other interconnected SOs (SO to SO trades) post gate closure and with other market participants pre-gate closure (i.e. while wholesale trading in relation to the relevant ISP is still going on) to adjust the flows over interconnectors; and
- Due to the inflexibility of some assets and the short time available from gate closure until the start of delivery, ESO takes such pre-gate closure actions to ensure adequate reserve capacity is available later in the day.

2.2 Overview of the Balancing Mechanism

Trading on the wholesale market ends in relation to an ISP at gate closure (which takes place one hour ahead of the start of the relevant ISP). Large generators and consumers, constituting primary BM units (BMUs),[4] submit Final Physical Notifications directly to ESO, indicating their planned pattern of production and consumption. They also submit bids and offers to increase or decrease their output or consumption. Smaller secondary BMUs can also submit balancing bids and offers via a Virtual Lead Party (VLP).[5] These bids and offers allow ESO to make adjustments to a BMU's expected physical position after gate closure until delivery:

- **offers** indicate a willingness to generate more electricity (or to consume less electricity) at a specified price. From ESO's perspective, this is adding energy to the system at a specified location; and

- **bids** indicate a willingness to consume more electricity (or to generate less electricity) at a specified price. From ESO's perspective, this is removing excess energy from the system at a specified location.

Participants also submit data to ESO to inform it of the capabilities of their plant (for example, maximum production, ability to change output quickly etc):

- ***Technical information*** known as Dynamic Parameters (also called the 'dynamic dataset') reflects the characteristics which reasonably describe the feasible operation of the unit are. Ofgem has clarified that these parameters should be purely "technical" (though its wording leaves some room for interpretation). In addition to the Dynamic

4 The minimum capacity for a primary BMU is 50MW in England and Wales, 30MW in South Scotland or 10MW in North Scotland. https://bscdocs.elexon.co.uk/guidance-notes/bm-units-registration-of-balancing-mechanism-bm-units

5 The minimum capacity for a secondary BMU is 1MW. They can be formed from individual units, or they can be created by VLPs aggregating the capacity of units below 1MW of capacity that are within the same Grid Supply Point Group.

Parameters, BMUs also submit their maximum export and import limits (MEL/MIL). These reflect the maximum export (import) to (from) the Transmission System that the unit is able to make.

- ***Physical notifications*** (PNs) which reflect users' best estimate of expected import/export of active power (in MW). These are submitted day ahead as Initial Physical Notifications (IPNs) and can change ahead of gate closure, but at gate closure are fixed as Final Physical Notifications (FPNs).

- ***Bid-offer pairs*** which consist of a 'from' capacity level (in MW) with a corresponding 'from' time (as the start of the relevant settlement period) paired with a 'to' capacity level with a corresponding 'to' time, and associated offer and bid prices (in GBP/MWh).

ESO uses its internal optimisation tool, the ESO Security-Constrained Economic Dispatch ("SCED") algorithm, to identify the optimal dispatch of the network reflecting both energy and system needs. This optimisation takes place ahead of gate closure to identify any necessary early actions, and then again after gate closure. Based on the outputs of this optimisation, ESO issues bid-offer acceptances (BOAs) to the BMUs (on a pay as bid basis) notifying them how to adapt their generation/consumption in order to resolve energy and system balance issues. It is worth noting that the same arrangements for FPNs and BOAs applies to storage BMUs, and while interconnectors are also BMUs, they are redispatched based on different arrangements that take place pre-gate closure. We discuss these aspects in more in the next section on potential inefficiencies.

In principle, ESO accepts the most competitive (i.e. the cheapest) bids and offers taking account of relevant technical constraints of plants and limitations in the capacity of the grid. Figure 1 below illustrates the timeline of this balancing process.

Figure 1 Balancing process timeline

	Prior to day-ahead deadline	Day-ahead deadline to gate closure	Intra-day gate closure to start of settlement period	Settlement period
Market	Before 11am on the day before delivery	-	60 minutes before settlement	30 minutes
	Wholesale trading		Balancing Mechanism	
BMUs	Dynamic parameters, physical notifications, and bid-offers are submitted		Final physical notifications submitted (FPNs)	
	Maximum export/import limits are submitted (in practice, dynamic parameters such as SEL or MZNT are also updated in real time)			
ESO	Demand forecast is published one day ahead	Indicative data is published, system demand, LOLP, margin, imbalance are intermittently updated	System imbalances are determined based on FPNs, Bid-offer acceptances (BOAs) are issued to BMUs	
	Negative reserve active power check and operating reserve management			

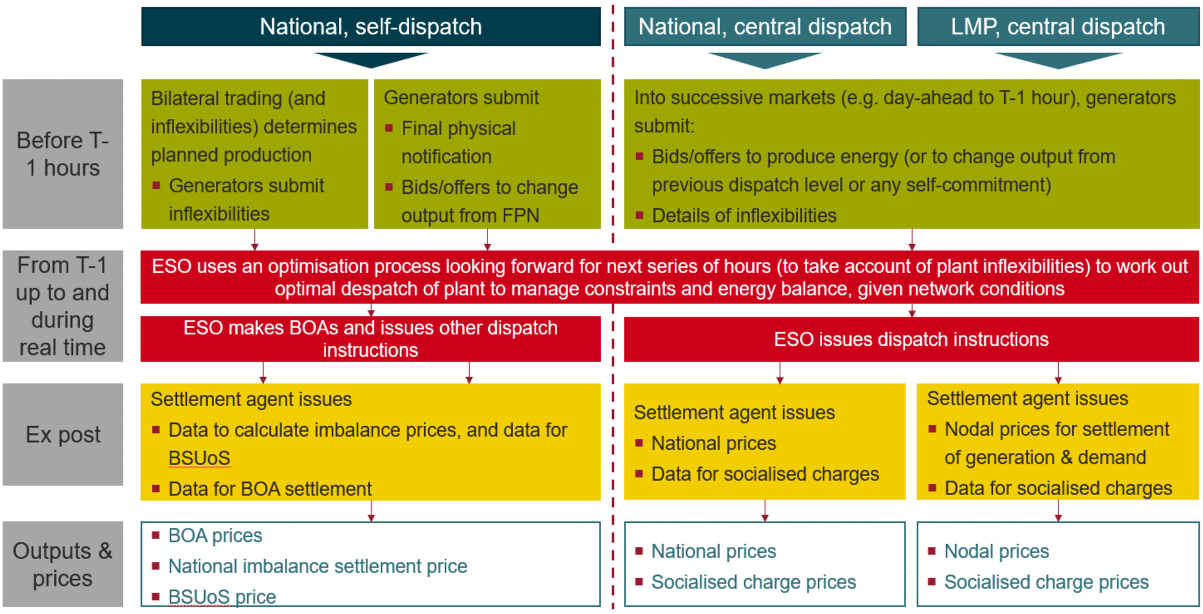
Source: *Frontier Economics*

Note: *This figure illustrates the timeline of BM operation. However, we note that some ESO actions take place ahead of gate closure due to inflexibility of some generating assets.*

2.3 Potential market arrangements in an LMP market

Although LMP has been ruled out in its second REMA consultation, LMP provides a helpful benchmark against which to compare current arrangements and potential reforms in a national market. Therefore, as context to the discussion that follows on potential inefficiencies and areas where specific changes or reforms may be needed to address them, we describe in broad terms some of the key features of an LMP market, and note how they compare with those in a national market. This comparison is set out in Figure 2 and the following text.

Figure 2 Operation of different forms of electricity market



Source: Frontier Economics

Below we describe some of the key features of LMP market processes:

- It would be likely that there would ***not be any forward trading for physical delivery*** (hence no need for a process for submitting FPNs), and that forward bilateral trading would become purely financial. Market participants may be able to hedge their exposure to nodal prices through financial trades at a central trading "hub" and the purchase of Financial Transmission Rights (FTRs).
- ***Market participants would submit data to ESO*** at various points in time (e.g. day ahead and various points intra-day) indicating availability, technical constraints on assets, and commercial price data. The precise data could be different from that submitted to the BM today. ***Appropriate technical data would need to be defined*** for capacity constrained assets (e.g. conventional power plants) and energy constrained assets (e.g. storage, certain forms of DSR).
- These data would form ***inputs to a pre-defined dispatch algorithm*** which optimised supply to meet demand over an optimisation horizon (which could be the next few hours or longer – e.g. the next day). This represents a shift from the current arrangements of self-dispatch to central dispatch.
- With central dispatch, market participants could also offer ancillary service provision alongside energy offers so that ESO could ***co-optimise both energy and ancillary services in a single market process***.
- ***ESO would run the nodal algorithm*** (based on its best forecast data for periods beyond the next ISP, taking into account particular plant inflexibilities) ***and determine an efficient dispatch*** that would meet modelled grid constraints and forecast demand (incl. potentially

requirements for reserve). The algorithm would also determine prices at each node which would be published to the market and used in settlement.

- The balance of supply and demand will change as the system moves closer to real-time i.e. as forecast data improves, and ***ESO would continue to re-run its algorithm to issue new instructions*** to change physical schedules from those previously instructed, and issue updated prices at each node (again, to be used in settlement).
- Arrangements for ***incorporating bidding information*** from smaller assets, and ***issuing instructions*** to those smaller assets would need to be defined.
- Arrangements for ***storage optimisation would need to be designed*** (i.e. over what time horizon), and ***arrangements for interconnector participation in the central dispatch algorithm*** at day ahead and intraday timescales would need to be defined.
- The nature of any ***information provided by ESO to the market would need to be defined*** (e.g. on demand forecasts, potential scarcity events, and the status and expected capacity of the transmission grid)

3 Review of balancing inefficiencies

In this section we identify areas of existing GB balancing arrangements that could potentially produce operational dispatch inefficiencies. First we explain what we mean by efficient dispatch, against which current arrangements can be assessed, and motivate the three potential drivers of inefficiency with which we structure our review of the current arrangements:

- information i.e. to what extent would the current information received by ESO from market participants in the BM inhibit efficient optimisation of available resources;
- optimisation i.e. to what extent would ESO's approach potentially prevent identification of an efficient pattern of dispatch; and
- implementation i.e. to what extent does ESO make use of systems and processes which hinder the implementation of an efficient dispatch.

3.1 Efficient dispatch

The primary purpose of the BM is to ensure security of supply in a manner that minimises the total operational system costs (i.e. fuel, carbon and variable operational costs) of all assets on the system. This means selecting bids and offers in least cost order, while respecting the technical constraints presented by different plants on the system and the grid itself.

From an economic perspective, the BM should operate on a least-cost basis. That means selecting the lowest cost bids and offers, subject to:

- The technical capabilities of the resources on the system (i.e. the technical constraints associated with power plants);
- The best forecasts (e.g. related to variable renewables) available at the point in time that decisions on dispatch must be made; and
- The particular risk appetite of the ESO.

In general, a BM that is unable to minimise costs can be described as sub-optimal. However, while it may be possible to judge with the benefit of hindsight that a certain pattern of dispatch was sub-optimal, in this study we are particularly focused on the extent to which that is a result of the market rules of the BM or the mechanisms by which dispatch decisions are made. In essence we assume that the constraints noted above are fixed, on the grounds that we are less focused on inefficiency due to the particular physical characteristics of the plants on the system, the forecasting capabilities of ESO, or the particular risk appetite of the ESO.

In this report, we also focus on dispatch cost. In broad terms, minimising dispatch costs will lead to lower customer costs. However there are complex transfers between generators and customers which may mean, in some specific cases, minimising dispatch costs does not minimise customer costs. We do not consider these specific cases as part of this report.

In principle, an idealised version of a national market (under either self or central dispatch) and an idealised LMP market should result in the same physical dispatch of power (if not the same commercial outcomes for participants). This is because the fundamental objective of each of these forms of markets is identical i.e. to satisfy demand over time at lowest cost subject to the constraints imposed by the physical production park and the network.

As we indicated in Figure 2, in both an LMP market and a national market with redispatch, at some point ESO runs an optimisation process to work out how to satisfy demand close to and during real time (given the production resources available and the condition of the network). If this is a "perfect" optimisation, and if it is fed consistent inputs across the different forms of market, then it should result in the same outcomes in terms of dispatch of resources.

An implication of this is that if the existing market arrangements are not achieving the level of efficiency which could be achieved by a new LMP market, this must be because either:

- the ***information*** being fed into the existing optimisation process (i.e. the process by which ESO chooses which BM bids and offers to accept) is in some way "inferior". This "inferiority" could have a number of dimensions, for example relating to the time of submission, the structure of data provided, the breadth of assumed participation, and the extent of uncertainty;

- the ***optimisation*** process being used is in some way "inferior". Again, this could have a number of dimensions, for example relating to the nature of the optimisation algorithm, the constraints assumed within the algorithm, or the timing of the optimisation process; or

- the ***implementation*** of the dispatch process is in some way "inferior" in the sense that ESO is not able to implement the dispatch that is implied by the optimisation process. For example, ESO may not have systems or processes to redispatch certain assets as easily as others in the available timeframe.

This conceptual starting point is useful in that it focuses the analysis of potential sources of lower operational efficiency into these three areas, and likewise indicates the nature of potential improvements to the current arrangements.

It is important to note that some of the drivers of inefficiency which we identify in relation to today's market may also apply to an LMP market (e.g. to the extent that they apply to systems and processes which could be identical between the markets). We highlight where this is the case in our description of reform options in Section 4, and consider the implications for the LMP counterfactual in Section 5.

3.2 Potential information inefficiencies

We have identified four ways in which limitations with the current information set provided to ESO may give rise to inefficiencies. These potential limitations relate to:

- how the operational inflexibility of some plants is communicated to ESO;
- the information ESO receives related to storage assets;
- the ‘pay as bid’ approach to pricing; and
- the accuracy and timeliness of information provision to ESO.

For each area we first set out the context and describe the particular aspect of the status quo arrangements that may give rise to the inefficiency, and then describe the efficiency impact.

3.2.1 Generation inflexibilities

Context and status quo

Participants in the BM are required to submit a set of technical parameters related to the physical operation of the plant, alongside FPNs and their Bid and Offer ladder.

By 11:00 on the day before the operational day (day-ahead deadline), ESO requires BMUs to submit relevant data for all settlement periods, which it then uses for its operational planning. All data may be modified through further data submissions at any point after the day-ahead deadline but before gate closure.

The technical data (the “dynamic data set”) includes the following information:

- ***Run-up and run-down rates:*** The rate at which the BMU can increase/decrease its electricity import or export (in MW/minute)
- ***Notice to deviate from zero (NDZ):*** The notification time required by the BMU to switch on and start importing/exporting electricity (from a zero level) as a result of a bid-offer acceptance
- ***Notice to deliver offers (NTO) and notice to deliver bids (NBO):*** The notification time required by the BMU to start delivering the capacity it has submitted as a bid-offer from the time that ESO has issued a bid-offer acceptance
- ***Minimum zero/non-zero times (MZT/MNZT):*** The minimum time the BMU needs to be switched off or on
- ***Stable export/import limits (SEL/SIL):*** The minimum electricity generation/import level a BMU can operate at, under stable conditions
- ***Maximum delivery volume (MDV) and maximum delivery period (MDP):*** The maximum electricity that the BMU may import (export) from bids (offers) over the period specified
- ***Last time to cancel synchronisation:*** The notification time required by the BMU to cancel its transition from operation at zero

Based on analysis carried out as part of ESO's BM Review, there is evidence that some of these parameters, in particular MZT and MNZT, are not being set on a purely technical basis i.e. the true technical minimum on and off times, as formally required by Ofgem. This may not be surprising. Costs of starting and ramping over a generation cycle may be a more direct driver of non-variable cost than the length of time the plant is on or off. Changes in MZT and MNZT parameters may therefore reflect changes in the planned recovery of start and ramping costs over a generation cycle, rather than the fundamental MZT/MNZT of the plant.

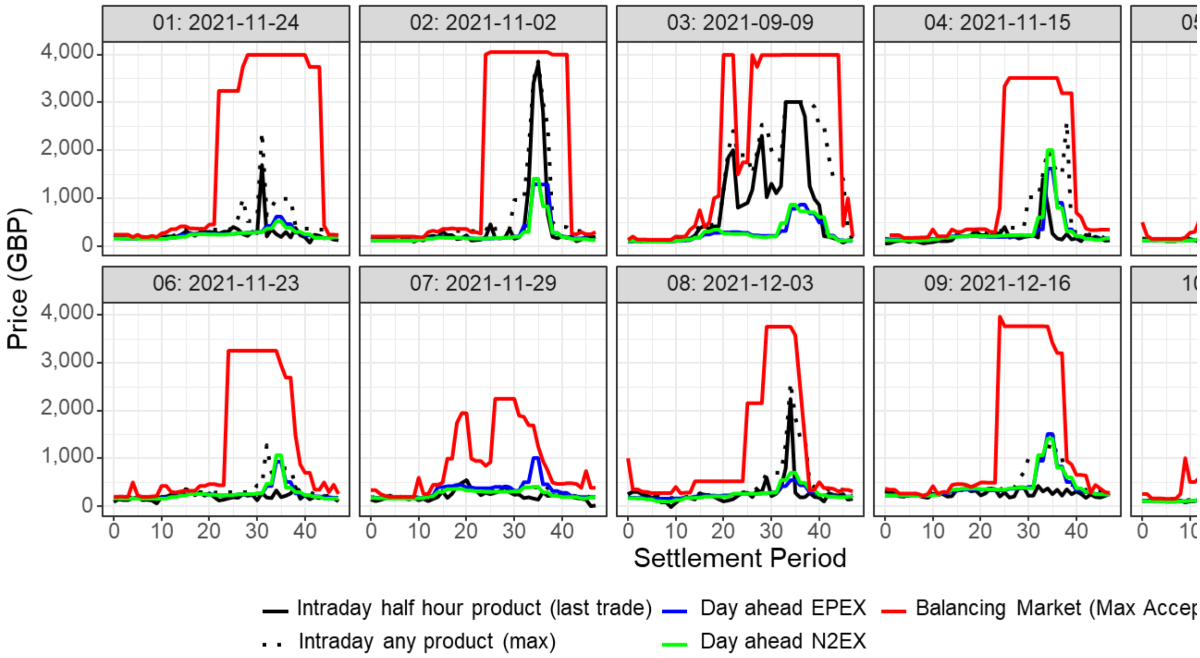
Nonetheless, ESO is required to strictly observe MZT and MNZT, with no flexibility in these values, when taking its balancing market actions.

Efficiency impact

The current system limits the options open to ESO to minimise system costs by limiting the ways in which the true capability of plants can be expressed i.e. by using MZT and MNZT and a single price £/MWh. ESO does not have an ability to run a plant in a manner that deviates from the strict limits implied by the "technical" parameters, even when doing so might be technically feasible and might reduce overall balancing costs after taking into account any additional costs the alternative running pattern would place on the individual inflexible plants.

The consequences of this inflexibility can be observed in the comparison between intraday prices and BM prices on very tight days as illustrated in Figure 3 below.

Figure 3 Relationship between day ahead, intraday and BM prices



Source: Frontier Economics, BM Review

It is not surprising that intraday and BM prices are similar in the peak period. Indeed, in general, intraday prices and BM prices for the same period should be closely related. The deviation of BM prices from intraday prices ahead of the peak period reflects the fact that unlike in the intraday market, BM participants can contract ahead of the peak in recognition of plant inflexibilities. This meant that BM prices significantly exceed intraday prices in the afternoon, when ESO was accepting high offers to ensure production was available over the peak period. For example, in order to ensure a plant was available for the evening peak ESO is sometimes required to accept offers earlier in the day to prevent a plant going offline with insufficient time (i.e. as defined by its MZT) for it to be brought back on later when needed. This market signal in the afternoon BM would imply the system is under scarcity conditions at the time when actually it was actually well supplied for afternoon ISPs.

With more operational flexibility, ESO may choose to run inflexible plants for shorter periods, accepting the implications for increased costs during the reduced running period.

3.2.2 Storage assets

Context and status quo

As the number of storage units in the market increases, there is increasing expectation that they will play an important role in the BM. However storage operators have indicated that they believe there are occasions when they are not being dispatched despite appearing to represent a cheaper option for ESO.[6]

Part of the explanation may relate to forecast errors by ESO. For example, ESO may have:

- thought it needed all available capacity for the evening peak and therefore dispatched some larger more expensive plants earlier in the day to ensure they were available at peak; and
- then only with the benefit of hindsight realised its demand forecast was too high, and that it may have been possible to have relied on just smaller storage plants available at peak.

However, another possible explanation relates to the technical information that storage assets provide to ESO. Storage, by its nature, has a limited duration. However, the technical information storage plants currently submit does not adequately capture the energy constraints they face. Specifically, there is currently no way for storage operators to indicate their level of charge or available discharge duration.

Efficiency impact

Without knowing the stored energy of storage, ESO cannot rely on it to be available. We understand that as a result, ESO currently operates the '15 minute rule' to ensure storage assets can provide reliable power in the BM, without knowing the state of charge.[7] The purpose of this rule is to reflect storage capabilities while working within current BM limitations. The rule means storage assets should submit technical parameters (Maximum Export Limit / Maximum Import Limit) that can be sustained for 15 minutes, which are then updated on an ongoing basis.[8] However, this may result in a reduced dispatch of storage in the BM relative to the possible efficient levels and thus an increase in the cost of resolving both energy and system balancing requirements.

3.2.3 Pay as bid

Context and status quo

The BM settles balancing actions on a 'pay as bid' approach. In other words, when market participants submit bids and offers, if this results in a BOA from ESO, they will be settled at the price set in their bid or offer. This is in contrast to a 'pay as clear' approach where all participants receive the market clearing price (at their node). This is illustrated in Figure 4

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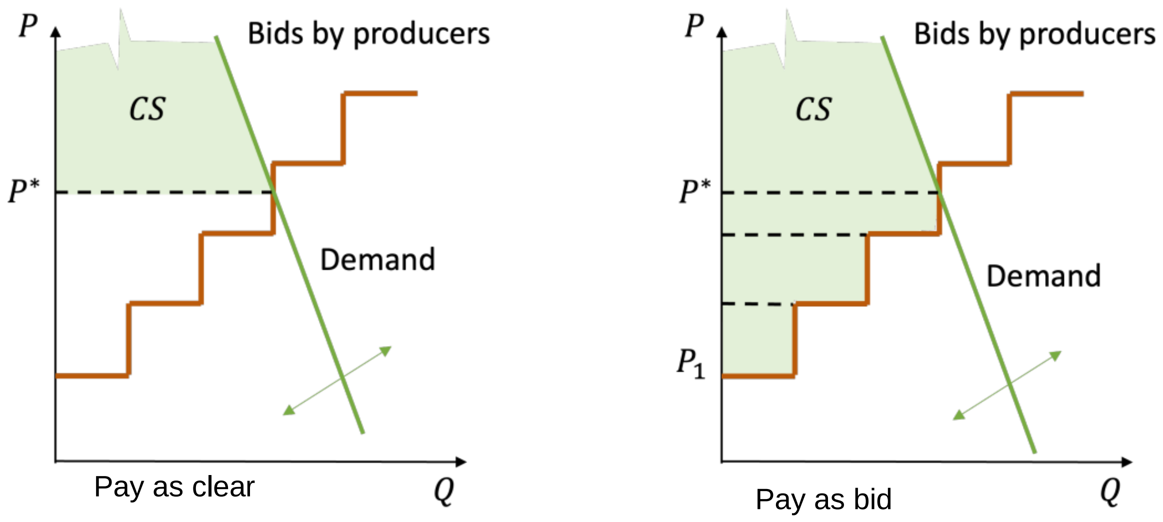
6 Electricity Storage Network (ESN) letter to ESO, 26 July 2023; and ESO response to ESN, 27 July 2023; https://www.nationalgrideso.com/news/eso-responds-esn-call-balancing-mechanism-reforms. ESO response outlines the way these issues are being addressed (see Section 4.1.2 and Section 4.3.5 for more details on reform).

7 National Grid ESO, *Unlocking Stacking of BOAs with Frequency Response Services*, Section 2; https://www.nationalgrideso.com/document/184466/download

8 ESO can issue BOAs for longer than the 15 minutes if the unit keeps it Maximum Export Limit above zero (or Maximum Import Limit below zero) as the energy is taken from the unit (or put in to the unit).

below with a single clearing price in the pay as clear market on the left and effectively multiple prices in the pay as bid market on the right.

Figure 4 Illustration of pay as bid and pay as clear arrangements



Source: https://www.tse-fr.eu/sites/default/files/TSE/documents/conf/2022/energy/yu.pdf

Pay as clear is adopted, for example, in the day ahead wholesale market auctions run by exchanges, and is typically adopted in LMP markets.[9]

The 'pay as bid' approach was established when NETA was introduced, in part as a means of limiting the impact of market power. If an individual power station was in a position to set a very high price (well in excess of its short-run costs) in the BM, the impact of any abuse of market power is limited by the fact that other parties would only be paid on the basis of their own bid or offer (which may not have anticipated the abusive behaviour).

However, in a pay as bid market, participants are not incentivised to bid their costs, but rather to bid at (or just below) the expected marginal bid or offer that would be accepted. This would ensure their bid is accepted, while still allowing them to capture infra-marginal rent. In contrast, in a pay as clear model, participants do not need to bid above their cost to secure infra-marginal rent, as they are assured of receiving the marginal bid or offer price.

Efficiency impact

With perfect information and foresight, pay as clear and pay as bid should lead to the same efficient market outcome, with identical dispatch and all participants receiving payments based on the marginal bid or offer accepted in the BM. However, with imperfect information in the

9 We also note that EC regulation 2017/2195 on guidelines on electricity balancing also required all TSOs to develop a pay as clear methodology for determining prices for balancing energy actions. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R2195 (Article 30)

real world, under the pay as bid model there is a risk that a market participant which should be in merit makes an error in forecasting the marginal bid and bids in a way which leaves them out of merit. In this instance, even if ESO accepts bids and offers in a manner that minimises its costs, because the bids and offers on which it optimises have been distorted, total system costs will not be minimised.

3.2.4 Accuracy and timeliness of information provision

Context and status quo

When making dispatch decisions, ESO must rely on the information that is provided to it. This can be in the form of FPNs, at gate closure, or IPNs, ahead of gate closure.

FPNs are submitted at gate closure, and for any individual asset should be consistent with expected physical output (and across a portfolio should also reflect the net contracted position).

However, FPNs may not reflect actual dispatch. Although the submission of FPNs is subject to *Good Industry Practice* and submitting deliberately misleading FPNs may be in breach of REMIT, it is possible that submitted data is simply inaccurate, on the basis that there would be no immediate financial penalty for BMUs that submit inaccurate FPNs. Additionally, there are also situations in which some market participants might find it commercially advantageous to deviate from their FPNs for their plants because imbalance charges are based on net portfolio volumes. Consider the following example:

- A single party with a portfolio consisting of a wind BMU and a dispatchable BMU;
- The party submits good faith FPNs for both BMUs but wind output falls below initial levels leaving the party exposed to imbalance charges;
- The party could avoid exposure to imbalance prices by increasing output from their dispatchable BMU such that their net generation volume is equal to their contracted position; however
- Output from the wind BMU would be below the FPN (due to forecast error) and the output from the dispatchable BMU would exceed the FPN for commercial reasons.

Significant sustained deviations between FPNs and metered volumes may not meet the GIP standard but enforcement may be difficult because there remains room for interpretation.

As we have noted, particularly as a result of the need to schedule inflexible assets, ESO frequently makes decisions ahead of gate closure (the point at which FPNs are submitted). When ESO is making these decisions, it must rely on submitted IPNs and its own forecasts.

IPNs are subject to change, including those which reflect the on-going optimisation of market participants as they trade bilaterally intra-day. Changes to IPNs reflecting intraday bilateral trading are likely to represent efficient adjustments to balance national supply and demand. However, it may also be the case that submitted IPNs are not accurate. Like FPNs, the submission of IPNs is subject to the GIP standard. As noted above this could be viewed as a relatively weak incentive to ensure accuracy at all times.

Efficiency impact

If ESO takes actions based on inaccurate information it is likely to give rise to dispatch inefficiency. In addition, ESO knows that IPNs and FPNs are subject to a degree of uncertainty in terms of delivery and therefore will tend to optimise the system with a margin for error to account for IPN/FPN inaccuracy, again implying lower efficiency.

3.3 Optimisation based issues identified

We have identified three ways in which limitations with the current optimisation process may give rise to inefficiencies. These limitations relate to:

- incomplete locational optimisation by ESO;
- intertemporal optimisation of storage assets; and
- the sharing of information by ESO with market participants on the optimisation process

We explain the context, status quo and efficiency impact for each of these issues below.

3.3.1 Incomplete locational optimisation

Context and status quo

ESO currently does not operate a national nodal optimisation algorithm. Instead it focuses on areas in which it identifies constraints and identifies actions to deal with these based on a local or regional optimisation.

Efficiency impact

It is difficult to judge the impact of not operating a nodal algorithm. However, by not implementing a national nodal optimisation algorithm, ESO may arrive at a suboptimal dispatch. Specifically, it raises the possibility that that the current ‘local’ approach may lead to:

- efficient redispatch options that involve assets outside of the immediate area of an individual locational constraint to be missed; and
- efficient redispatch options that could potentially contribute to resolving multiple constraints concurrently to be missed.

3.3.2 Storage assets

Context and status quo

Storage assets can only provide energy to the system on a time-limited basis. The optimisation of storage is also complex, and in theory (particularly for storage sites with durations which are long compared to an ISP) should involve optimisation over a number of periods. This is because the optimisation question for an energy constrained plant is about when the energy should be used. If it is used in period T, it is not available to be used in T+1, and so an analysis of both time periods is relevant.

We understand that ESO does not currently seek to optimise the dispatch of storage assets over extended time periods.

Efficiency impact

The most efficient dispatch of a storage asset over a given time horizon is to schedule its dispatch to displace the highest cost alternative generation option over that time horizon. By not optimising storage dispatch over an extended timeframe ESO may miss the opportunity to dispatch storage when it can reduce costs by the greatest amount. In other words, ESO might dispatch a storage asset in time T, whereas had it optimised over time T and time T+1, it would have realised that the greater cost saving would have arisen from the dispatch of the storage asset in time T+1.[10]

To illustrate the potential size of the impact, the potential scale of growth in battery storage is shown by National Grid's Future Energy Scenarios. In these scenarios battery capacity in 2022 was under 3GW but in some cases this rises to as much as 35GW by 2050.[11] [12] For context, current storage capacity is just over 6GW (including non-battery storage) of which under 2.5GW has a duration of more than 4 hours, which is predominately pumped hydro storage. Given that much of the current battery storage is shorter duration, there is likely to be a requirement for optimisation over multiple time periods.

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10 We note that optimisation of storage over a longer time horizon in a market with bilateral trading and a gate closure period near to real time is complex, because ESO is not the only party that can dispatch the storage. For example, while at time T the ESO might determine that they wish to use a (currently charged) storage asset at T+4, the ESO will remain uncertain as to whether the owner of the storage asset will discharge the asset in the intervening hours unless ESO were to contract ahead of time for the storage asset to be available (at a contracted state of charge) through a service such as Balancing Reserve.

11 National Grid Future Energy Scenarios 2023

12 Whilst this is clearly a very significant increase in storage capacity it is difficult to translate that into a specific impact in the BM – although most battery storage will be participating across wholesale and balancing markets.

3.3.3 Provision of information on the optimisation process

Context and status quo

Prior to gate closure, market participants trade to optimise to ensure balance between their physical and commercial positions. However, the way in which they optimise may also take into account their expectations of ESO's requirements for balancing in the BM, in particular in relation to locational balancing. For example, a storage plant may choose to hold energy for the BM if it believed there would be more value in that market (e.g. due to its location relative to expected constraints) compared to the wholesale market. Therefore, the resources available to ESO in the BM are linked to the expectations formed by market participants.

The current provision of data to market participants may limit their ability to anticipate locational price signals in the BM and therefore to optimise their assets' operation to best support efficient balancing market outcomes. While data is provided on (historical) accepted bids and offers, this does not allow easy computation of the value of energy at nodes at which there were no acceptances (in a nodal market historical nodal prices are published for each node for each ISP).

Efficiency impact

In a national market with redispatch, short term locational price signals only arise in the BM. Therefore, for plants to target their availability at ISPs where it is likely to be most valuable (including its locational value in relieving constraints), asset owners must form expectations of likely BM prices. The absence nodal historic will tend to make it more difficult for asset owners to forecast BM prices effectively.

This will tend to reduce the options which ESO has to resolve locational balancing issues. For example, if storage asset owners cannot accurately forecast BM prices, they may discharge stored energy in ISPs with higher national prices despite the fact that higher BM profits would have been available to them had they waited. This may in turn mean they are unavailable for use by ESO to redispatch, which in turn may increase locational balancing costs.

3.4 Implementation based issues identified

We have identified two ways in which limitations with the current ability of ESO to implement an optimised set of dispatch actions may give rise to inefficiencies. These limitations relate to:

- Interconnection dispatch; and
- Smaller assets.

We explain the context, status quo and efficiency impact for each of these issues below.

3.4.1 Interconnectors

To consider the degree of inefficiency regarding interconnector redispatch, it is helpful to consider the current arrangements:

- pre-gate closure, where redispatch of interconnectors takes place intraday via ad hoc ESO run auctions on a number of existing interconnectors; and
- post gate closure, where arrangements exist between ESO and some neighbouring SOs, but are used much less frequently.

Pre gate closure

Context and status quo

On a number of interconnectors, arrangements are in place for ESO to adjust the flow pre-gate closure relative to the commercial position set by traders in the wholesale market.

Holders of interconnector capacity must confirm their flow nominations in 24 hourly nomination gates, each of which is one hour prior to delivery. ESO can trade with parties to influence these nominations for balancing purposes. ESO does this by holding ad hoc intra-day auctions for parties to nominate a flow against the direction of the expected commercial flows. These ESO auctions may run multiple times throughout the day but not after gate closure.

Once a bid is accepted, the party can either use interconnector capacity they already held to give effect to the agreed nomination or must participate in an intra-day capacity auction to ensure it has the necessary capacity. These intraday capacity auctions usually take place multiple times a day, although their schedules differ between interconnectors.

We understand that this process does result in a material volume of ESO trades on a daily basis, and that in deciding to make these trades ESO is making efficient judgements, trading off the relative cost of using domestic or international balancing resources, based on the available information at the time.[13] In other words, ESO is comparing the expected cost of interconnector trades with alternative options they expect to be available in the BM.

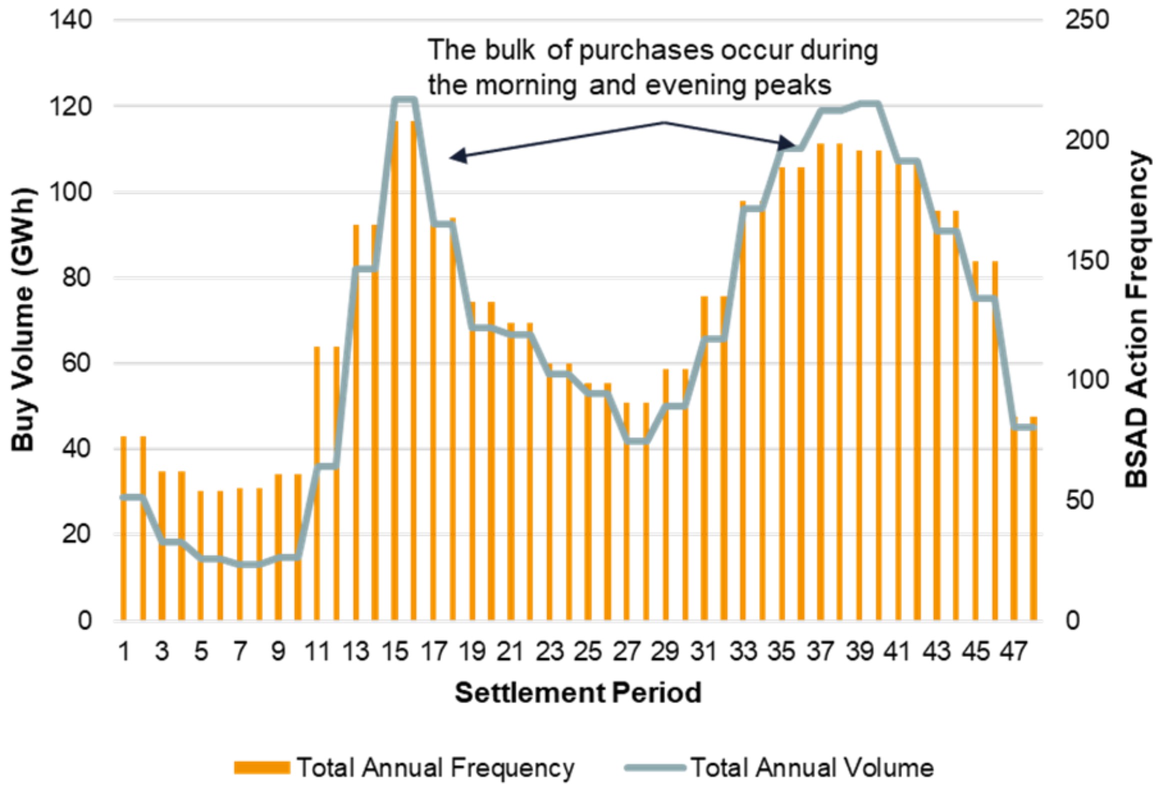
Based on analysis of Balancing Services Adjustment Data (BSAD) from 2022 we observe that ESO frequently took actions via the auctions to adjust interconnector flows.[14] Across the five interconnectors in the South East of GB, ESO facilitated 3.2TWh of energy imports through BSAD actions across 310 days in 2022, and 0.79TWh of energy exports across 88 days. A summary of BSAD buy volumes (i.e. actions to increase imports) and the number of

13 National Grid ESO, Interconnector Requirements and Auction Summary, https://www.nationalgrideso.com/data-portal/interconnector-requirement-and-auction-summary-data/interconnector_requirements_and_auction_summary

14 BSAD actions are balancing actions taken outside of the BM and published. These actions are bilateral trades between ESO and a counterparty. These are a mix of pre- and post-gate closure actions.

buy actions (i.e. imports) by settlement period is shown in Figure 5.[15] This shows that ESO has adjusted flows in all periods of the day, but most typically during the early morning, and throughout the afternoon and evening peak periods. See Annex A for more details. This is not directly reflected in FTI's counterfactual, in which when dispatchable gas is available on the system, redispatching interconnectors is assumed to be a more expensive option.[16]

Figure 5 Interconnector BSAD actions in South East England – buy volume



Source: LCP analysis of Balancing Services Adjustment Data

Note: South East England interconnectors considered are IFA, IFA2, BritNed, Nemo and ElecLink

Efficiency impact

While actions by ESO appear to be frequent, we also observe that there may be potential for ESO to make further efficient adjustments to interconnector flows. Figure 6 shows the scheduled and adjusted interconnector flows on 10 November 2022. In this example, there was a constraint on flows from Scotland to England, requiring a reduction of generation (increase in demand) in Scotland, and an increase in generation (reduction in demand) in England. As is fairly typical, ESO chose to reduce wind output in Scotland and increase gas generation in England. This is shown in Figure 6, where we can see that throughout the day,

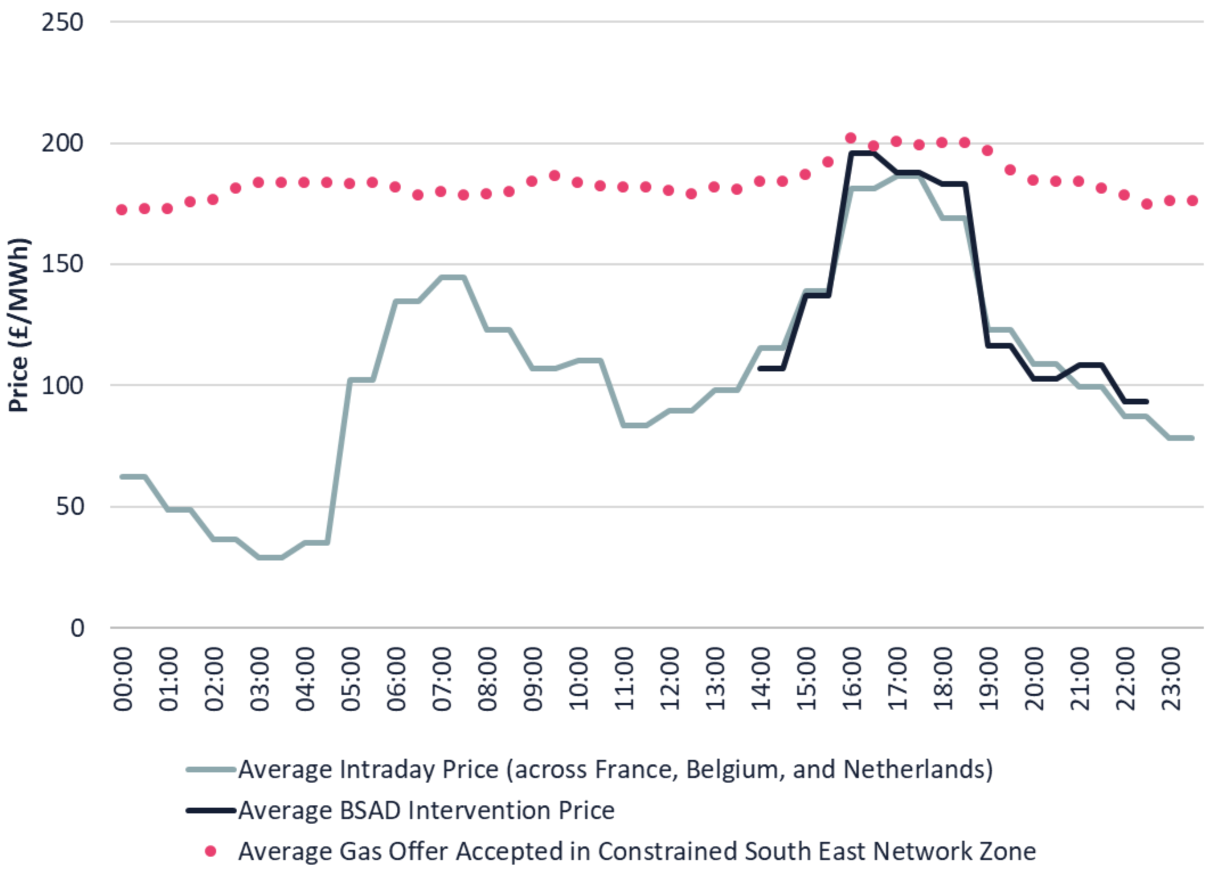
[15] The equivalent chart for BSAD sell volumes and the number of sell actions by settlement period in shown in Annex A

[16] In practice, FTI does not assume any interconnector redispatch until 2035.

ESO accepted offers to increase gas generation with an average half-hourly price that ranged between £175/MWh and £200/MWh.

In addition, over the evening peak ESO made BSAD adjustments to the interconnector flows to reduce exports over the interconnectors in South East England, paying a price very close to the intra-day price on the continent. As a result, as shown in Figure 6, across most of the evening peak period ESO paid a price to increase the supply of power in England from interconnectors below the price it paid to gas generators.

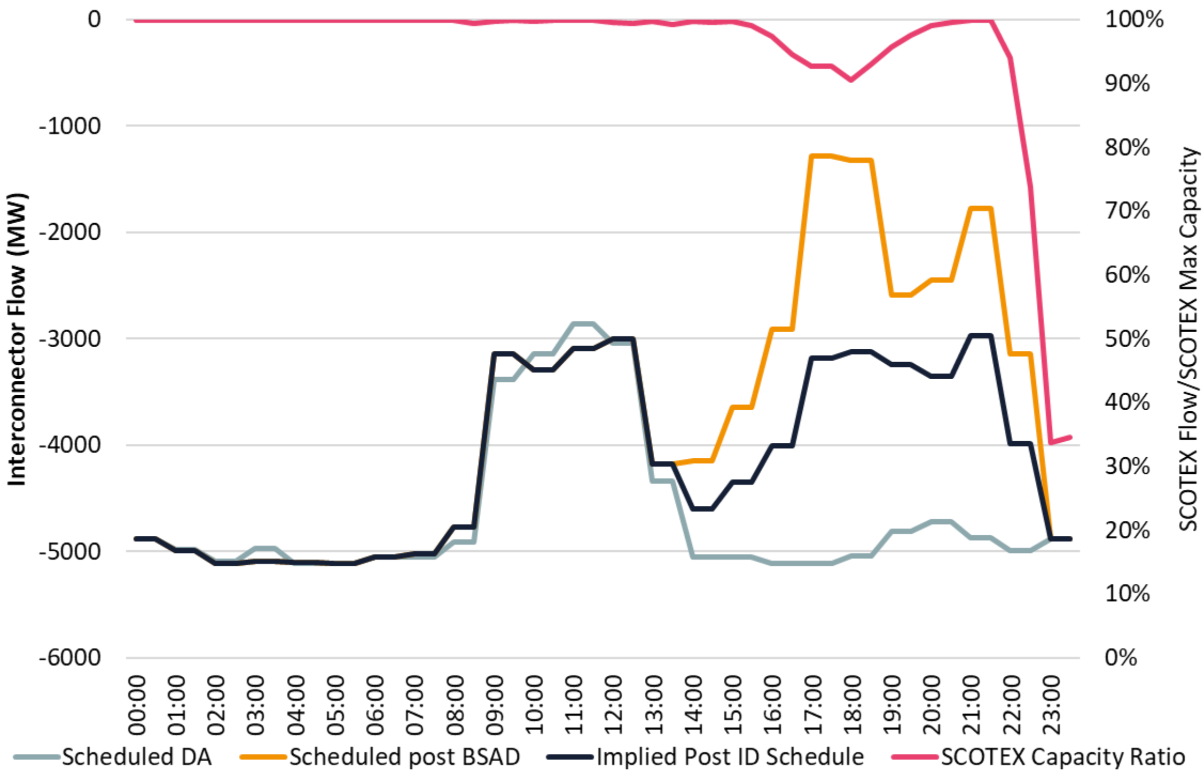
Figure 6 Intraday, BSAD intervention and accepted offer prices



Source: LCP analysis of Balancing Services Adjustment Data

Importantly, we do not observe similar actions being taken at other points of the day when the cost of doing so (for which continental intra-day prices are a reasonable proxy) was likely to have been significantly below the price ESO paid to increase gas generation. In other words, while ESO did take some efficient actions to redispatch interconnectors, based on the historic data available, it would appear that further potential for efficient actions may have existed. This is shown by Figure 7: the interconnectors are net exporting during the early hours of the morning despite the constraint.

Figure 7 Net scheduled interconnector flows and Scotland to England import flow as a proportion of maximum capacity



Source: LCP analysis of Balancing Services Adjustment Data

Note: When SCOTEX flow is 100% of max capacity this indicates that there is an active constraint on the SCOTEX boundary.

The day illustrated in Figure 6 and Figure 7 is not unique. We observe similar behaviour on other example days which are described in Annex A . It is obviously important to stress that, given our analysis considers public data, we cannot know precisely why the ESO did not take more action over interconnectors.

However, stepping back from the specific examples, there are a number of reasons why ESO might not be expected to achieve perfectly efficient flows.

First, such ad hoc auction arrangements are not currently available across all interconnectors. The NSL interconnector between Norway and northern England does not have an intra-day trading mechanism.[17] Therefore, ESO is not able to bring about intraday changes in the planned flow over NSL, reducing the options available to it.

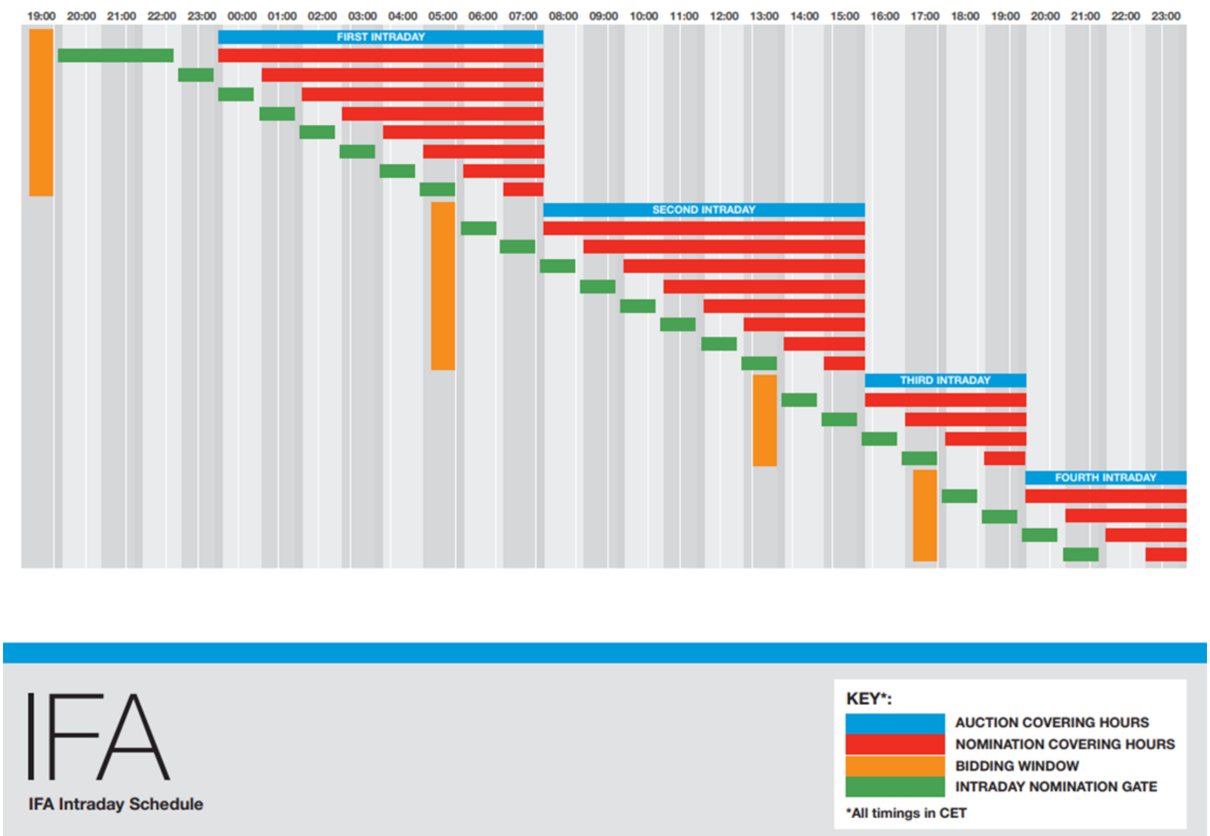
Second, to the extent that the outcome of the ad hoc ESO auctions require follow-on actions by some successful bidders to adjust their capacity holding, ESO auctions must be timed to allow such trades to happen in the intraday interconnector capacity auctions. This imposes a

[17] We understand this is because it has not been possible to secure agreement with Statnett on the arrangements.

constraint on how close to gate closure these ESO auctions can take place. These constraints will vary by interconnector: for example, NGV interconnectors (IFA, IFA2, BritNed, NEMO) have four intra-day auction windows, whereas ElecLink only has two.

Figure 8 provides the intra-day interconnector capacity auction schedule for IFA.

Figure 8 IFA intraday auction schedule



Source: IFA1 interconnector schedule; https://ifa1interconnector.com/media/1241/ifa-intraday-schedule.pdf

To influence the flows in period midnight to 8am, ESO must run its ad hoc auction prior to the completion of the 7:15pm to 7:45pm bidding window. The latest time that ESO can influence flows varies depending on the time of the day, but based on IFA's schedule it appears to be between 3-5 hours ahead of gate closure.

The further ahead of gate closure ESO must decide whether to take actions to reschedule IFA, the greater the uncertainty will exist as to what system conditions and (competing) domestic bids and offers will be for the delivery ISP, and hence there may be greater scope for inefficiency.

Finally, it is worth noting that these arrangements rely on explicit capacity allocation. If GB were to move to implicitly traded intra-day markets these current ESO arrangements would no longer be feasible because ESO would not be able to trade directly with an interconnector capacity owner. With implicit capacity allocation, individual market participants cannot provide a guarantee to ESO that they can influence the interconnector flow.

Post gate closure

Context and status quo

Actions taken by ESO pre-gate closure rely on ESO's ability to correctly forecast the real-time physical position of the system. Forecast errors (including those resulting from short-term changes to the physical system) mean that there is also likely to be a benefit from the ability to redispatch interconnectors post gate closure.

On some interconnectors, ESO currently has the opportunity to engage in SO to SO trading of balancing energy post gate closure. Under these arrangements, the interconnected SO will offer to sell to ESO balancing energy based on the flexibility available on its system (and the commercial terms demanded by its balancing services providers).

Efficiency impact

We have identified the two potential sources of inefficiency with the post gate closure interconnector arrangements.

First, as with pre-gate closure arrangements, post gate closure SO to SO trading arrangements do not exist on all interconnectors.

Second, even where they exist, there are a number of inefficiencies associated with these arrangements:

- the pricing of SO to SO trades is not necessarily transparent and may not be reflective of real-time market conditions in each hour. We understand interconnected SOs may set prices well ahead of gate closure (e.g. day ahead) and as a result efficient balancing options may be "priced out" of the GB market.

- They are not firm, in the sense that there is no obligation for interconnected SOs to accept a request to trade, even if a price has been posted, meaning that in short post gate closure timescales, ESO may prefer a higher priced offer from a domestic BMU to an uncertain but lower priced SO to SO option.

We understand that, perhaps because of these issues, SO to SO trades are typically used by ESO only as a last resort.

We have summarised the current pre- and post-gate closure arrangements on all interconnectors in Figure 9.

Figure 9 Summary of current interconnector trading arrangements

Interconnector	Capacity (GW)	Intraday trading arrangements	Number of intraday auctions	SO to SO arrangements
IFA	2.0	Explicit	4	Yes
IFA2	1.0	Explicit	4	Yes
BritNed	1.0	Explicit	4	Yes
East West	0.5	Implicit	2	Yes
Moyle (NI)	0.5	Implicit	2	Yes
North Sea Link	1.4	None	N/A	N/A
Nemo	1.0	Explicit	4	No
Elec Link	1.0	Explicit	2	Yes
Viking Link*	1.4	Explicit	4	TBC

Source: *Based on information from Ofgem, https://www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/interconnectors; Interconnector Operator information; and BMRS https://www.bmreports.com/bmrs/?q=transmission/*

Note: ** Viking Link operations not commenced at time of writing. As far as we understand, there is no publicly available information that describes Viking Link SO to SO arrangements.*

3.4.2 Smaller assets

Context and status quo

Smaller assets can provide ESO with flexibility in just the same way as larger assets. Currently, assets that provide BM services via independent aggregators of energy (Virtual Lead Parties (VLPs)) and are between 1MW and up to 50MW are classed as Secondary BMUs.[18]

When large adjustments are required on short timescales, it requires significantly more coordination to change the schedules of a large number of small units than to accept bids or offers from a small number of large units. Thus, when ESO wants to make large adjustments in the BM relatively quickly, it is easier for it to dispatch one large unit (and hence send out one instruction).

These practical challenges with the coordination necessary to dispatch multiple smaller units can lead to “skips” in the BM. A skip is defined as an “*instruction sent by the ESO Control*

18 Minimum size of primary BMUs are 50MW in England and Wales, 30MW in South Scotland and 10MW in North Scotland.

Room to increase or decrease the output of a generator but at a price that was higher than an alternative option”.[19]

According to ESO, the “*majority of skips are taken for operational reasons and are not preventable*”.[20] The dispatch transparency dataset is published weekly and records the volume of actions and skips. As part of this dataset, a number of reasons are published for why the assets are not being dispatched efficiently.[21] [22] These include:

- manual processes and legacy systems used by ESO during redispatch;
- the lack of technical capability to give multiple units different instructions;
- the lack of time for ESO to make decisions;
- the existence of locational constraints to consider alongside each assets’ unit size, making each individual decision more complex. This is more complex with VLPs, particularly if Secondary BMUs are in locations in-front of and behind constraints; and
- the accuracy and availability of necessary information (particularly from smaller storage providers).

Efficiency impact

While the inability to dispatch one small asset when to do so would have been the efficient action is unlikely to represent a material inefficiency at the system level, smaller assets taken together represent a significant share of capacity overall. This share is only likely to increase. Therefore inefficient treatment across all of these assets is likely to represent a material issue.[23]

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19 National Grid ESO (Feb 2023), Balancing Programme Quarterly engagement session, page 27; https://www.nationalgrideso.com/document/276211/download

20 National Grid ESO (Feb 2023), Balancing Programme Quarterly engagement session, page 27; https://www.nationalgrideso.com/document/276211/download

21 National Grid ESO (2023), Dispatch Transparency Event; https://www.nationalgrideso.com/document/281156/download page 31

22 National Grid ESO, Dispatch Transparency Methodology; https://storage.googleapis.com/dx-national-grid/national-grid/resources/93abbdbf-06fa-4576-a94f-593d95b893c1/dispatch-transparency-methodology-v2-jan-2022.pdf?X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Expires=60&X-Amz-Credential=GOOG1EWNNJ44UCTJ4GI3FNXEKCVGS5AOA4WQ5FHJYOJNTI3QQOV4OBKOA5CWA%2F20230928%2Feurope-west1%2Fs3%2Faws4_request&X-Amz-SignedHeaders=host&X-Amz-Date=20230928T095044Z&X-Amz-Signature=fa4417edcbfd9abd3bba64bf4419c35aba10cbffe06d00e3e4e41dab2640696e

23 National Grid ESO (June 2023), Balancing Programme Quarterly engagement session, page 28; https://www.nationalgrideso.com/document/282086/download

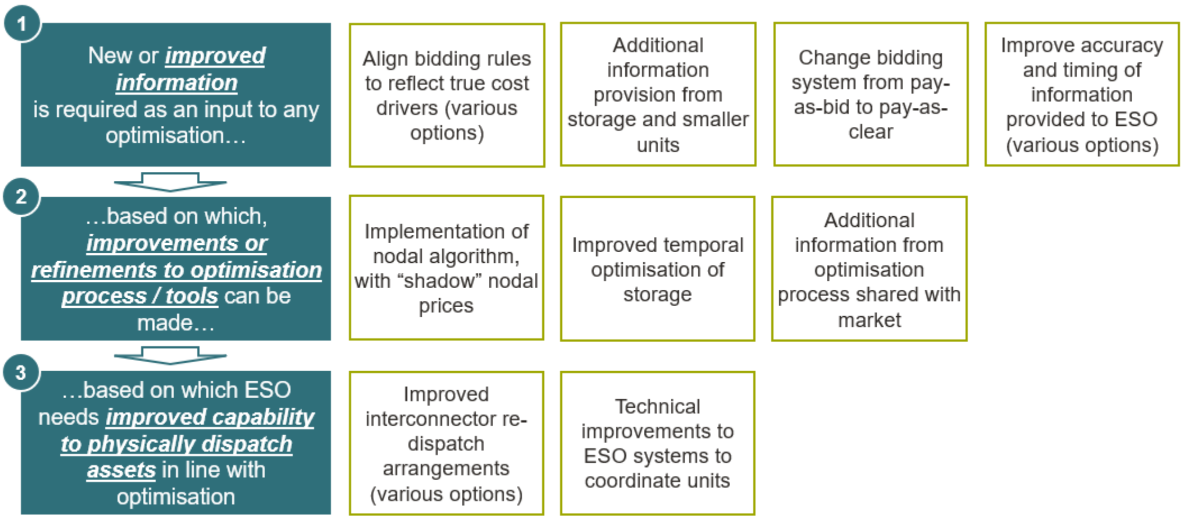
4 Identification and assessment of individual reform options

To address the issues described above we have identified a number of potential reforms that could be considered in GB. In broad terms, we have linked the options to the same three categories of potential inefficiency identified in the previous section:

- Options that improve the information that ESO has available to make redispatch decisions;
- Options that improve the optimisation process i.e. the identification of an optimal set of actions based on the information available to ESO; and
- Options that improve the capability of ESO physically redispatch assets based on the outcome of the optimisation.

The options organised in these three categories are summarised in Figure 10.

Figure 10 Improvements to balancing can be thought of in three broad areas



Source: Frontier Economics

In general the options are not mutually exclusive. Therefore, a potential package of reform could cover all or some of the areas identified, though as we will go on to show, in some areas there are a number of sub-options from which to choose, that would ultimately allow us to define a number of different packages of reform.

In general, the options identified are consistent with improving efficiency in a national market. However, if the national market moves from self-dispatch to central dispatch, this will affect which sub-options are practically implementable The BM itself is essentially a centrally dispatched market. However, if a decision were taken to also have a pre-gate closure centrally dispatched market as well, then this may inform some of the decisions related to the type of information and optimisation algorithm applied in the BM e.g. it would make sense to match the information requirements in the central dispatch algorithm with those required for the BM.

In the sections below, we describe the options (including any sub-options) in more detail and include a high-level assessment of the potential efficiency benefits of the option and the challenges for implementation. We include a summary of each option together in a single table at the end of the section, including Harvey Balls ratings.

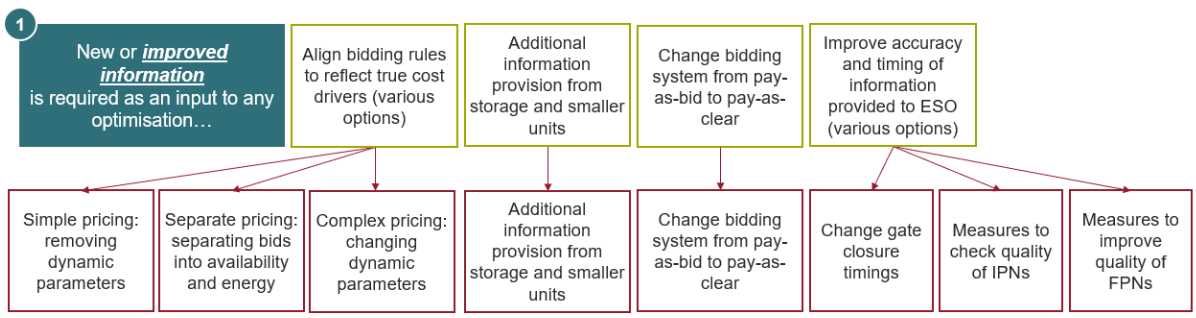
We have taken the following approach to the Harvey Balls:

- We include separate ratings for efficiency impact and ease of implementation;
- For *efficiency*, a full ball represents very high efficiency impact, and for *ease of implementation*, a full ball represents a very difficult reform to implement;
- Without quantitative analysis it is difficult to be accurate with the ratings, and therefore they should only be viewed as indicative of the relative impacts of the different options.

4.1 Improved information provided to ESO

In this section, we describe in more detail potential reforms for improving the information set which ESO bases its optimisation of the system on. Figure 11 summarises the options and sub-options that we will describe.

Figure 11 Summary of reform options relating to improved ESO information



Source: Frontier Economics

4.1.1 Aligning bidding rules with cost drivers

In the previous section we identified potential issues associated with information provided by BMUs, particularly in relation to the specification of the technical parameters. The current set of parameters limits the way the true flexibility of assets can be expressed (e.g. only single values for MZT, MNZT and a single price). As a result, ESO is forced to make decisions constrained by these hard parameters, when in reality there are more options as to how plants could be run, albeit with different commercial consequences for the plant owners.

Option description

There are a number of different ways in which the bidding rules in the BM can be changed to better reflect the continuous nature of the trade-offs in how plants are operated, three of which are summarised in Figure 12 and described in more detail below, which we have termed as:

- ***Simple pricing***, which would mean removing dynamic parameters so that participants internalise their own costs in their bids;
- ***Separate pricing***, which would mean separating the bids into availability and energy, in line with ESO's new proposed Balancing Reserve; or
- ***Complex pricing***, which would mean changing dynamic parameters so that they reflect underlying cost drivers of plants.

The key difference between the sub-options reflects the extent to which the responsibility and for and risk of optimising the operation of the plants rests with ESO or market participants.

Figure 12 Alternative approaches to bidding arrangements

SIMPLE PRICING

- Remove dynamic parameters so ESO can choose offers in cost order for each half-hour
- Market participants internalise the implications of their own technical characteristics into their bids
- All incremental costs (including start costs) recovered by market participants over course of a running cycle.

SEPARATE PRICING

- In line with ESO's proposed Balancing Reserve
- ESO procures day ahead availability of assets.
- Contracted parties then responsible for:
  - being available, taking into account technical characteristics; and
  - placing bids and offers into BM for relevant period.

COMPLEX PRICING

- Offers reflect the underlying cost drivers of the plant output, including for example:
  - start costs (cold, warm, hot start £/kW) reflecting time since last on
  - cost to run at SEL (£/MWh), and
  - cost to run up to MEL (£/MWh)
- ESO then selects offers that minimise overall system costs

Decreasing responsibility (and risk) on generators to internalise the recovery of their underlying costs into bids and offers →

Source: Frontier Economics

One sub-option (***simple pricing***) would be to significantly simplify the bidding structure by removing the need to submit some dynamic parameters, with ESO instead choosing offers in cost order for each half-hour. The idea is that market participants internalise the implications of their own technical characteristics into their bids in just the same way that they do when bidding in the wholesale market. In other words, it would be the participants' responsibility to ensure incremental costs associated with operating the plant over the course of a running cycle are recovered through the submitted prices. For example, a generator with positive PN in the morning (and MZT of 6 hours) keen to capture peak prices in the evening, would need to offer power in the intra-day market or BM at prices to ensure they are operating at SEL ahead of the evening peak, and therefore could be selected by ESO.

Separate pricing is similar to simple pricing in that market participants internalise the implications of their own technical characteristics in the wholesale market. However, the difference is that ESO runs an auction for plants to commit to be available day ahead based on its forecasted requirement, paying a competitively set availability payment i.e. it is separating the costs of being available, from the marginal cost of providing incremental power in the BM when ESO needs it. The availability payment then places an obligation on the party to be available for the specified period e.g. evening peak on the next day. As a result, plants must now ensure they are available by offering power in the intra-day market and BM to ensure they are operating at SEL for the agreed period. In the agreed period, they provide bids and offers in the BM as normal. This idea is in line with the newly implemented ESO Balancing Reserve.

An alternative approach (***complex pricing***) would be to place the responsibility for optimising the operation of the plant with ESO. However, instead of relying on the current set of dynamic parameters submitted, plants would provide information more directly related to the cost drivers which plants are having to internalise when bidding in the wholesale market. This is a more complex set of bidding information and could include the costs associated with a cold start (or warm or hot start, all in £/kW) as well as costs to run at Maximum Export Limit (MEL) or Stable Export Limit (SEL) (£/MWh). ESO would consider the costs associated with dispatching each plant given conditions of the plant and the system requirements and select offers that minimise overall system costs.

These types of complex bidding parameters map closely to those present in LMP markets. In PJM, generating units provide information related to their underlying costs in order to sell energy in that market (unless they fulfil certain other regulatory requirements). These costs are split into three categories: start-up costs, no load costs and incremental costs associated with incremental energy offers. Within each category generating units must provide a range of costs including fuel costs, operating costs, emission allowances and more.[24]

Option efficiency assessment

In general, each of these sub-options above should allow ESO to optimise on the basis of information that better reflects the underlying cost drivers of the plants. This should in turn give ESO more options to consider when making dispatch decisions.

Simple pricing would mean simpler dispatch decisions by ESO, as optimisation of plants (taking into account full range of optionality given technical characteristics) would be internalised by plant owners. ESO's sole focus would be on dispatching plants in price order, subject to a more minimal set of technical parameters. Greater simplicity for ESO should also mean greater transparency of ESO dispatch decisions.

[24] PJM fuel cost policy, schedule 2, https://pjm.com/-/media/committees-groups/committees/mic/2021/20211103/20211103-item-03c-fuel-cost-policy-oa-schedule-2-revisions.ashx

Separate pricing, like simple pricing, would mean simpler dispatch decisions for ESO. However, it places additional burden on ESO to forecast its requirement earlier at the day ahead stage effectively locking in costs of availability payments which may ultimately turn out not to be needed. In contrast, simple pricing places the responsibility on the market to determine what is needed rather than the ESO. Market participants are also required to bid in the day ahead auction based on their expectation of the costs associated with their technical constraints that they won't be able to recover in the wholesale market.

A more **complex pricing** approach would mean greater optionality and flexibility for ESO to minimise system costs. That flexibility means it can trade-off shorter and longer run times for plants with high start-up costs. Complex bids would make it easier for ESO to see the value of waiting to dispatch inflexible plants. For example ESO could choose not to dispatch inflexible plants early without necessarily removing the option of dispatching them later, as is currently the case (though prices and costs will vary).

To the extent that these sub-options allow ESO to make more efficient trade-offs between dispatching different plant, they have the potential to avoid actions with very high-cost impacts. As described in the review of the balancing market there have recently been a number of high-cost days in the BM where impacts might have been somewhat mitigated if ESO had had better information.[25]

Option challenges

Each of these sub-options would come with a different set of challenges for ESO and market participants. For the **simple pricing** approach:

- Market participants would have to consider the multiple constraints on their plant in their bidding. This would be more complex and might create some new barriers to entry. However, the skills required to internalise these considerations are in line with the current requirements to trade in the intraday market. Therefore it is unlikely to be a challenge for a potential participant in the wholesale market and balancing mechanism.

- While the simpler bid information would lead to improved transparency for ESO balancing actions, the impact of plant characteristics on balancing and overall costs would be less transparent as these are internalised by market participants. Therefore it will be less clear ex-post what caused a price to be set in the way that it was.

For **separate pricing**, the challenges are similar to simple bidding. It would be more complex than simple bidding, but still relatively simple, especially given the ESO already has developed the proposed approach to the day ahead auctions for availability payments. The costs associated with the inflexibilities would also be more transparent than under simple bidding.

25 https://www.frontier-economics.com/media/l43dzwca/frontier-lcp-cornwall-review-of-the-balancing-market-v2.pdf Section 4

However, a choice would still need to be made about how the availability payments are reflected in imbalance prices.

For the **complex pricing** approach, the challenges are more associated with ESO:

- More complex IT systems and algorithms would be required to optimise on the basis of a more complex set of information.
- It would be less clear why ESO has made a dispatch decision since, for any given bidding period, there would be a wider range of factors to consider. This approach would potentially reduce transparency of ESO decision making in the BM.
- There may also be a reduction in transparency around the calculation of imbalance prices with a more complex algorithm. For example there are likely to be difficult choices to make about how non-continuous operating costs (such as start costs) are reflected in imbalance prices, which may lead to concerns about their efficiency and transparency. We note that this issue would also be faced by an LMP pricing algorithm or national pricing under a centrally dispatched market.

4.1.2 Additional information provision for storage

As described in Section 4, there are units participating in the BM that are being "skipped" despite appearing to be in merit. When in merit, total dispatch costs would be reduced if ESO were to call on them. However, ESO has limited information about these units and is not able to take into account all of the relevant constraints e.g. the state of charge of a storage unit.

Option description

As part of ESO's Balancing Programme, ESO and industry are currently working together to resolve these informational issues.

ESO is considering additional parameters to monitor the energy availability in a storage unit. A parameter that signals the "state of charge" or "maximum available energy" would help ESO determine when the most appropriate point to dispatch that asset would be. ESO is working with stakeholders in industry to identify the precise parameters to be trialled. A grid code modification was submitted in November 2023.[26] Consultation of new storage parameters that consider the state of charge are set to commence in Q2 2024 and continue throughout the year. A final assessment of the reform should take place in Q4 2024.[27]

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26 National Grid ESO, Grid Code Modifications, GC0166: Introducing new Balancing Programme Parameters for Limited Duration Assets; https://www.nationalgrideso.com/industry-information/codes/gc/modifications/gc0166-introducing-new-balancing-programme-parameters-limited-duration-assets

27 National Grid ESO, *Enhancing energy storage in the balancing mechanism*, https://www.nationalgrideso.com/news/enhancing-energy-storage-balancing-mechanism

This might also apply to some demand-side response (DSR) which have limited response hours. For example, a DSR asset may only be able to provide time-limited response. ESO would also need to know the most appropriate point in time to dispatch DSR.

These considerations would also have to be made under LMP. The way storage is included in the LMP dispatch algorithm and the nature of information around state of charge would also need to be taken into account.

Option efficiency assessment

If resolving issues associated with dispatching storage can result in lower cost alternatives to meet the system's needs being considered and used, there are likely to be efficiency benefits. Since the prevalence of storage is likely to increase significantly in the future, then the importance of resolving issues around their dispatch is crucial to an efficient BM.

For example, removing the "15-minute rule" on battery units may not only allow these units to operated more frequently, but also for longer. This will become increasingly important as the importance of battery storage increases, as more medium duration battery storage assets are added to the system.

Option challenges

From a system perspective, implementing these changes would place greater emphasis on ESO to take into account more parameters when organising redispatch. This would then require additional optimisation tools from the ESO. Storage operators would also need to share more information but, in return, they would more likely be dispatched onto the system.

4.1.3 Change bidding system from pay as bid to pay as clear

Option description

When market participants bid into the BM, the price they receive depends on the type of bidding system being operated. The BM currently operates under a pay as bid system. This means that successful BM participants are paid based on their own bid. If two participants in the auction bid different prices and are both successful, they will each be paid the prices at which they bid, no matter what the price of the marginal clearing action is.

An alternative bidding system is pay as clear. Under pay as clear, all participants with successful bids are paid the market clearing price, equal to the price bid by the marginal clearing action, no matter their individual bids. In the context of the BM, this would mean "local" clearing prices for each group of unconstrained nodes in each period. This would be analogous to the application of pay as clear in a nodal market.

Option efficiency assessment

A pay as clear system potentially has some efficiency benefits over a pay as bid system.

Under a pay as bid system participants are incentivised to bid at (or just below) the expected marginal bid that would be accepted rather than their own marginal cost. This means that when ESO accepts bids in cost order, it cannot be confident that the lowest cost bids to ESO reflect the set of dispatch instructions that will minimise system costs (lower cost bids may reflect errors in forecasting the marginal unit by bidders rather than a truly lower cost).

In a pay as clear system, with a competitive BM, participants will bid at their short-run marginal costs in order to maximise their chances of being dispatched profitably. Thus ESO can be certain it is running the least-cost assets because it can be confident that bids are reflective of participant's marginal costs. However if there is market power in a pay as clear market, a participant could potentially manipulate the clearing price. [28] This would distort the prices paid, not only to the participant with market power, but all BM participants.

Moving to a pay as clear system would be likely to reduce system costs and thus increase efficiency. However, whether this would be at the expense of increased consumer costs arising from the exploitation of market power by BMUs will depend on the extent of competition in the BM.

Option challenges

There are likely to be some concerns that moving to a pay as clear BM would risk increasing market power impacts.[29]

4.1.4 Improved accuracy and timing of information to ESO

We have identified three reform sub-options that can help ESO be more certain about the accuracy of the information that it receives:

- Change the timing of gate closure and extend the timelines of the BM;
- Introduce measures to check the quality of Initial Physical Notifications submitted by participants; and
- Take measures to incentivise better quality Final Physical Notifications submitted by participants.

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28 In the context of the BM, this would mean "local" clearing prices for each group of unconstrained nodes in each period. This would be analogous to the application of pay as clear in a nodal market.

29 Although we note that EC regulation 2017/2195 on guidelines on electricity balancing already required all TSOs to develop a pay as clear methodology for determining prices for balancing energy actions. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R2195 (Article 30)

Change gate closure timing

Sub-option description

At the implementation of NETA, gate closure was 3.5 hours ahead of real time. It is currently 1 hour before the start of delivery. If gate closure were moved earlier, it might provide ESO with more certain information at an earlier stage. It would give ESO a longer period during which they would know that bilateral trading would not result in changes in planned output or consumption from that previously notified. For example, a storage plant may indicate to ESO at T-12 hours that they plan to be fully charged at the start of an ISP, but trading decisions in bilateral markets may mean that by T-1 hour they are likely to be less than fully charged.

The exact timing of an earlier gate closure would need to be assessed as part of any reform, taking into account the competing factors we discuss below. We note that while DESNZ rules out shortening gate closure in the second REMA consultation, it does not appear to have considered an earlier gate closure.

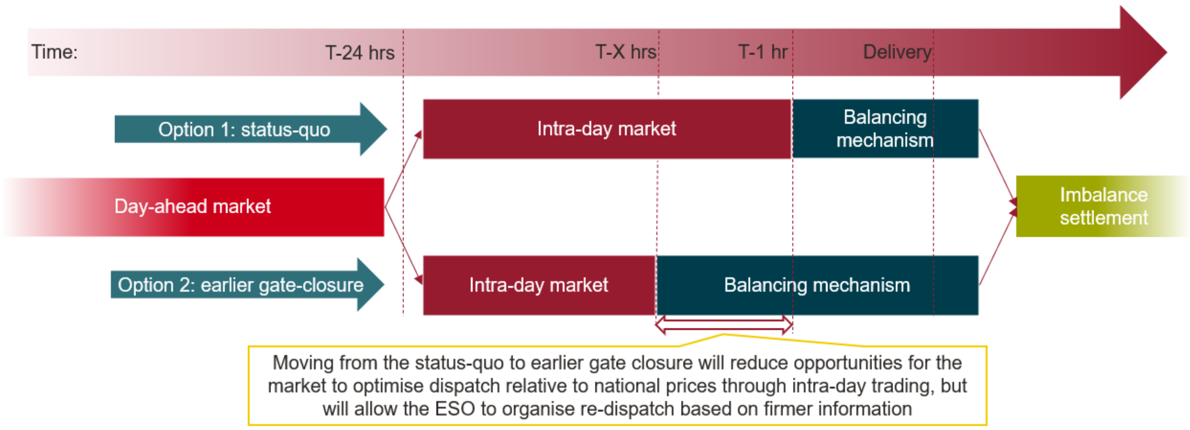
Sub-option efficiency assessment

Earlier gate closure may influence efficiency in different directions:

- On the one hand, earlier gate closure provides firmer information to ESO and allows ESO more time to optimise the system and determine the most efficient balancing actions. This should have a positive efficiency impact;
- On the other hand, earlier gate closure reduces the time during which the market can optimise the balance of supply and demand, placing greater reliance on ESO to respond to short-term deviations between demand and supply.

This trade-off is illustrated in Figure 13

Figure 13 Options for gate closure timing: status-quo versus earlier gate closure



Source: Frontier Economics

- The overall efficiency impact of this change is therefore difficult to determine. The rationale behind the introduction of NETA was that allowing participants to trade and self-dispatch would result in a more efficient outcome than a central algorithm. This rationale also underpinned the pushing back of gate closure to its current timing, which increased the opportunity for trading and reduced the role of the system operator (which is a monopoly and therefore does not have the same commercial incentives or information set as asset owners).

- However, the more the system operator has to take decisions more than one hour ahead of real time, the more it will be doing so on the basis of forecast information which may change. Removing elements of the resulting uncertainty might enable ESO to take better decisions.

It is important to note that while the relative efficiency of market balancing was a key motivation for the self-dispatch model in GB, the market optimises against national prices. Therefore, given the expected increase in importance of ESO redispatch going forward, and the fact that ESO must take some redispatch actions more than 1 hour before delivery (current gate closure timing) there may be more of an argument for allowing ESO more time to optimise for both energy and locational reasons.

Sub-option challenges

- This would constitute a significant change for market participants who would have less time to ensure they can balance their portfolios. It would require changes within their organisations, and they would arguably face increased risks of exposure to imbalance prices.

Incentives to improve quality of IPNs

The second reform sub-option relates to the quality of IPNs.

Sub-option description

Prior to submitting their FPNs, market participants provide Initial Physical Notifications (IPNs) which indicate an operator's expected physical dispatch in an upcoming period. However, FPNs may turn out to be materially different to IPNs. To the extent that ESO has to rely on IPNs to understand the planned pattern of dispatch and power flows, inaccuracy will affect the efficiency of pre-gate closure actions. This may imply that ESO is not able to place significant reliance on IPNs.

Differences between IPNs and FPNs may be explained by efficient bilateral trading between market participants to balance their positions, or by forecast error. However, there may also be differences that are simply the result of inaccurate information provision by market participants. These could be addressed through more systematic checks of the commercial reasons for movements in PNs. For example, market participants could be required as part of their license condition to provide, if requested, information underpinning differences between the PNs. ESO could review this information as part of its market monitoring function to ensure compliance with the Grid Code.

Sub-option efficiency assessment

As we note above, increasing the accuracy of information (including IPNs) can improve the efficiency of early balancing actions by ESO.

The incremental efficiency impact of this measure depends on extent to which movements in PNs are driven by non-commercial reasons. When providing PNs, market participants are already required to apply "Good Industry Practice" as defined in the Grid Code, and some pre-gate closure information provision is covered by REMIT. Therefore, any benefits of this measure would relate to the existing degree of non-compliance with these requirements.

Sub-option challenges

This measure is relatively easy to implement, but it would place an extra regulatory burden on participants to establish a process for retention of (potentially complex) trading information and its provision to ESO. The extent of burden would depend on the regularity of checks and the level and extent of information required.

Improve quality of FPNs

The third reform sub-option relates to improving the accuracy of FPNs.

Sub-option description

FPNs should provide reliable information regarding expected dispatch to ESO. Market participants are already required to submit FPNs consistent with good industry practice, and FPNs can also be covered by REMIT. However, further incentives could be considered.

One potential incentive is to utilise the Information Imbalance Charge, which is an existing mechanism in the BM.[30] This charge is calculated by multiplying the information imbalance volume (which is the difference between expected and actual delivery of volume in the BM) by the information imbalance price. The information imbalance price is currently set to zero but, in theory, this could be set to a non-zero value to further incentivise accurate FPNs.

Sub-option efficiency assessment

To the extent this sub-option incentivises improvements in FPN accuracy (e.g. due to improved forecasts) this could improve the efficiency of ESO BM actions.

30 https://www.elexon.co.uk/glossary/information-imbalance-charge-2/

Sub-option challenges

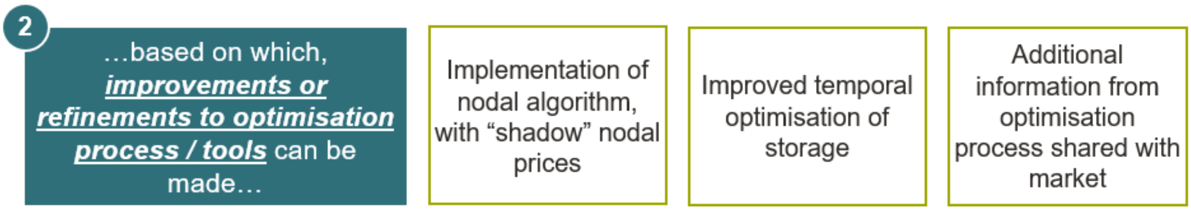
This would be straightforward to implement, as the arrangements have existed in the BSC since the initial implementation of NETA. However:

- ESO would need to determine a fair and well-justified information imbalance price; and
- this would increase risk, particularly for generation with less predictable output, and so it would be important to believe that the countervailing efficiency benefits were material.

4.2 Improved optimisation

In this section we describe the potential options for reform of ESO's optimisation processes. These are summarised in Figure 14.

Figure 14 Summary of reform options relating to improved ESO optimisation



Source: Frontier Economics

4.2.1 Implement nodal optimisation

Option description

ESO currently does not operate a nodal algorithm. We understand that once a constraint is identified ESO focuses on the region around the particular constraint and identifies least cost actions to deal with these constraints. In contrast, an LMP market would involve dispatch via a full optimisation across the whole system on a nodal basis.

It should be feasible for ESO to use a system-wide algorithm to identify the most efficient redispatch actions – indeed, in theory, any algorithm that could be used in an LMP market should conceptually be capable of being used by ESO to determine which bids and offers to take in the BM (provided the structure of technical information relating to BM bids were defined appropriately, as discussed above). Once ESO has identified the optimal dispatch, it would then accept the relevant BM bids and offers. If there are no constraints to the dispatch of individual assets, the dispatch outcome of an LMP algorithm should be identical to the dispatch outcome from a redispatch algorithm.

Option efficiency assessment

Relative to the status quo approach, a nodal dispatch algorithm could, at least in theory:

- make use of more granular information outside of the immediate area of an individual locational constraint to identify efficient balancing actions, building on existing ESO local constraint optimisation modelling; and

- identify more efficient dispatch decisions across the wider system, rather looking within a defined region, to find solutions that might contribute to resolving multiple constraints.

The extent of improvement of dispatch efficiency achieved will depend on the nature and effectiveness of the current ESO optimisation tools and is therefore difficult to judge without detailed analysis.

Option challenges

Implementing a full nodal optimisation algorithm would be a material system implementation task for ESO and for other parts of the industry. It would require:

- significant investment in new optimisation software, and in the integration of this software with ESO's other systems and processes; and

- new information to be provided by market participants to ESO.

It is also worth noting that some of the other inefficiencies and reform options would interact with the implementation of a new optimisation algorithm. For example, any algorithm will need to have a clearly defined set of input data, and typically dispatch algorithms will make use of data along the lines of the complex bidding information described above (e.g. start costs, no-load costs etc.) and so a change in the algorithm would be likely to interact with changes in the information set associated with bids and offers. Similarly, each algorithm will have a defined set of data associated with storage (e.g. starting charge level).

4.2.2 Improved temporal optimisation of storage

Option description

We highlighted above potential reforms in relation to the provision of information on storage.

We understand that ESO currently considers the use of battery storage in a single period.[31] By considering the optimal use of storage (and other balancing sources) over multiple periods, ESO may be able to reduce overall system costs by using stored energy more efficiently.

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[31] National Grid ESO, *Enhancing Energy Storage in the Balancing Mechanism*, https://www.nationalgrideso.com/document/291061/download

It is worth noting that the approach to optimisation of storage will be a key feature of any algorithm. If ESO is to implement a new algorithm (as per the option discussed above), there would be a benefit in ensuring that the new algorithm treated storage in an appropriate manner. This may also be true of other time-limited options, such as demand-side response (DSR). For example, if demand reduction can only happen for a specific number of hours, ESO will need to consider when the optimal time to reduce demand is. This will need to consider in which hour the demand reduction is most effective while also taking into account what might happen when demand returns and whether that would exacerbate system issues.

Temporal optimisation of time-limited assets is likely to be an issue under LMP as well as under national markets.

Option efficiency assessment

The efficiency improvement due to this reform ultimately depends on the extent to which there is material value in ESO choosing when to dispatch storage assets. This is increasingly likely to be the case as storage becomes a critical technology in future to balance the expected significant increase in low marginal cost technologies.

Option challenges

The nature of the challenges with this option are likely to depend on other option choices. If a new nodal algorithm is to be implemented, then the incremental challenge associated with ensuring that storage is appropriately treated may be low. If it is to be implemented in isolation, then it may require some complex developments to ESO's existing optimisation tools.

4.2.3 Provision of information to market participants

Option description

If market participants are not able to understand easily the historic value of balancing energy at the nodes to which their assets are connected the options available to ESO may be unduly constrained. Asset owners may optimise their plant differently (e.g. charging or discharging storage sites) with better information about likely system conditions.

If a nodal optimisation algorithm has been implemented, ESO could in theory publish historic prices for energy at each node. The provision to the market of clear historic information can help assets plan for delivery and increase the options open to ESO at times when having additional options is likely to be most valuable.

Option efficiency assessment

Improved information of this nature could improve efficiency of market dispatch, simply by increasing the set of actions among which ESO is able to choose. For example, storage operators may adjust their state of charge in order to be ready to capture value from expected future system conditions (derived from an analysis of historic prices or from explicit forecasts) in a way they would not if they had less information. This is the logic behind Capacity Market Notices, which signal to the market that system conditions are expected to be tight in order to encourage capacity to make itself available.

However the value of additional information to the market must be balanced with concerns about market abuse and gaming. If operators have market power in certain system conditions (most obviously, locational market power in relation to a constraint), the provision of additional information risks signalling the ability to abuse that market power to them.

An overall judgement in relation to efficiency needs to balance these two possible effects, taking into account the regulatory interventions (e.g. the TCLC) already in place to guard against the abuse of market power.

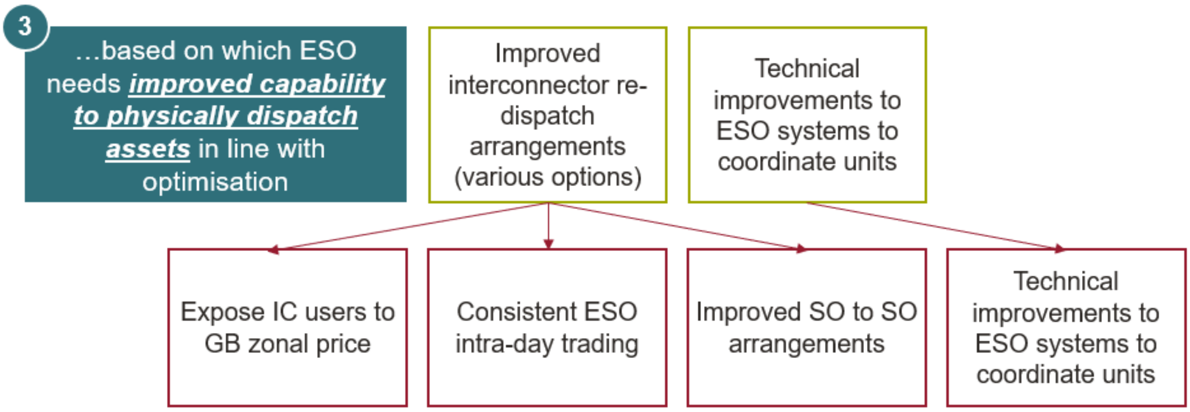
Option challenges

The provision of nodal historic information is closely linked to the implementation of a nodal optimisation algorithm. The challenges of that reform are therefore relevant to provision of improved historic information. In addition, there may be additional regulatory burden (in relation to monitoring and record keeping) arising from such a reform in order to mitigate the risk of increased abuse of market power.

4.3 Improved ability to physically dispatch assets

Once ESO has identified the optimal set of dispatch actions, it needs to be able to physically redispatch assets in line with its optimisation. We have identified two key areas, interconnectors and smaller assets, where there is a significant risk of sub-optimal dispatch, as described in Figure 15.

Figure 15 Summary of reform options relating to improved ESO dispatch



Source: Frontier Economics

In this section, we first summarise the scope for improved interconnector redispatch at the moment. We then consider three reform options for improving interconnector dispatch. Finally we discuss the potential for improvements in the dispatching of smaller assets.

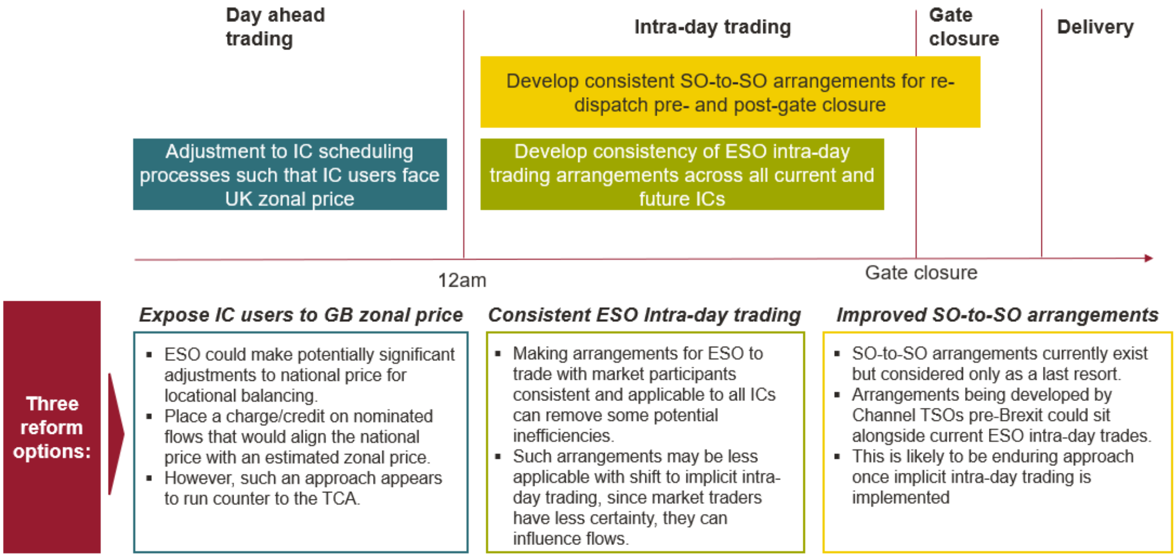
4.3.1 Interconnector redispatch

In the previous section we explained that there are arrangements under which ESO makes adjustments to interconnector flows pre and post gate closure with the objective of reducing overall balancing costs. However, we identified that:

- these are not consistently applied on all interconnectors;
- these only give ESO limited flexibility to make adjustments pre-gate closure;
- post gate closure arrangements are only treated as a last resort; and
- arrangements do not appear to be future proof.

As a result, we have identified three sub-options which can improve the current arrangements pre and post gate closure. In addition, we have considered a sub-option where market participants are incentivised to schedule flows over the interconnector taking into account expected congestion onshore in GB. These are summarised below in Figure 16.

Figure 16 Interconnector reform options



Source: Frontier Economics

Each of the interconnector reform sub-options we have identified can in theory work alongside each other. However, as we will go on to explain, the suitability of ESO redispatch sub-options may also be linked to the particular interconnector trading arrangements prevailing at the time:

- Placing charges/levies on interconnector flows so that cross-border trade takes into account GB congestion should be possible under both explicit auctions for interconnector capacity and with implicit trading, but may require adjustments depending on the arrangements;

- The current ESO intra-day trading arrangements are likely to work best with explicit intra-day trading, and therefore may not be an enduring option if the GB market ultimately moves to implicitly traded intra-day markets; and

- SO TO SO arrangements are more able to operate with implicitly traded intra-day cross-border markets in place, although they are also feasible under the current explicit arrangements as well.

We go on to discuss each sub-option in turn.

4.3.2 Expose interconnector users to GB zonal prices

Sub-option description

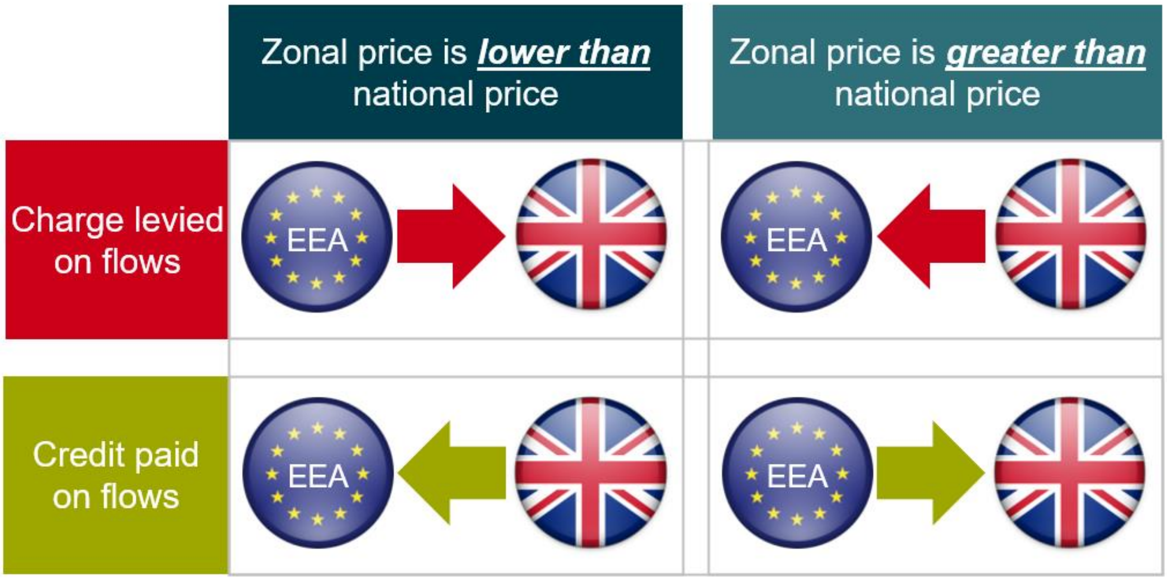
Currently, cross-border interconnector flows are determined by the relativity between GB national prices and the price in the neighbouring market zone. This can result in flows that exacerbate congestion where there is a difference between the national price, and the relevant price that would have been the result of a zonal market.

A possible reform would be to adjust the arrangements effectively to apply a zonal price to interconnector users so that cross-border trade reflects congestion in GB without the need for ESO redispatch actions.

To achieve this, an ex-post levy or payment could be applied to the interconnector (who would pass it on to any party nominating a flow over the interconnector). This levy or payment would be based on the difference between the national price and an ex-post estimate of a zonal price (derived from BM bids and offers , potentially using outputs from a nodal optimisation algorithm if that option has been followed). Knowing that the levy/credit would be applied ex post would force traders to take account of the expected value of the levy/credit when purchasing capacity and nominating flows. Provision of information on expected constraints by ESO would enhance the ability of traders to form an expectation of the value of the levy/credit.

The conditions under which charges and credits are imposed are illustrated in Figure 17 and explained below.

Figure 17 Charges and credits are imposed depending on the relevant zonal price relative to the national price



Source: Frontier Economics

As illustrated by the figure:

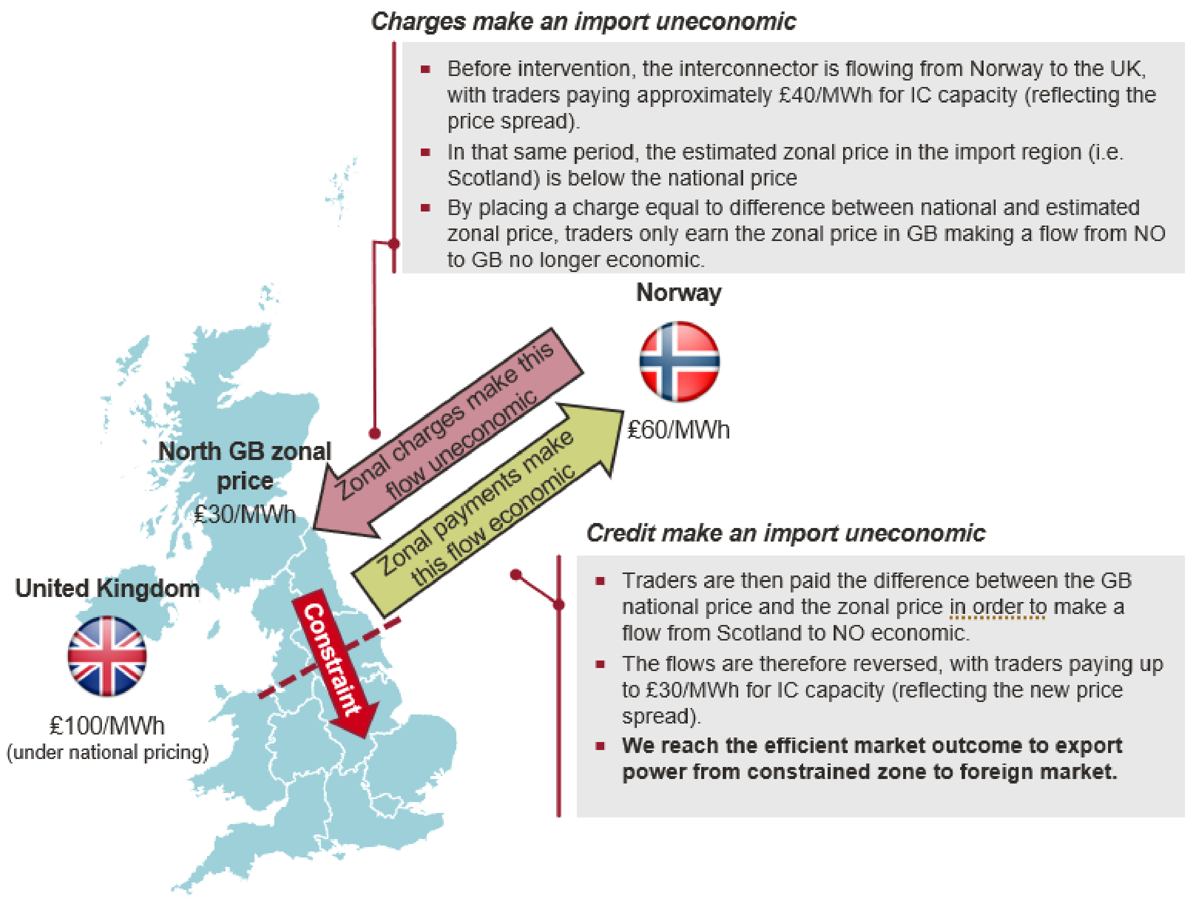
- When the estimated zonal price is below the national price:

- a charge (equal national price less zonal price) would be levied on nominated flows into the GB zone; and
- a credit (equal national price less zonal price) would be paid on nominated flows out of the GB zone.

- When the estimated zonal price is above the national price:
  - a credit (equal zonal price less national price) would be paid to nominated flows into the GB zone; and
  - a charge (equal zonal price less national price) would be levied on nominated flows out of the GB zone.

Figure 18 illustrates how this system of payments and charges might work in practice, for a scenario where, based on a GB national price relative to the Norwegian price, the market would schedule the interconnector to be fully importing to GB. By levying a charge on flows into GB, and crediting flows to Norway, interconnector capacity holders should schedule interconnector flow from GB to Norway, provided they are able to correctly anticipate what the ex-post levy/credit would turn out to be.

Figure 18 Illustration of the application of zonal prices to interconnector users



Source: Frontier Economics

Sub-option efficiency assessment

From a system perspective, the reform would place the emphasis on market participants to dispatch interconnector flows according to estimated zonal GB prices and therefore reflect expected constraints in the GB market. This should reduce the volume of interconnector redispatch required to be carried out by ESO post gate closure for locational reasons.

Traders would need to predict the levy/credit when deciding how much they are willing to pay for interconnector capacity. This additional forecasting requirement is likely to mean that traders face greater uncertainty when bidding for interconnector capacity relative to current arrangements (where traders only have to forecast the national wholesale price spreads). As a result, some degree of inefficiency in flows would be expected relative to the zonal price. This may be in line with or greater than the current inefficiency in flows observed under explicit arrangements relative to national prices.

Placing levies and credits on interconnector flows should also be possible under implicit trading arrangements. However, it may be necessary for the credit or levy to be set ex-ante (rather than ex post) to allow it to be taken into account by traders.

Sub-option challenges

While this sub-option can improve efficiency of the interconnector dispatch, it treats interconnector flows differently to other domestic producers in GB, with potentially significant but uncertain implications for interconnector revenues. The value of interconnector capacity is likely to change since interconnector owner would receive the difference between the zonal price and the foreign price rather than the difference between the GB national price and the foreign price. The impact of this would depend on relative price spreads. In the example set out above in Figure 18, the interconnector owner would lose value on their capacity.

There is also a key legal challenge to applying this option. The Trade and Cooperation Agreement (TCA) requires that:

> *"there are no network charges on individual transactions on, and no reserve prices for the use of, electricity interconnectors"*[32]

This constraint also applies to Norwegian interconnectors, albeit with a separate agreement to the TCA.[33] Therefore for all interconnectors to implement this option would either require such charges not to be interpreted as network charges, or a change in the legal text.

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32 Trade and Cooperation Agreement (TCA), April 2021, Article 311, para 1(e); https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22021A0430(01)

33 Cross-border trade in Electricity agreement, UK and Norway, Article 4 Para 1(d), 16 September 2021; https://assets.publishing.service.gov.uk/media/61431e2cd3bf7f05b2ac2075/TS_18.2021_Agreement_UK_Norway_Cross_Border_Electricity.pdf

4.3.3 ESO intraday interconnector arrangements

Sub-option description

Currently ESO makes regular and significant adjustments to interconnector flows by trading with market participants intra-day on some interconnectors. However, arrangements to do this do not exist on all interconnectors, and where they do, arrangements are inconsistent, leading to some potential inefficiencies.

To improve the situation, consistent arrangements for ESO intra-day trading across all current and future interconnectors could be developed. This would include:

- Agreeing arrangements where they currently do not exist (NSL),[34] and ensuring arrangements are put in place as part of the development of all future interconnectors (e.g. as a condition for eligibility for the cap and floor regime).
- Identify the optimal number of intra-day auctions and aligning their number and timing, so that ESO has consistent options to consider across all interconnectors (e.g. there are currently four daily auctions on NGV interconnectors, but only two on Eleclink).

We note that ESO has an active project on the "Creation of an Interconnector Framework" with the aim of creating a "*framework for the operational and commercial arrangements that enables consistent and efficient arrangements to help with the management of interconnectors (both current and future), whilst also increasing transparency.*" [35] The project is targeting delivering an agreed Interconnector Framework implementation plan by Q4 2024/25.

We also note that implementing LMP would require similar intra-day processes to be agreed.

Sub-option efficiency assessment

Expanding the scope and consistency of interconnector trading should lead to ESO having more options and an improved ability to make choices between options, and should therefore improve the efficiency of dispatch.

Such improvements should help ESO to capture more of the potential for efficient redispatch of interconnectors that was illustrated by the example day presented in Figure 19. While in reality it is unlikely to be possible to capture all of the potential savings, as an illustration, if the ESO had been able to fully capture the potential from interconnector redispatch across the course of the day, costs could have been £4.7m lower.[36]

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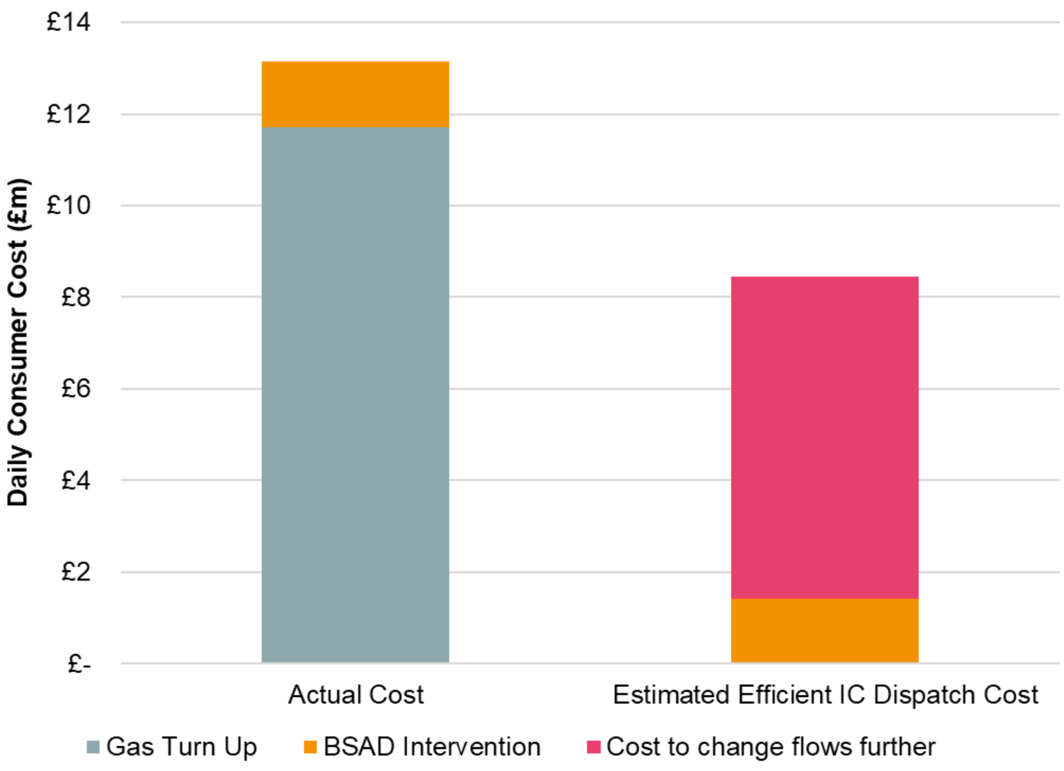
34 This would require agreement between ESO, National Grid Ventures and Stattnett

35 https://www.nationalgrideso.com/document/289701/download

36 The cost reduction assumes that the volumes were available over the interconnector and priced at the continental intraday price (such that volumes could be redispatched over the interconnector without moving the intraday market).

Figure 19 Potential consumer cost savings from more efficient dispatch on 10 November 2022



Source: LCP analysis of Balancing Services Adjustment Data

However, it is important to note that these arrangements work well only in with explicit capacity arrangements. This is because under explicit trading, ESO can trade energy with a market participant who can then as a result purchase capacity (if necessary) and adjust their interconnector flow nomination in line with the agreement made with ESO. This guarantees the change in flow which ESO wishes to bring about.

The same guarantee cannot be achieved under implicit trading arrangements, because any individual trader cannot guarantee that they can influence the flow over the interconnector (which is the outcome of an algorithm rather than individual flow nominations). The TCA envisages a move to implicit trading (loose volume coupling) day ahead. Once this is achieved, implicit intraday trading may be a next logical step. Implicit intra-day trading is already undertaken on the Irish interconnectors.

The benefits from improvements to the existing arrangements (and indeed the benefits of the existing arrangements themselves) are not likely to persist if implicit trading arrangements are successfully implemented intra-day. That said, any move to implicit intra-day trading is unlikely in the short term so there may still be value in making improvements in the short term.

Sub-option challenges

The processes required to facilitate intraday redispatch of interconnectors are in place and functioning at present on most of the links to the continent. Implementation of refinements should be relative straightforward procedurally, both for existing and new links, subject to the position of the connecting country.

However, changes to arrangements require agreement with the interconnector owners and neighbouring SO. The lack of intra-day markets on NSL is evidence that is difficult to achieve in all circumstances.

4.3.4 SO to SO interconnector arrangements

Sub-option description

SO to SO arrangements currently exist between GB and foreign SOs, though in practice they appear to generally be considered only as a last resort to address security of supply, rather than as a tool for reducing balancing costs.

More dynamic SO to SO arrangements (relative to today) are likely to be achievable. For example SO to SO trades based on available bids and offers in foreign balancing markets were being developed by the Channel TSOs prior to Brexit (the intention being that they would work alongside XBID). Similar arrangements could sit alongside current ESO intra-day trades providing pre-gate and post gate closure options as an alternative to domestic balancing options.

To make SO to SO arrangements more dynamic would require:

- The potential to complete trades pre- and post-gate closure (with interconnector capacity available to the market to be adjusted reflecting agreed SO to SO trade when wholesale markets are still open (i.e. pre-gate closure)).
- Pre-gate closure:
  - improved information sharing e.g. with prices offered by each SO based on expected availability of marginal balancing bids and offers in its market;
  - updated information intra-day as expectations of system conditions change; and
- Post gate closure, each SO offering available and feasible bids and offers in its balancing market.

It is also worth noting that under LMP, similar arrangements for the neighbouring SO to enter bids and offers into the algorithm would also be need to be agreed.

Sub-option efficiency assessment

These arrangements could provide a material improvement in efficiency relative to current arrangements (which are only considered only as a last resort). ESO would have more up to date and firmer bids and offers from other systems available to it in pre- and post-gate closure timescales, and could more easily compare the cost and effectiveness of those actions against domestic alternatives. This should lead to an improvement in the efficiency of despatch.

In the future, there are likely to be further moves towards implicit trading, increasing the importance of SO to SO trading. As a result, SO to SO arrangements are likely to be an enduring solution to support redispatch of interconnectors, ultimately replacing current ESO interconnector trading arrangements.

Sub-option challenges

Negotiating SO to SO arrangements with foreign TSOs and interconnector operators that are consistent and compatible with the GB system is likely to be challenging. However, there was some appetite for agreement on these matters pre-Brexit, suggesting that the challenges are unlikely to be insurmountable.

4.3.5 Technical improvements to ESO systems to coordinate units

Option description

One of the reasons that ESO is currently unable to dispatch at the lowest cost is because ESO's current processes are unable to manage complexity of dispatching multiple smaller units. ESO is better equipped to manage system fluctuations at short notice by controlling the dispatch of a single large generating asset (rather than taking the additional time and optimisation necessary to control multiple small assets).

This issue has been recognised by ESO and, as part of the Balancing Programme, there are a number of planned improvements to address this issue.[37] For example, as part of the new Open Balancing Platform, ESO has developed a Bulk Dispatch system to allow multiple instructions to be sent to small BMUs in one step.[38] After Bulk Dispatch is in place, the intention is to enhance the process of information gathering and co-optimising services.[39] The goal of these optimisations is to automate and optimise the process for dispatching multiple generation assets across different instruction types.

[37] National Grid ESO, Balancing Programme, https://www.nationalgrideso.com/what-we-do/electricity-national-control-centre/balancing-programme

[38] As per National Grid ESO's Balancing Programme Event (28th November 2023) https://www.nationalgrideso.com/document/294786/download

[39] National Grid ESO's Dispatch Transparency Event (5th December 2022), page 18 https://www2.nationalgrideso.com/document/273316/download

Option efficiency assessment

The importance of smaller distributed assets for whole system is likely to increase over time, and therefore smaller assets are increasingly likely to represent cost effective options for balancing. Even with improved access to the market facilitated by VLP process, and optimisation to identify opportunities to dispatch smaller assets that we discussed in the previous section, issues with current ESO systems are likely to continue to lead to missed opportunities. More efficient processes would enable the dispatch of multiple smaller assets in place of fewer larger assets when it is economic to do so, leading to fewer “non-economic” skips, and encouraging wider market access.

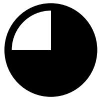
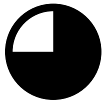
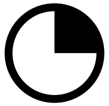
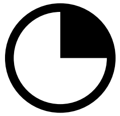
Option challenges

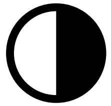
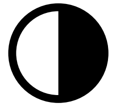
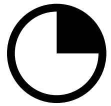
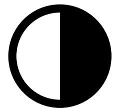
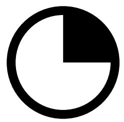
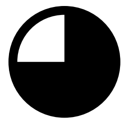
The implementation of the reforms will require significant upgrades required to ESO systems, although we note that this is in progress as part of the Balancing Programme.

4.4 Summary of reform option assessments

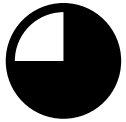
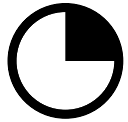
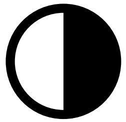
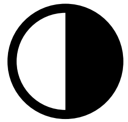
Table 1 Summary of improved information reform options

Reform option / sub-option	Description	Summary of efficiency assessment	Efficiency rating	Challenges	Ease of implementation
Simple bidding	Removing some dynamic parameters so ESO chooses offers in cost order for each ISP. Market participants internalise implications of their own technical characteristics in bids.	Each sub-option should allow ESO to optimise on basis of information that better reflects underlying cost drivers of plants. This should in turn give ESO more options to consider when making dispatch decisions, in contrast to the absolute constraints implied by some of the current set of parameters.	◑	Participant bidding behaviour becomes more complex, and implications of technical characteristics on balancing and pricing are less clear.	◑
Separate bidding	Simpler dispatch decisions but burden is on ESO to make forecast of requirements and to lock in availability payments	For both the simple bidding and separate bidding options an ex ante forecast must be made regarding the need for capacity to be available. Under complex bidding, the ESO as the party with the most information is making the judgements closer to real-time, and therefore has the potential to be more efficient than the other bidding options.	◑	This is already being proposed through the ESO Balancing Reserve and therefore should be relatively easier to implement than other bidding options.	◕
Complex bidding	Update existing dynamic parameters such that bids and offers reflect the underlying cost drivers associated with plant output (such as start costs).		◕	More complex ESO IT implementation required, with potentially reduced transparency and questions around how non-continuous operating costs are	◔

Reform option / sub-option	Description	Summary of efficiency assessment	Efficiency rating	Challenges	Ease of implementation
	ESO would choose offers that minimise overall system costs.			reflected in imbalance prices.	
Additional information requirements from storage	Additional technical parameters (e.g. to capture 'state of charge') can help ESO to be better informed about storage's true capabilities for balancing.	To the extent that additional information about storage can provide ESO greater certainty about dispatch capabilities, it is more likely to be able to rely on storage as an option ahead of other more expensive options. Potentially significant given potential scale of future storage.		ESO needs to define the information required. Additional IT developments may be required by both ESO and participants. Should be straightforward given existing ESO work.	
Pay as clear	Change the payment rule in the BM from pay as bid to pay as clear	Potential to reduce inefficiencies in dispatch due to parties making errors when estimating marginal bids and offers under pay as bid. However, unclear how significant this issue.		In principle, relatively straightforward to implement. However, it is unclear if ESO can implement with its current local nodal optimisation and may effectively require the implementation of a nodal algorithm.	

Reform option / sub-option	Description	Summary of efficiency assessment	Efficiency rating	Challenges	Ease of implementation
Earlier gate closure allowing ESO more time to optimise	Move gate closure from T-1 to earlier period e.g. T-4 to provide ESO with firmer information to support early decision making.	Efficiency gains depend on the relative ability of the market and ESO to optimise dispatch, and the relative materiality of early ESO decision making.		Increase in participant risk as they will not be able to trade to improve overall balance as close to real time as today	
Monitoring differences between initial PNs and final PNs	Greater monitoring of reasons for deviations from IPNs would help to increase the chance of ESO receiving more accurate information, and in turn may increase efficiency of early actions.	Incremental efficiency impact depends on extent to which market participants currently deviate from IPNs for reasons other than bilateral trading or forecast error, and on materiality of early decision making.		Potential for a heavy regulatory burden on ESO, Ofgem and market participants	
Measures to improve the quality of FPNs at gate closure	Activate existing “information imbalance charge” to further incentivise accurate FPNs, helping to give the ESO better information from which to choose efficient BM actions.	Incremental efficiency impact depends on extent to which market participants currently submit inaccurate FPNs. Impact likely to be small given current incentives.		In principle easy to implement, but derivation of charge level likely to be contentious, and would increase risk on participants so improvement in efficiency would need to be material	

Reform option / sub-option	Description	Summary of efficiency assessment	Efficiency rating	Challenges	Ease of implementation
Nodal algorithm	ESO implements nodal algorithm to identify optimal dispatch in BM. This should then guide ESO dispatch actions	ESO currently does not operate a national nodal algorithm – it focuses on areas of constraint and identifies actions to deal with these constraints. National nodal algorithm would allow ESO to identify optimal dispatch. Impact limited if constraints on implementing dispatch (e.g. relating to interconnectors) remain.	◑	This would require reasonably significant intervention to create algorithm and it would require additional complex bidding information.	◔
Improved temporal optimisation of storage	Optimising storage assets over multiple time periods when identifying balancing actions.	Since storage has limited dispatchable energy, choosing the timing to optimise dispatch is essential. Signalling in advance when storage is likely to be required may help storage operators optimise their charging and discharging.	◑	Designing and implementing complex algorithms to account for optimal storage dispatch over multiple time periods is likely to be a challenge for ESO.	◑
Additional information from optimisation process shared with market	The ESO could share more information regarding future system conditions, in particular congestion. If a nodal algorithm is implemented it could share shadow prices ex-post.	Improved information of this nature could improve efficiency of market dispatch, simply by increasing the set of actions among which ESO is able to choose. However the value of additional information to the market must be balanced with concerns about market abuse and gaming.	◔	This places an additional process on the ESO to publish data . There may also be concerns related to market power.	◑

Reform option / sub-option	Description	Summary of efficiency assessment	Efficiency rating	Challenges	Ease of implementation
Improved interconnector market dispatch (zonal levy)	An ex-post levy/credit applied to the IC owner (which would likely get passed on parties nominating flows) based on the difference between the national price and an estimate of a zonal price.	Effective zonal price in GB would ensure cross-border trade reflects congestion in GB, thereby reducing the need for ESO redispatch actions post gate closure. Likely to have a significant impact.		Key legal challenge since the TCA explicitly does not allow ICs to face network charges, therefore difficult to implement.	
Improved interconnector re-dispatch arrangements (ESO intraday auctions)	Where possible, improved coverage (including all future interconnectors) and consistency of approach of the current ESO approach to intra-day pre-gate closure interconnector re-dispatch.	Incremental improvement to current ESO approach, and ensures approach expands in line with expected growth of interconnection. Arrangements most suited to explicit trading. Therefore cannot be applied to all current interconnectors, and cannot be enduring solution with move to implicit intra-day trading on all interconnectors.		Consistent arrangements rely on agreements with foreign TSOs, which is currently a barrier with NSL arrangements for example.	

Reform option / sub-option	Description	Summary of efficiency assessment	Efficiency rating	Challenges	Ease of implementation
Improved SO to SO interconnector arrangements	More dynamic SO TO SO arrangements relative to today, based on planned approach by Channel TSOs prior to Brexit - provision of expected available bids and offers to neighbouring TSOs, updated intra-day as information changes, supporting trades pre-gate or post gate closure.	Significant improvement in efficiency relative to current arrangements (which are only considered only as a last resort) due to clearer cross-border system executing trades when cheaper than domestic actions.	◕	Enhanced arrangements rely on agreements with foreign TSOs, though appetite was there pre-Brexit.	◔
Improve systems to coordinate a greater number of units	Improved dispatch systems to enable dispatch of multiple smaller assets.	More efficient processes enables dispatch of multiple smaller assets in place of larger assets (when economic) leading to fewer “non-economic” skips, and encourages wider market access.	◑	Significant upgrades required to ESO systems, although this is in progress as part of the Balancing Programme.	◕

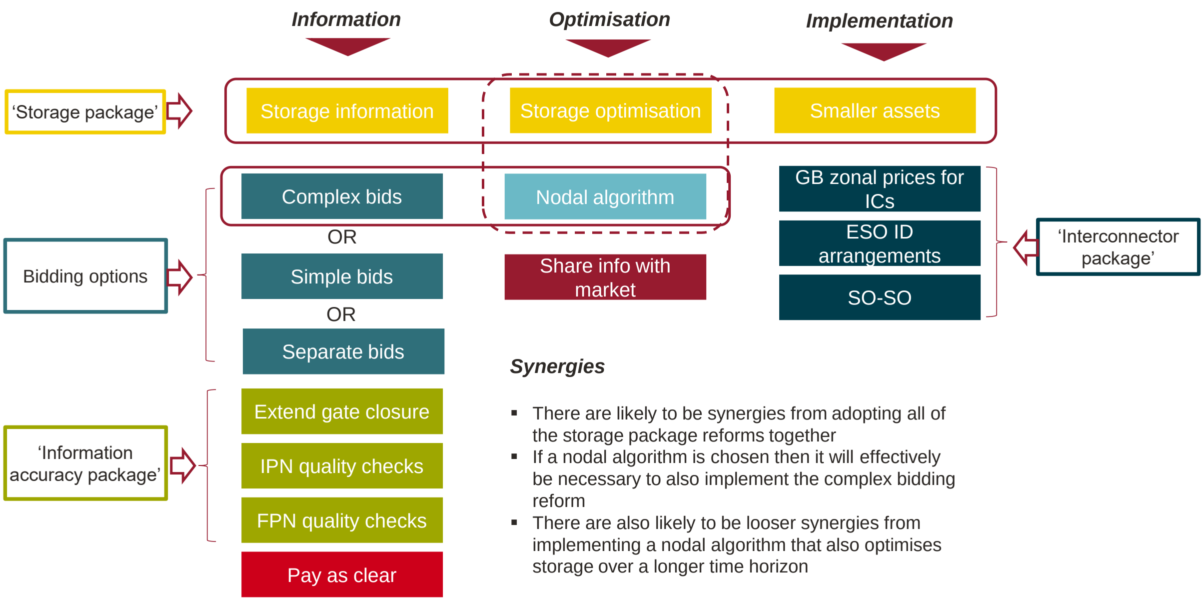
Source: Frontier Economics

4.5 Packages of reform options

The majority of the reform options and sub-options identified can be implemented independently (i.e. each reform could be implemented on its own, or in conjunction with any of the other identified reforms) with some limited logical exceptions. In addition, there are also a number of synergies between reforms that mean that certain reforms could sensibly be pursued as packages.

Finally, there are also a number of thematic reforms that could be pursued as packages but which do not necessarily have clear synergies. Figure 20 below illustrates these interactions and they are described further below.

Figure 20 Illustration of possible reform packaging



Source: Frontier Economics

There are a number of **restrictions on groupings** of reform options, which include:

- It is necessary to select a single bidding reform sub-option (i.e. it is not possible to have both simple and complex bidding arrangements at the same time).
- If a nodal optimisation algorithm is adopted then complex bidding must also be adopted.

There are also a number of **synergies** suggesting 'packages' of reform:

- There are three reform options that are closely linked with the use of storage assets and could be pursued as a **'storage package'**. Strictly each of the reforms grouped in the 'storage package' could be adopted independently of each other.

- In addition, there is also a potential synergy from integrating the optimisation of storage assets over a longer time horizon with the nodal algorithm.

For the remaining reforms, there are two thematic packages related information accuracy and interconnectors, and individual reforms related to pay as clear and information sharing. Each of these options could be pursued independently, or in combination with others as part of a broader package.

5 Implications of status quo reforms for locational market counterfactual

As we set out in the introduction, the motivation for this work was to highlight viable options for reforms that would support greater operational efficiency in a national market, and in doing so, to develop a more realistic counterfactual for a locational market. In this final section we consider the potential ability of the reforms that we have identified to capture some or all of the efficiency benefits claimed for an LMP market. We note that if a zonal market were to be implemented any efficiency benefits would likely be smaller than those claimed for LMP.

In considering each of the reform options in the previous section, we noted whether aspects of a particular reform would require consideration as part of the implementation of an LMP market. Based on this we can identify:

- ***Consistent national and LMP market reforms*** - those reform areas in which consistent developments would be needed anyway as part of designing and implementing an LMP market, and so areas in which the extent of reform success (i.e. whether or not the reform is successful or not at resolving an inefficiency) would also be reflected in the outcomes in a nodal market; and
- ***Unique national market reforms*** - those reform areas which are unique to a national market i.e. where incremental effort is required in a national market to resolve inefficiencies that would not be required in the design and implementation of an LMP market.

Table 2 below summarises our categorisation of the reforms.

Table 2 Categorisation of consistency of national market reforms with LMP

Reform option	Consistency of reforms with LMP market	Category
Information		
Simple pricing Separate pricing Complex pricing	Reform to the information requirements from plants would be a key part of developing a nodal market. The complex bidding approach is the only option we identified consistent with a centrally dispatch LMP market	Consistent with LMP
Additional information from storage	Optimisation of storage will be just as important in LMP market. Defining appropriate information for its optimisation is needed irrespective of market structure	Consistent with LMP

Reform option	Consistency of reforms with LMP market	Category
Pay as clear	LMP markets are pay as clear	Consistent with LMP
Earlier gate closure	Concepts of gate closure, IPNs and FPNs do not exist in LMP market so reforms not needed under LMP.	Unique to national market
Monitoring of difference in IPNs and FPNs		
Measures to improve quality of FPNs		
Optimisation		
Nodal algorithm with “shadow” nodal prices	This is the same basis on which a nodal market would be optimised. Efficiency of dispatch identified for national or LMP market based on the quality of the optimisation tool.	Consistent with LMP
Improved temporal optimisation of storage	Optimisation of storage will be just as important in LMP market. Inter-temporal optimisation of storage needs to be addressed as part of any LMP algorithm.	Consistent with LMP
Additional information from optimisation shared with market	By moving away from self-dispatch, LMP relies less on optimisation by market participants, however, there is still likely to be value from additional information sharing.	Consistent with LMP
Implementation		
Improved interconnector market dispatch	This option is only relevant for interconnector trading in a self-dispatch market	Unique to national market
Improved interconnector redispatch arrangements (ESO intra-day auctions)	Interconnector arrangements will need to be developed for integration of LMP market with self-dispatched neighbouring markets. However, the redispatch arrangements under national market would not be required under LMP.	Unique to national market
Improved SO TO SO interconnector redispatch arrangements		
Improve systems to coordinate greater number of smaller units	Issuing dispatch instructions to a large number of smaller units in line with nodal optimisation is an issue to resolve in both markets	Consistent with LMP

Source: Frontier Economics

From this analysis we can conclude that, in broad terms, there is no reason to suggest that if the information and optimisation tools necessary to identify the most efficient dispatch can be developed for an LMP market, they cannot also be developed for the national market. For example, to the extent that there are challenges to ensuring optimisation of storage across all time periods and locations, these challenges would apply equally to the optimisation of the calling off of bids and offers in the BM of today's national market and optimisation in any LMP market. Similarly, an identical optimisation algorithm could be used by ESO in both markets.

The key area where there may be differences in the arrangements that are fundamental to the final dispatch under each market relate to the processes required for implementing the dispatch identified through the optimisation process, and in particular those processes that relate to interconnection.[40] This is particularly important given Ofgem's view that the dispatch of interconnectors in an LMP market produces significant consumer benefits.

Our analysis therefore suggests that the difference between the operational efficiency of dispatch in an LMP market and the dispatch in a realistic counterfactual for a national market appears to hinge to a significant extent on the degree to which the interconnector options we have identified can match the dispatch of interconnection under a nodal market.

Before commenting on the extent to which the reform options can achieve the same dispatch as a nodal market, it is important to recognise that the current arrangements without reform do not imply that interconnectors can never be redispatched. In today's market, a scheduled interconnector flow is determined at the day ahead stage. This flow is then subject to redispatch, as we have explained in section 3.4.1. Interconnectors are regularly redispatched by ESO under current arrangements in order to reduce overall costs of balancing, albeit there are limitations to efficiency and coverage of the current arrangements. It is worth noting that such behaviour is not reflected in FTI's analysis, where interconnectors are assumed to have a fixed price for redispatch and effectively assumed to be always more expensive to redispatch than unabated gas.[41]

In comparison to the treatment of interconnectors today:

- one of our reform options would see interconnector day ahead flows scheduled as in an LMP market; and
- the other options would see day ahead flows scheduled as today, with successive opportunities for redispatch intraday and post gate closure.

If all of our options were implemented, it would essentially imply day ahead interconnector flows schedules to be similar or the same as under an LMP market, and then updates to that

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40 While reforms related to IPNs and FPNs to ensure that the ESO has access to more accurate information pre- and post-gate closure are also unique to a national market, it is unlikely these will be as significant in impact as those related to interconnector arrangements.

41 FTI fixed the price of interconnector bids at €130/MWh in 2025 and €100/MWh from 2030 onwards, effectively making it more expensive than unabated gas, thereby making changes to interconnector flows a "last resort" option for ESO while unabated gas remains on the system.

schedule to be made over the intraday period reflecting later information. There is therefore little reason to suspect that the efficiency of interconnector dispatch would be very different.

We note that issues around agreements of other SOs and interconnector owners in relation to intraday arrangements are likely to be a constraint under both today's market and an LMP market. If this constraint is significant, it means that ensuring efficient day ahead scheduling of flows is of increased importance (because arrangements to move away from the day ahead schedule may be imperfect).

If our first reform option is not implemented, reliance will effectively be placed on the options we have identified to improve the efficiency of redispatch of interconnector flows.[42] These are likely to represent a significant step-change in how interconnectors are redispatched and as a result enable a large share of the operational efficiency benefits claimed for LMP to be captured under a national market. However, if there are significant constraints from other SOs and interconnector owners as to their design, they are unlikely to completely achieve the LMP dispatch efficiency.

Even though it would be reasonable to assume that in a national market ESO would be able to identify the efficient dispatch for all interconnectors, assuming it has developed the appropriate nodal optimisation tools, any improved redispatch arrangements will rely on close cooperation with neighbouring TSOs on short timescales or redispatch instructions based on expectations of future system conditions across the different systems.

We therefore conclude that the ability of reformed national market arrangements to mirror the operational dispatch efficiency under an LMP market largely relates to the ability of ESO, interconnected SOs and interconnector owners to agree consistent and effective improvements to existing intraday and post gate closure redispatch arrangements. The less the need for multipartite agreement constrains the nature of these arrangements, the closer the dispatch under a reformed national market is likely to come to that suggested under LMP.

[42] As we note, these could be designed to sit alongside current explicit intra-day trading arrangements, or future implicit trading arrangements should cross-border trade ultimately achieve that goal.

Annex A – LCP analysis of past interconnector actions

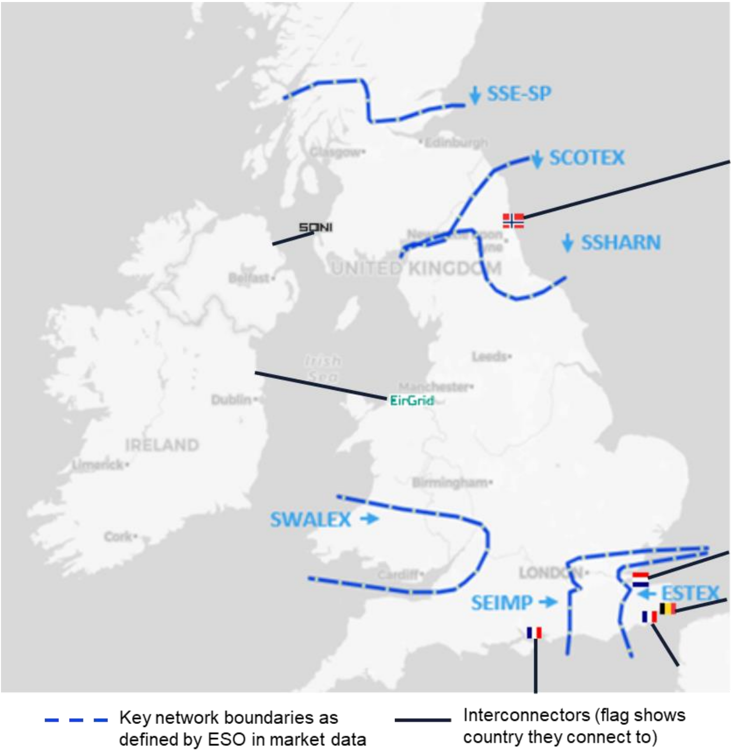
A.1 Scope of historical analysis

To better understand the inefficiencies caused by limited interconnector dispatch as outlined in 4.4.1, LCP Delta has undertaken a limited historical analysis of market activity where redispatch under current market arrangements led to inefficient market outcomes for consumers. The analysis has identified examples of interactions between interconnector commitments and the Balancing Mechanism (BM) that led to inefficient market outcomes.

The analysis outlines market activity in six examples across five days where interconnector activity increased consumer costs incurred in managing network constraints. Interconnectors participate in the day ahead market, which does not take network constraints into account. However, these interconnectors are also restricted in their ability to change their flows from the day ahead stage. Consequently, when parts of the transmission network are constrained, the analysis highlights instances of interconnector activity leading to the curtailment of cheap power (often wind) and/or the turning up expensive plants (often gas) on either side of a constraint boundary. If system arrangements allowed, a more cost-effective scenario for consumers would be to change flows on the interconnectors.

The map below outlines some of the key network constraints in GB and where interconnectors connect to the GB grid from different countries. Interconnectors mostly connect to areas whose boundaries are often constrained: within the Southeast Import boundary (SEIMP), above the Scotland Export boundary (SCOTEX) and above the North East England export boundary (SSHARN).

Figure 21 Map of key GB constraints and interconnectors



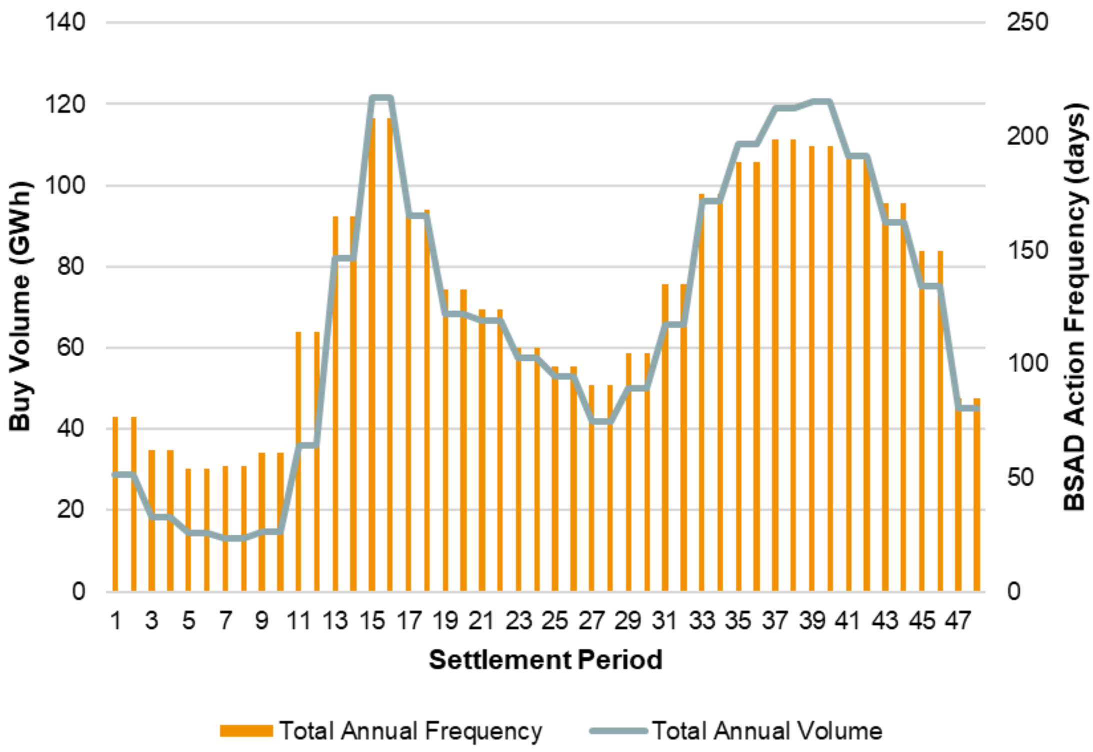
Source: LCP analysis

A.2 Balancing Service Adjustment Data (BSAD)

LCP Delta has used data from the LCP Enact platform to carry out the analysis. This platform provides real-time trading analytics on the electricity market, integrating data from a range of sources. Historical data from Enact enables the analysis of individual assets, as well as market prices, constraints on the network, and ESO flagged actions within the balancing mechanism (BM). The analysis includes the use of Balancing Services Adjustment Data (BSAD), which details balancing actions taken outside of the BM. BSAD actions are bilateral trades between National Grid ESO and a counterparty, which are typically agreed and published ahead of gate closure but can be agreed post-gate closure with non-BM plants such as interconnectors. For interconnectors, this data includes SO-SO trades taken post-gate closure.

To provide some context on how often interconnectors change their flows as a result of BSAD actions and their hourly distribution, LCP Delta has analysed the BSAD actions for five interconnectors in the Southeast across 2022. The graph below shows the distribution of total volume of generation bought across a year in each settlement period, and the number of days in which there was a purchase of generation in each settlement period. Across the five interconnectors in the Southeast, GB bought 3.2 TWh through BSADs across 310 days in 2022. The majority of buy actions happened during the morning and evening peaks.

Figure 22 SE interconnectors BSAD actions in 2022 – buy volume and frequency



Source: LCP analysis of Balancing Services Adjustment Data

A.3 Example day analysis

This section shows the market outcomes from six examples across five days outlining how current arrangements lead to inefficient market outcomes. The six examples identified are outlined in the table below.

Table 3 Selected example days

#	Day	Situation	Inefficient Market Outcome
1	10/11/22	SE England interconnectors exporting while Scottish wind curtailed	Turn up of gas at a much higher price in SE than intraday price in connected market
2	10/11/22	SCOTEX export constrained while importing from Ireland over the Moyle IC	Wind curtailment while importing at a much higher price than wind bid prices

#	Day	Situation	Inefficient Market Outcome
3	11/11/22	SEIMP import constrained and SE interconnectors exporting	Gas plant turned up in SE at a higher price than intraday price in connected market
4	23/10/21	SSHARN export constrained and NSL importing	Scottish wind turned down to alleviate SSHARN constraint (SCOTEX unconstrained)
5	25/1/23	SE interconnectors scheduled to export then pulled back through BSAD actions, but only partially	SE gas turned up at very high prices to while power is exported at lower prices
6	20/7/22	Exports pulled back within-day to manage SEIMP import constraint	Very high costs incurred on interconnector BSAD actions taken close to real time (up to £9,000/MWh for some actions)

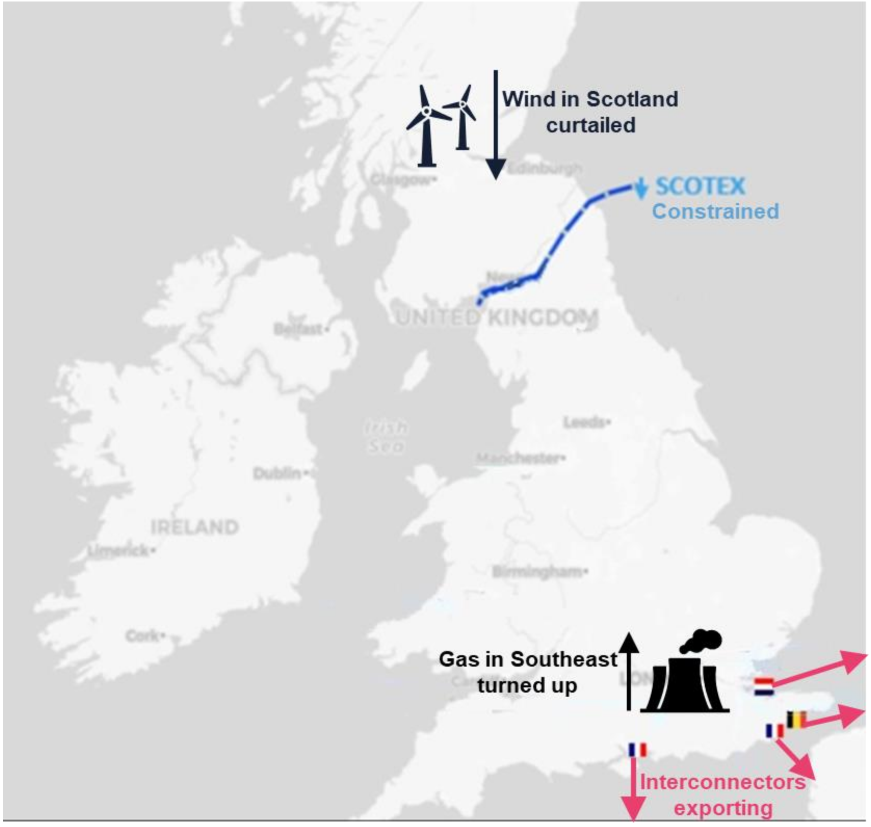
Source: LCP

Example 1, 10/11/2022 – SE England interconnectors exporting while Scottish wind curtailed

In this example, SCOTEX (also known as the "B6" boundary) is export constrained, limiting exports from Scotland to England. Consequently, electricity from wind in Scotland scheduled for generation at the day ahead stage is turned down in the balancing mechanism. At the same time, interconnectors in south east (SE) England are net exporting to France, Belgium, and the Netherlands, even after BSAD interventions. The active SCOTEX constraint means electricity generated in Scotland cannot meet the demand in England, so gas plants in SE England need to be turned up, at a high price, to meet local demand and net exports.

This is likely an inefficient market outcome as it would be more cost effective to reduce interconnector exports (or switch to imports), rather than turning up gas.

Figure 23 Example 1 Illustration (10/11/2022)

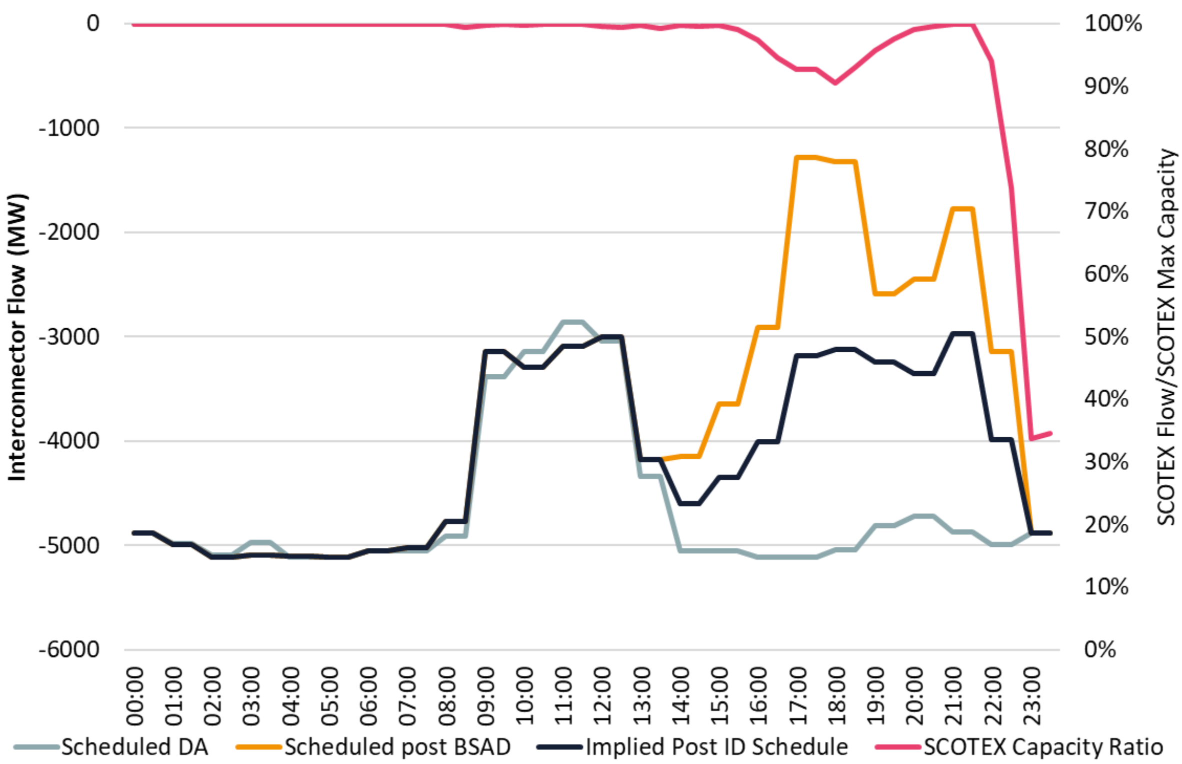


Source: LCP analysis

Figure 24 below shows that SCOTEX is constrained with flows at 100% of the boundary capacity in many hours of the day (pink line), limiting electricity exports from Scotland to England. Simultaneously, the interconnectors in SE England are net exporting to France, Belgium, and the Netherlands. At the Day Ahead (DA) stage (grey line), interconnectors are scheduled to net export at 5GW for most of the day, except for a drop to around 3GW over the morning. For most hours of the day, these exports remain unchanged after intraday auctions and BSAD actions despite the SCOTEX boundary being constrained, hence energy from Scottish wind cannot meet demand in SE England (including net exports).

Exports are reduced through intraday auctions and BSADs during the late afternoon and evening. BSAD actions and intraday auctions reduce net exports by up to 3.9GW from the DA schedule, with up to a 2GW reduction through intraday auctions (blue line) and 1.9GW from the implied intraday schedule[43] through BSAD actions (yellow line). However, the interconnectors are still net exporting during these periods even after these changes in flows.

Figure 24 10/11/2022 – Flow on SCOTEX boundary as proportion of max capacity and interconnector net imports on SE interconnectors (to France, Belgium and Netherlands) at day ahead stage, intraday stage and post BSAD action stage



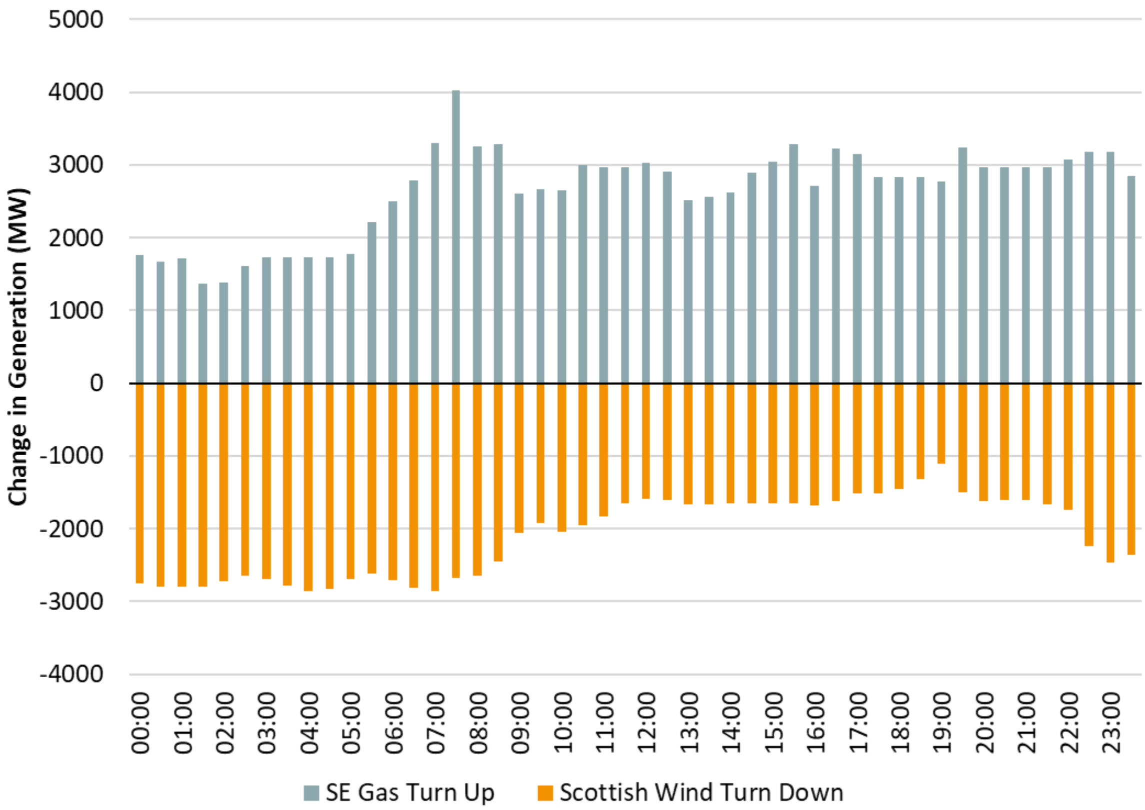
Source: LCP analysis of BSAD actions

The active SCOTEX constraint means wind is curtailed in Scotland throughout the day. Figure 25 shows that up to 2.8GW of wind was curtailed and that as a result, up to 4GW of gas was turned up in SE England to ensure that supply meets demand across the network, despite interconnectors in SE England exporting at the time. If market arrangements allowed, then

43 Note that from data available, it is not possible to see exactly what the scheduled interconnector flows are post intraday auctions only, so this has been calculated by taking the volume of BSAD actions from scheduled flows post BSAD

exports via the interconnectors could be reduced or even switched to imports, reducing or even eliminating gas turn-ups. This could reduce GB emissions and consumer costs.

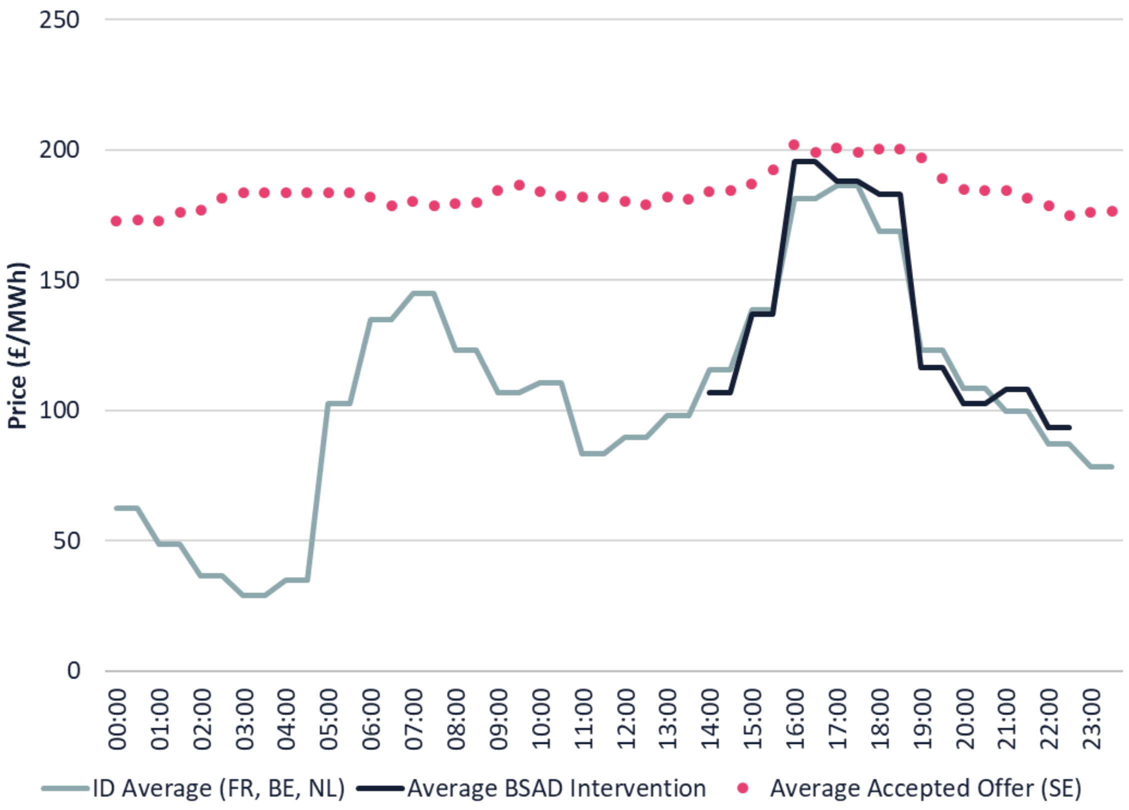
Figure 25 10/11/2022 – Wind turn-downs in Scotland and gas turn-ups in the SE



Source: LCP analysis of BSAD Actions

Figure 26 below shows the average prices of accepted offers in the BM to turn-up generation in the SE, the average Europe intraday price across France, Belgium and Netherlands, and the average price of BSAD interventions. As seen above, BSAD interventions only happen during the late afternoon and evening, with a price between £93/MWh and £195/MWh to reduce interconnector exports during these periods. The average BSAD intervention price (blue) tends to track the average intraday European price (grey) closely, suggesting that the intraday price can serve as a proxy for what the BSAD price would have been had there been better market arrangements in place that allowed the interconnector flows to be changed more regularly. The average accepted offer (turn-up) price for gas plants (pink) in the SE varies between £173/MWh and £202/MWh. Comparing these to the BSAD price and average European intraday price (across France, Belgium and the Netherlands) shows that the accepted offers are much higher than the average price in Europe, indicating that it would likely have been cheaper to reduce net exports to Europe rather than turn-up gas.

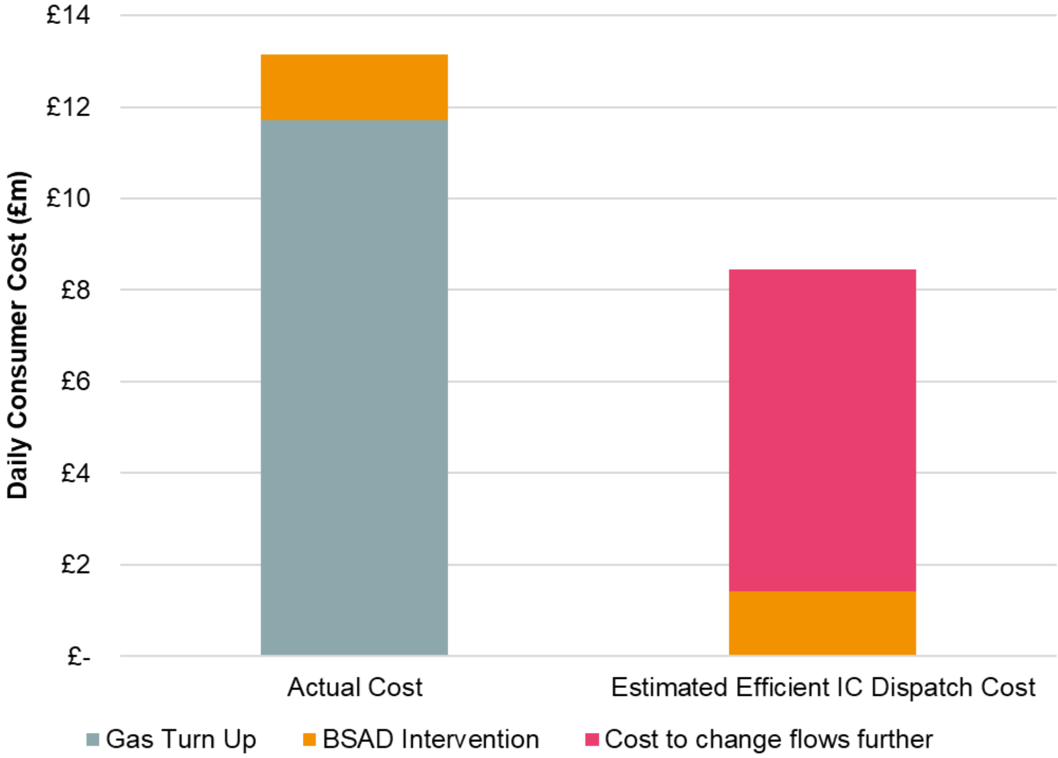
Figure 26 10/11/2022 – Average European intraday, BSAD intervention, and accepted gas offer prices in the SE



Source: LCP analysis of BSAD actions

Figure 27 below shows the differences between the actual cost of turning up gas to deal with constraints vs the estimated cost if interconnectors were dispatched more efficiently. The actual cost from turning up gas (and making small changes to interconnectors within day) totalled £13.1m across the day, which feeds through to consumers bills via BSUoS. If interconnector flows could be changed more effectively to avoid turning up gas on this day, this could have reduced costs across this example day by £4.7m (to £8.4m). This assumes that interconnector flows could be changed at the average intraday price, which is similar to the observed BSAD price in the evening peak. Note in both scenarios shown here there are additional costs in balancing, such as turning down wind, but these are not shown as both scenarios would incur the same cost for this action.

Figure 27 10/11/2022 – Potential consumer cost savings if Interconnectors had been dispatched more efficiently

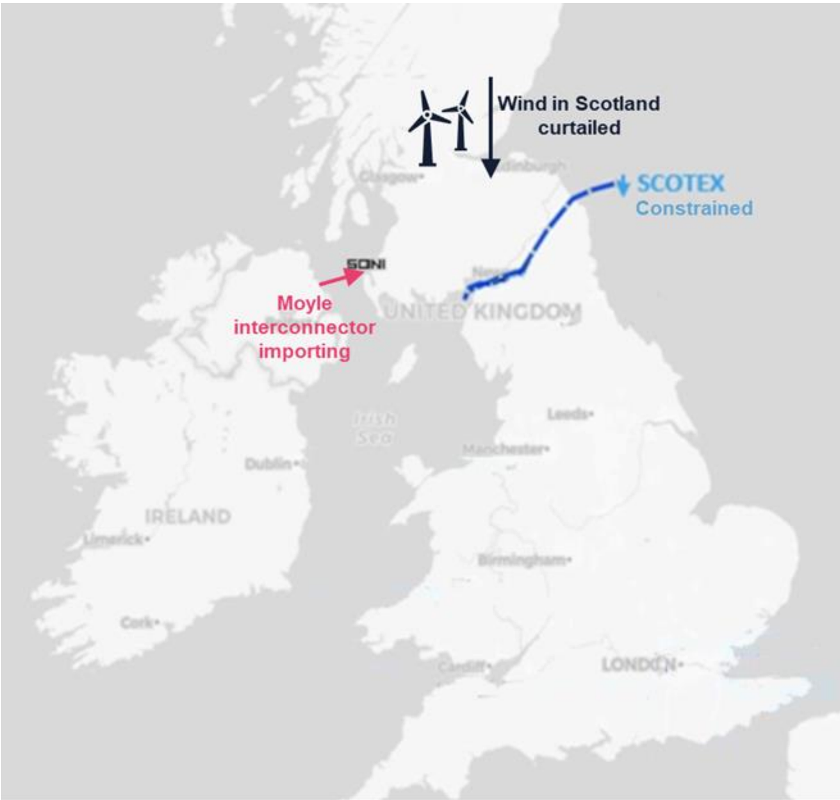


Source: LCP analysis of BSAD actions

Example 2, 10/11/2022 – SCOTEX is export constrained while importing from I-SEM over the Moyle Interconnector

This example uses the same day as example 1 but focuses on a different area of the network. Figure 28 below illustrates that SCOTEX (B6 boundary) is once again export constrained, limiting electricity exports from Scotland to England. This means that wind is being curtailed, but Scotland is also importing electricity from Northern Ireland via the Moyle interconnector. These imports from Moyle mean that more wind in Scotland is being curtailed than needs to be, increasing costs to consumers.

Figure 28 Example 2 Illustration (10/11/2022)

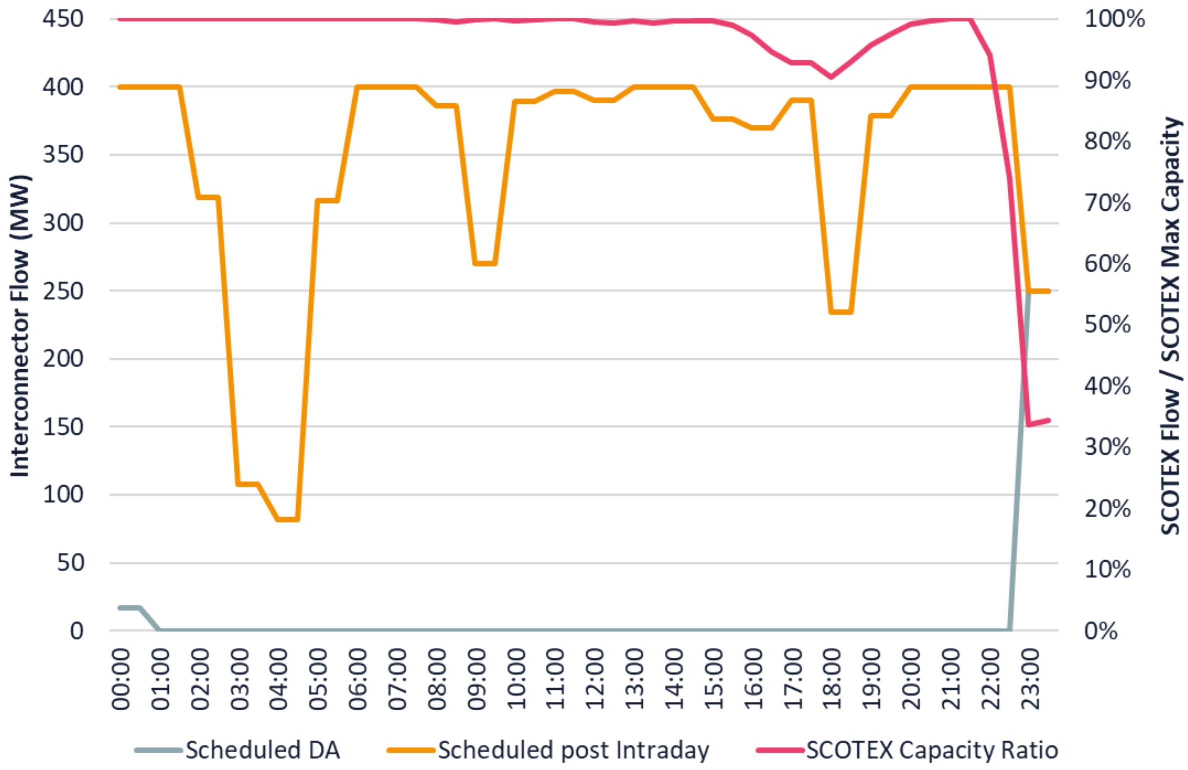


Source: LCP analysis of BSAD Actions

Figure 29 below shows that SCOTEX is export constrained for most of the day (at 100% of its capacity) meaning that no more electricity can be exported from Scotland to England. Simultaneously, the Moyle interconnector is importing up to 400MW. This exacerbates the SCOTEX constraint and requires further wind curtailment.

In this example it is not the DA scheduled flows, but the changes within day that lead to flows across the interconnector. These changes are a result of intraday auctions, and are driven by the relative intraday prices in the two markets, which do not consider network constraints. There are no BSAD actions or SO-SO trades to adjust the interconnector flows.

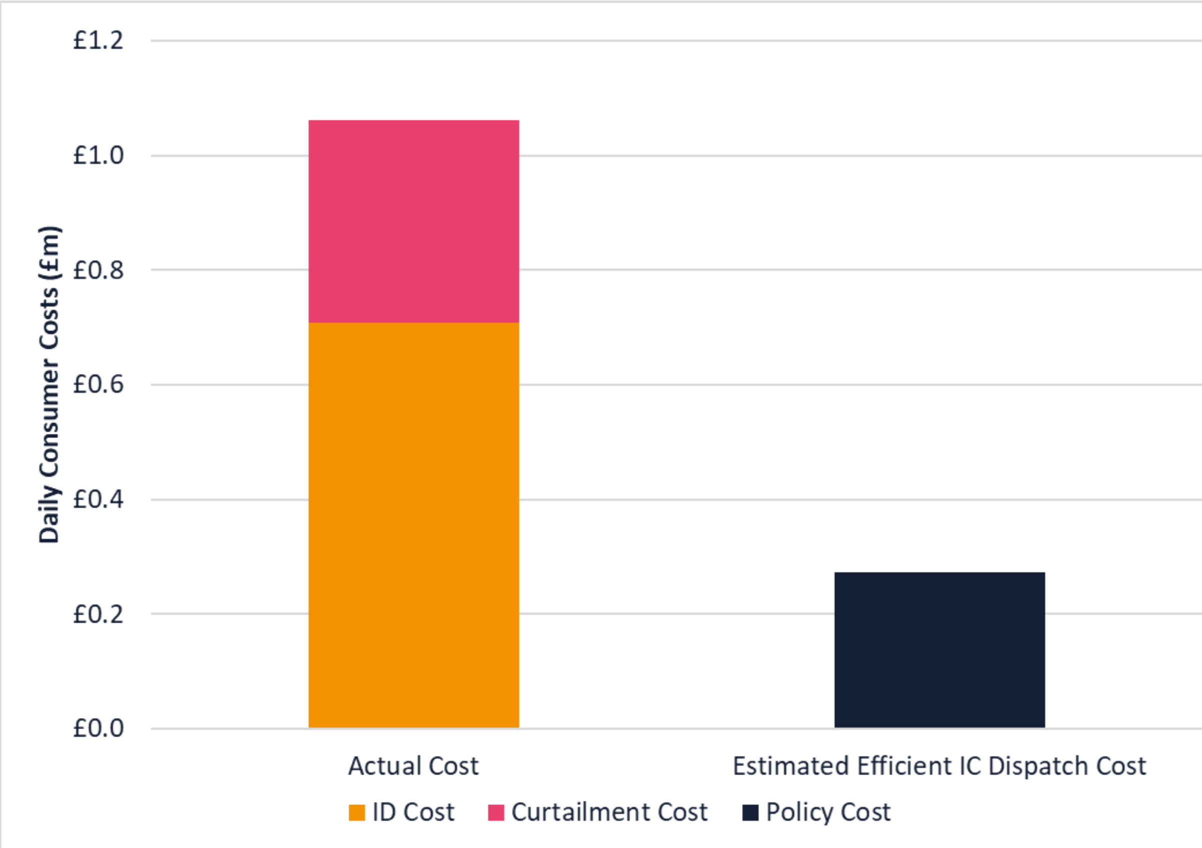
Figure 29 10/11/2022 – Flow on SCOTEX boundary as proportion of max capacity and interconnector net imports on the Moyle interconnector (to I-SEM) at day ahead and post BSAD



Source: LCP analysis of BSAD actions

As shown in Figure 25, up to 2.8GW of wind is being curtailed across the day. This could be reduced by up to 400MW if net imports on the Moyle interconnector were reduced to zero. Wind plants tend to bid to turn down at negative prices in the BM, so the system operator pays the plant to curtail their generation. By not curtailing as much wind, the efficient dispatch scenario saves £75,000 – the difference between the curtailment cost and the policy costs to support the wind generation. However, maintaining the generation of wind plant incurs a net policy cost as they will still need to be paid their renewable support costs (through the CfD or RO mechanisms). Assuming that the flows on Moyle were reduced at the I-SEM intraday price, this would be overall net saving of £790,000 for consumers across the day. The Moyle interconnector could in theory switch to full export of 400MW which would reduce wind curtailment by another 400MW. However, this would depend on the prices and available generation in the I-SEM market.

Figure 30 10/11/2022 – Potential consumer cost savings if interconnectors had been dispatched more efficiently.



Source: LCP analysis of BSAD actions

Example 3, 11/11/2022 – SEIMP import constrained and SE interconnectors exporting

In this example, the SEIMP boundary was constrained in SE England. This limited the volume of electricity that could flow into SE England from the rest of the GB system. The interconnectors connected in the South and SE of England were net exporting to France, Belgium and the Netherlands, even after BSAD interventions. To meet demand (including net exports) in SE England, local gas power plants were turned up. These gas plants were turned up at significantly higher prices than the intraday price in the European export markets. This was an inefficient market outcome. It would have been more cost effective to reduce exports to Europe from the SE (or switch to imports), rather than turn up expensive gas in SE England.

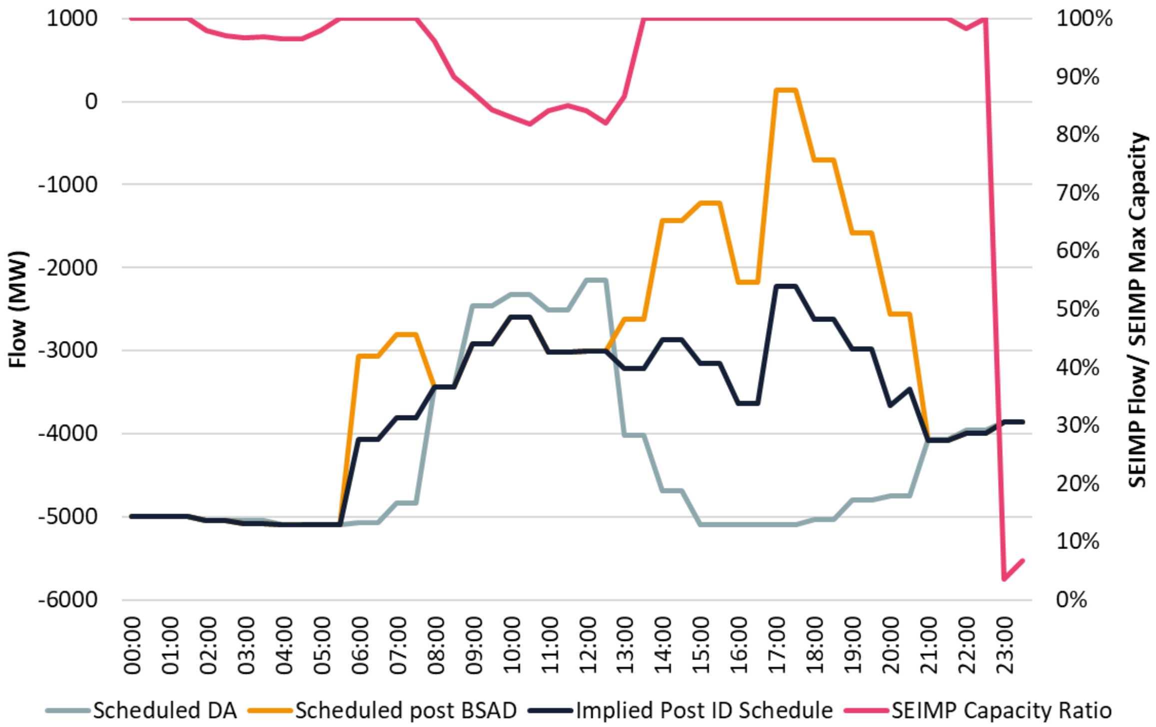
Figure 31 Illustration of Example Day 3 (11/11/2022)

Source: LCP analysis

Figure 32 below shows the active SEIMP constraint which was limiting flows of electricity into SE England from the rest of the GB network. At the same time, interconnectors in the SE were net exporting to France, Belgium and the Netherlands. At the day ahead stage, interconnectors were scheduled to export at 5GW for much of the day with lower levels of exports scheduled across the middle of the day. The implied schedule post intraday auctions show that net exports reduced during some periods across the day, particularly during morning and evening peaks. BSAD actions reduced interconnector flows even further during these periods. However, the interconnectors were still net exporting during all periods except 5-6pm. When the SEIMP is not constrained between 9am and 12.30pm, BSAD interventions increase exports.[44]

[44] It should be noted that from the data available, it is not possible to see exactly what the scheduled interconnector flows are post intraday auctions only. An estimation of this figure has been calculated by taking BSAD actions away from scheduled flows post BSAD actions.

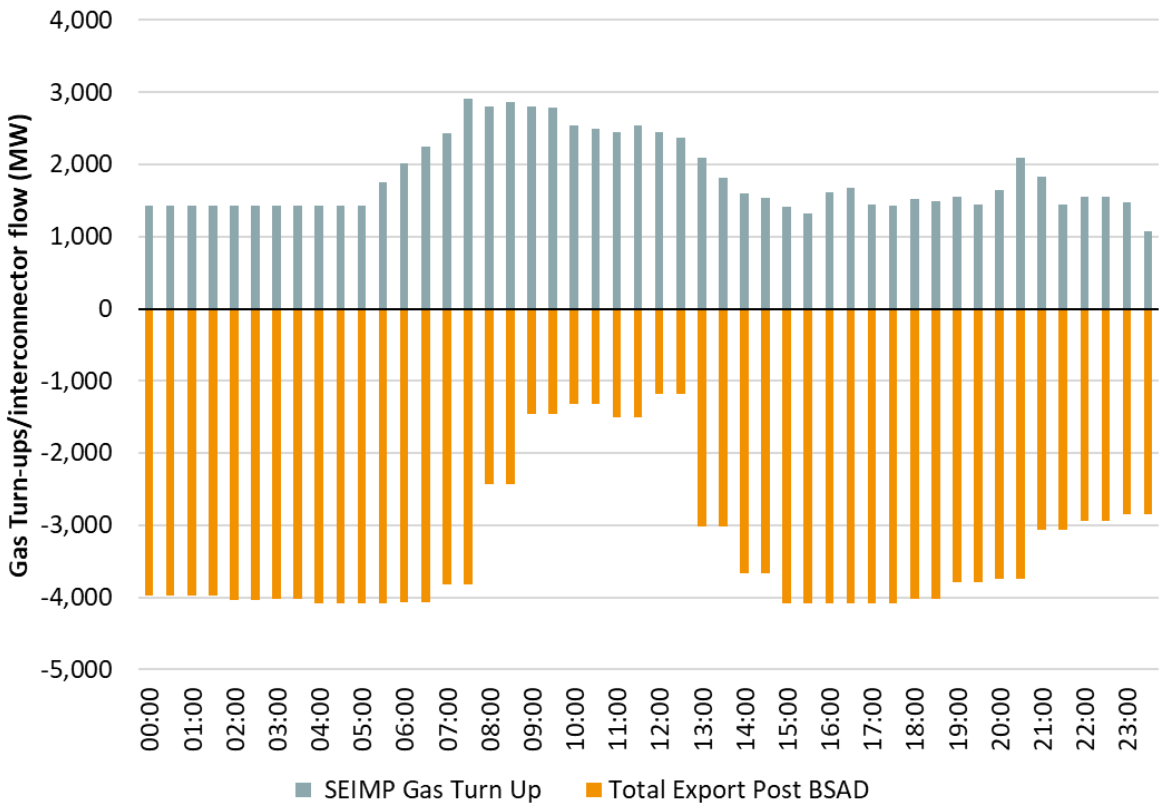
Figure 32 11/11/2022 – Net scheduled IC flows (IFA1, EL, Nemo, BritNed) and SEIMP flow as a proportion of max capacity



Source: LCP analysis of BSAD actions

To meet demand in SE England, gas is turned up across the day. Figure 33 below shows the total interconnector export and the total gas turn up in the SE England area. In the morning peak, gas in SE England is turned up by up to 3GW as electricity from other areas of GB cannot transmitted to the SE zones due to the transmission constraints. In most periods, export volumes exceed gas turn ups, which implies gas is only required to maintain exports. This is an inefficient market outcome as consumers are paying for the gas to be turned up, when interconnector exports could, in principle, be reduced at a lower price.

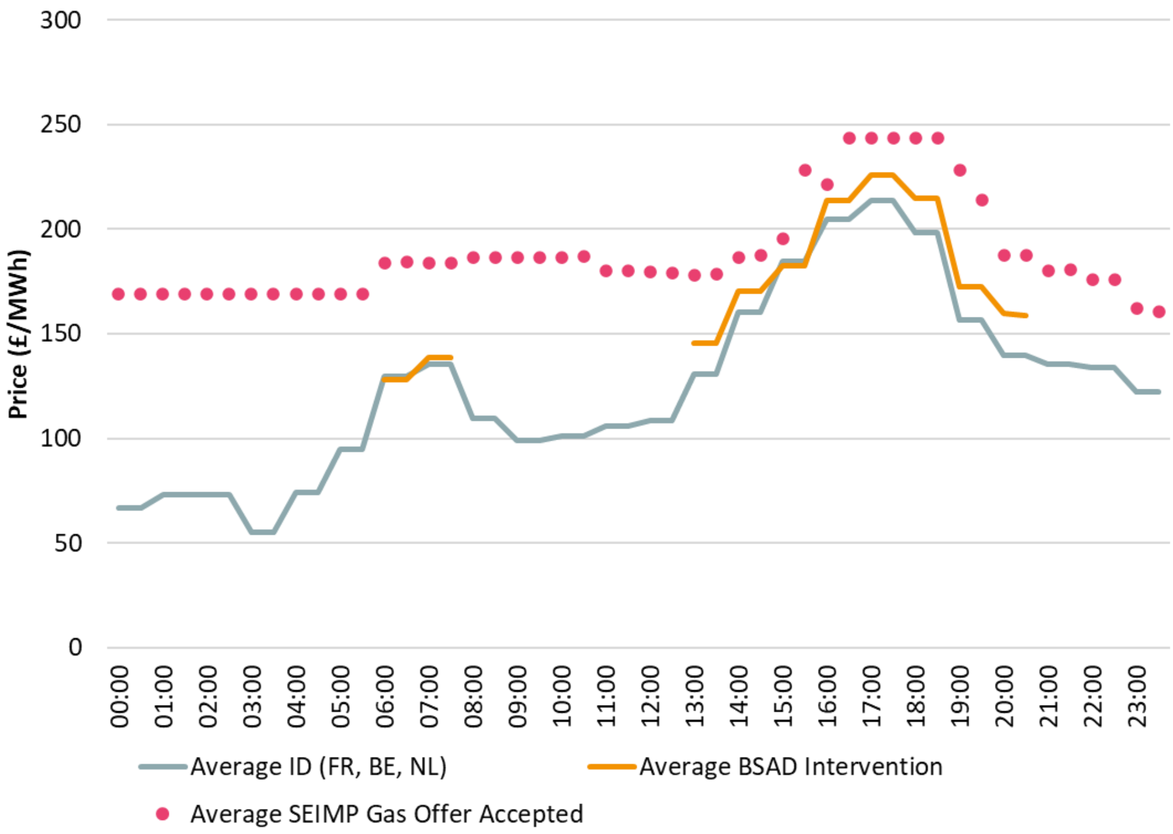
Figure 33 11/11/2022 – Net scheduled IC flows (IFA1, EL, Nemo, BritNed) and gas turn-ups in the SE



Source: LCP analysis of BSAD actions

Figure 34 below shows the different prices of accepted offers to turn up generation in the SE in the BM, the average intraday price across France, Belgium and Netherlands, and the average price of BSAD interventions. Comparing these prices shows that some accepted offers are much higher than the average price in the European markets. This suggests that it would have been cheaper to reduce net exports rather than turn up gas. As with Example 1, the average BSAD intervention price tends to align closely to the intraday price in the European markets, which can be cheaper than turning up gas.

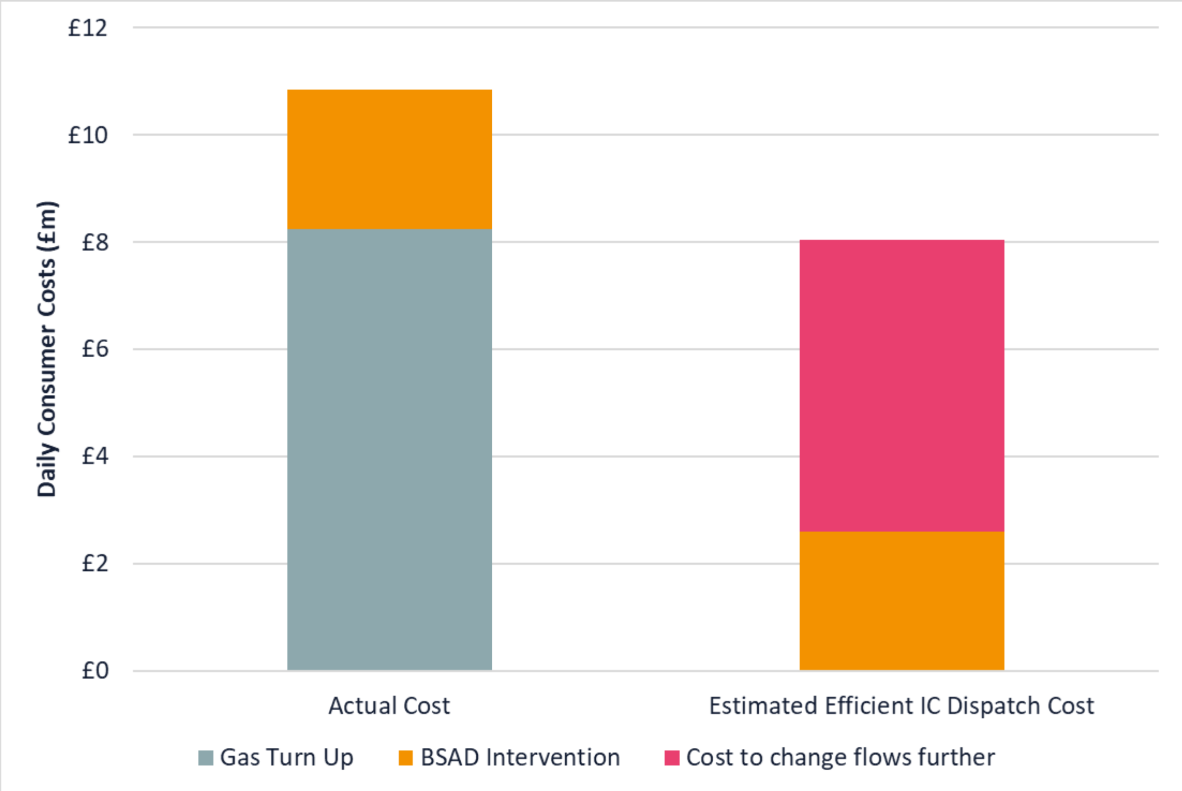
Figure 34 11/11/2022 – Intraday, BSAD intervention, and accepted offer prices



Source: LCP analysis of BSAD actions

If the system could be operated more efficiently and interconnector exports were able to be reduced (or flipped to import when necessary) rather than turning up gas, this would significantly reduce costs for consumers. As shown in Figure 35 (below), consumers would have saved £2.8 million across the day, assuming that all domestic energy needs could be covered by reducing exports or importing at the foreign market intraday price.

Figure 35 11/11/2022 – Possible consumer savings from dispatching interconnectors more efficiently

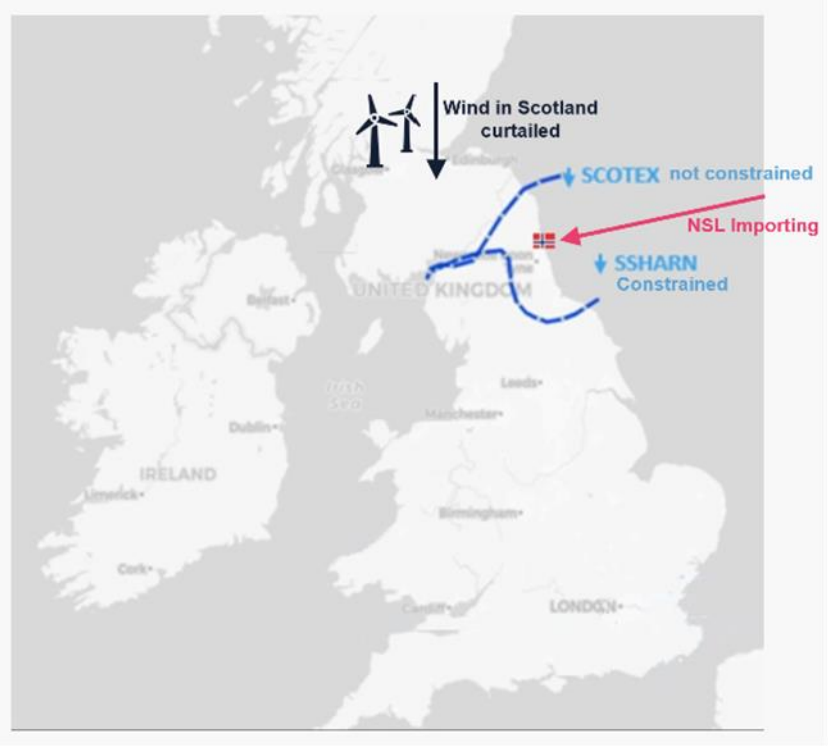


Source: LCP analysis of BSAD actions

Example 4, 23/10/2021 – SSHARN export constrained and NSL importing

In this example day, SSHARN in north east (NE) England is export constrained, limiting electricity exports from NE England to the south. These constraints mean that Scottish wind is curtailed, despite the SCOTEX (B6) not being constrained. At the same time, the NSL interconnector from Norway to Northern England was importing. Norwegian imports are exacerbating the active SSHARN constraint, meaning wind is being curtailed unnecessarily.

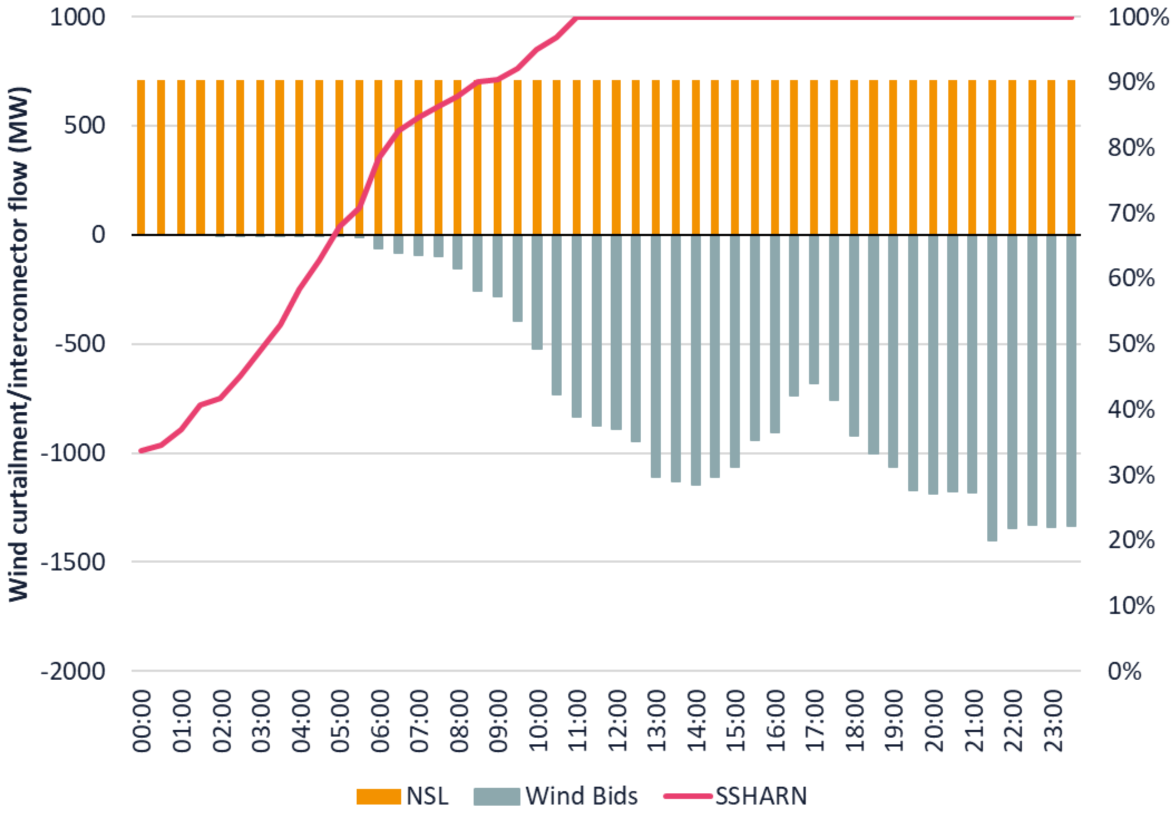
Figure 36 Illustration of Example 4 (23/10/2021)



Source: LCP

Figure 37 below shows that the SSHARN boundary in NE England had an active constraint from 11am to the end of the day, limiting electricity exports to the southern part of the country. At the same time, the NSL interconnector is importing north of the SSHARN constraint for the whole day at 700MW. All flows on NSL are unchanged after the DA stage, as there are no arrangements with Norway to change flows after this point. Up to 1.4GW of wind north of SSHARN is curtailed on the day, despite SCOTEX not being export constrained. This could be reduced by 700MW if there were no imports through NSL and reduced further if NSL switched to exports.

Figure 37 23/10/2021 – NSL Flow and SSHARN Flow as a proportion of the boundary maximum capacity

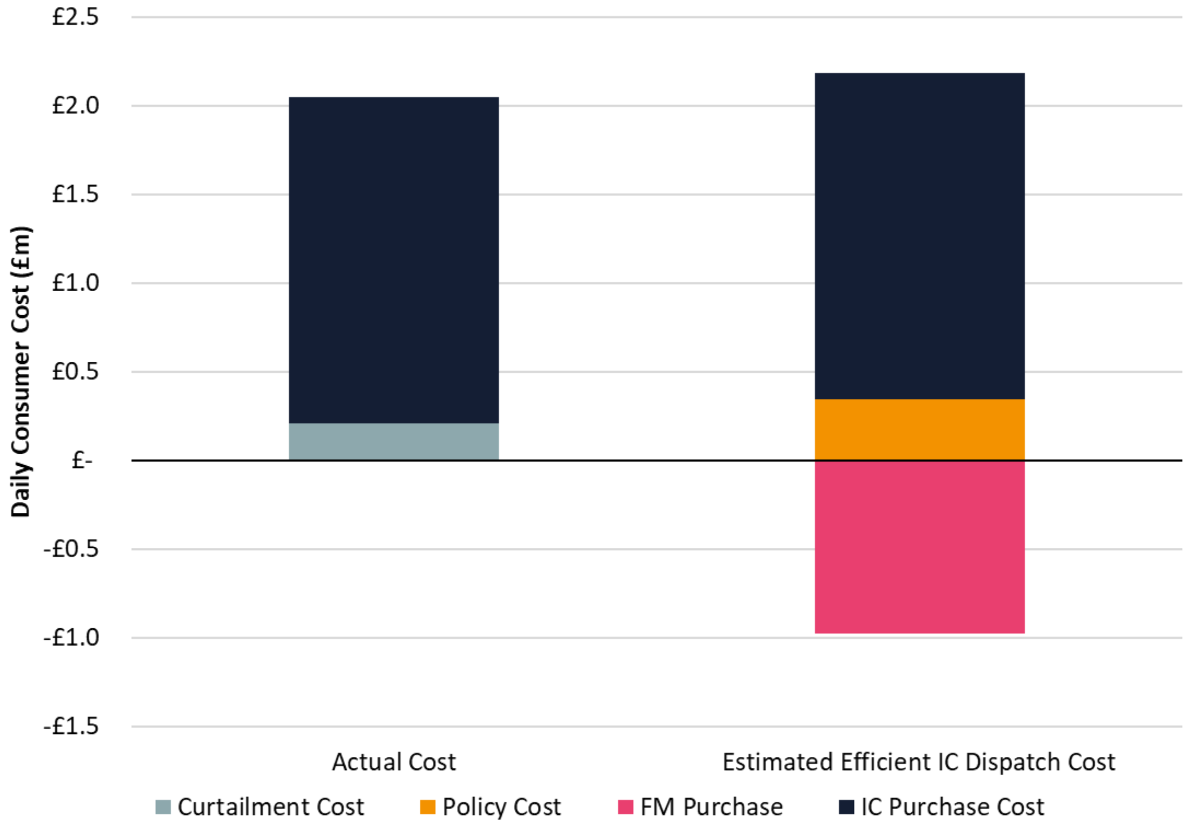


Source: LCP analysis

If market arrangements allowed for intraday trading between Norway and GB markets, flows on the NSL interconnector could decrease, which would require less wind curtailment. In such a market, assuming that NSL would purchase on the lowest of the existing intraday prices of IDA1, IDA2, and NO2[45], this would save consumers £830,000 across the day. Although IDA1 and IDA2 are not directly connected to Norway, using existing intraday market prices to calculate consumer savings is consistent with the other analysis provided in this annex. In theory, the NSL interconnector could switch to full export at 1.4GW to reduce wind curtailment further. In Figure 38 (below), the purchase of electricity by NSL for export in the hypothetical intraday market with Norway is represented as a negative cost to consumers (saving), corresponding to the FM (foreign market) purchase bar.

[45] IDA1 and IDA2 are the two intraday auctions coupling GB and I-SEM. NO2 is the Norwegian bidding zone which connects Norway to GB via NSL.

Figure 38 23/10/2021 – Possible consumer savings from dispatching interconnectors more efficiently



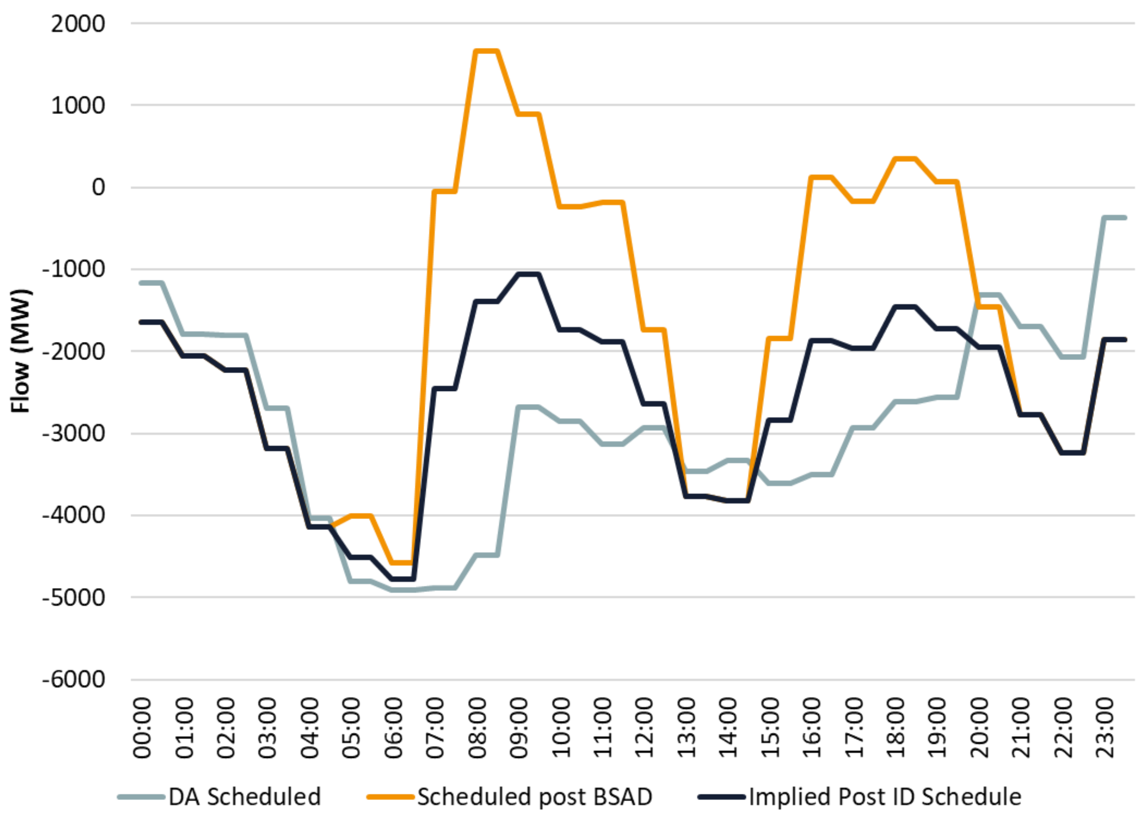
Source: LCP analysis of BSAD actions

Example 5, 25/01/2023 – SE interconnector exports reduced, but only partially

This example shows a day where the BSAD interventions do not change interconnector flows in the most cost-effective way.

Interconnector flows in the SE are adjusted using BSAD interventions, but these only occur at certain points of the day, and only switched from exports to imports for a few hours across the day. Instead, gas is turned up at a higher price than the connected market price in European countries. This is an inefficient market outcome as consumers are paying more to turn-up gas than they would to change interconnector flows. Figure 39 below shows that the interconnector flows are changed across the day compared to the day ahead schedule through use of intraday auctions and BSADs, but use of these are intermittent and varied. At the same time, Figure 47 shows that gas is being turned up in most hours across the day, including at some times (e.g. 13:00-14:30) where interconnector flows are not being changed.

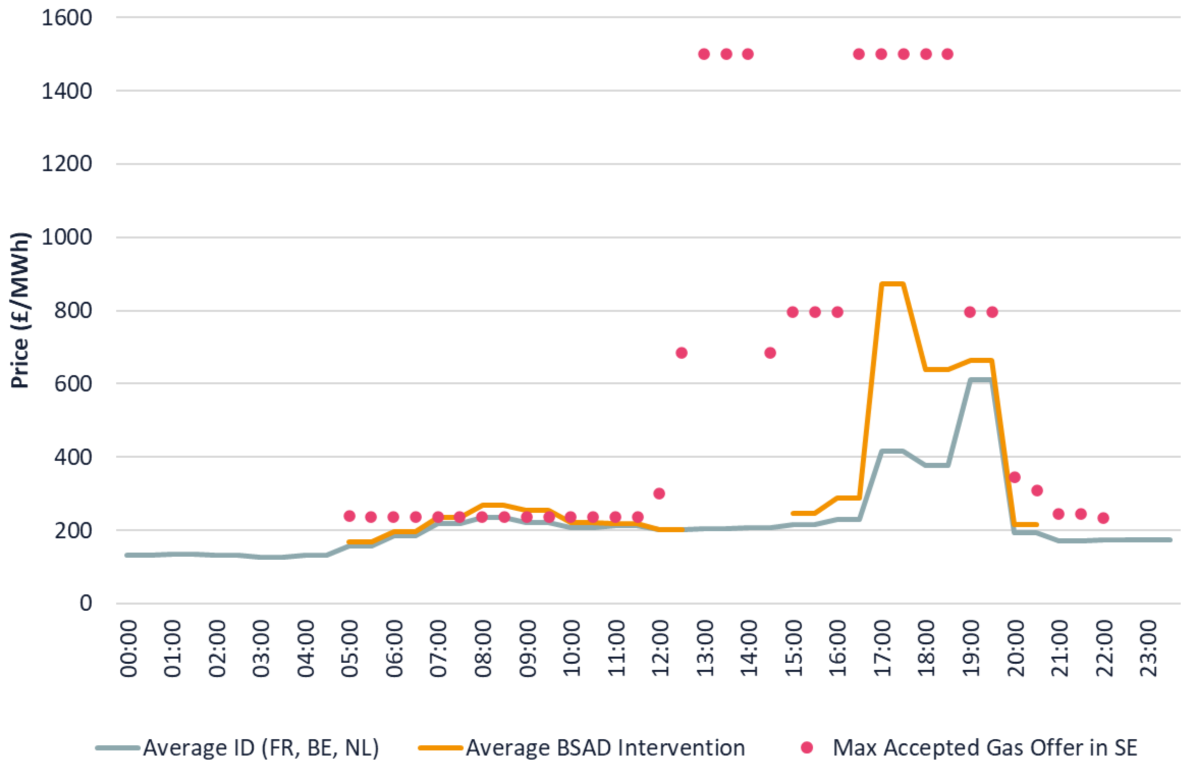
Figure 39 25/01/2023 – net scheduled IC flows to FR, BE and NL



Source: LCP analysis

Figure 40 below shows the maximum accepted offer to turn up gas generation in the SE, the average intraday price across France, Belgium and Netherlands, and the average price of BSAD interventions. Comparing these prices shows that the average accepted gas offer tends to be slightly higher than the average price in Europe and the BSAD intervention price. Some accepted offers are around £900/MWh higher than the BSAD intervention price during the evening peak. This suggests that it would be more cost effective to change interconnector flows further, rather than turning up gas, notwithstanding the high BSAD intervention costs from 17:00-19:00.

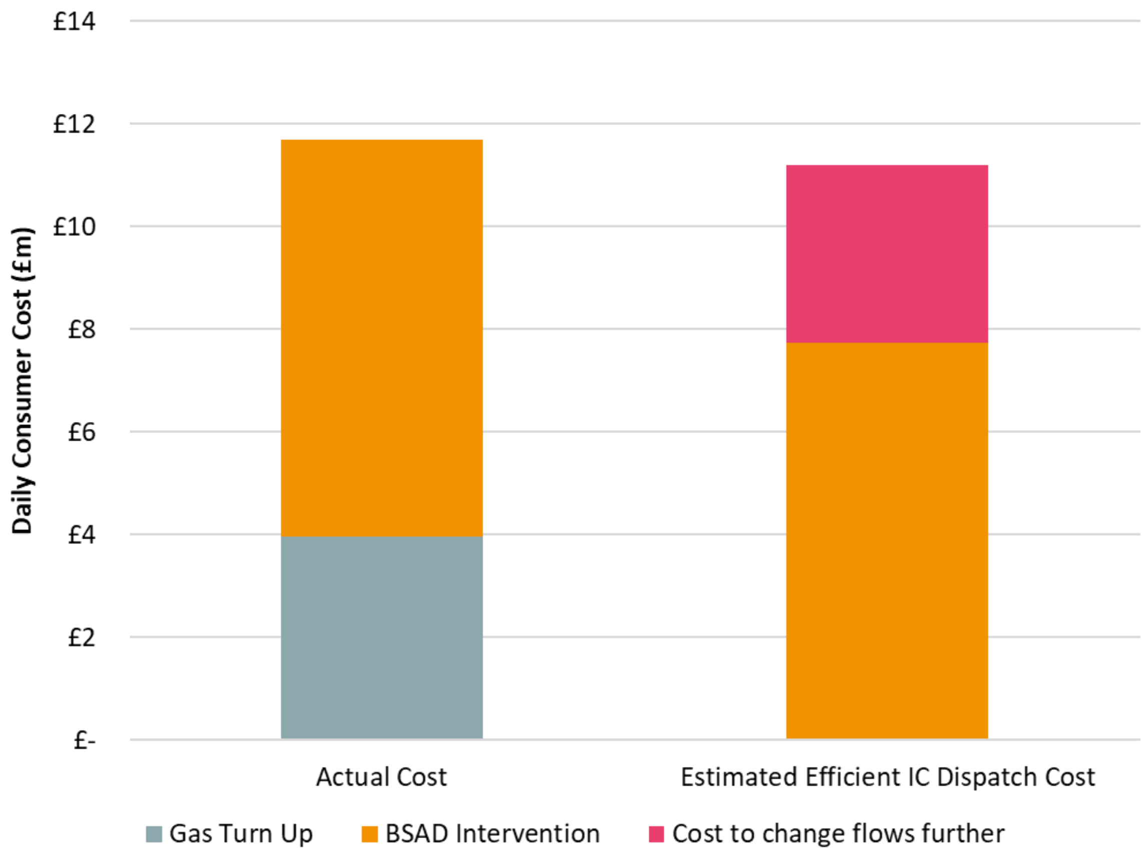
Figure 40 25/01/2023 – Intraday, BSAD intervention, and accepted offer prices



Source: LCP analysis of BSAD actions

On this example day, the cost of turning up gas is greater than the cost of the changing flows on the interconnectors at the foreign market intraday price. If flows on the SE interconnector were able to be changed to remove gas turn-ups throughout the day, and flows were purchased at the foreign market intraday price, then this would have provided consumers with a net saving of £500,000.

Figure 41 25/01/2023 – Possible consumer savings from dispatching interconnectors more efficiently

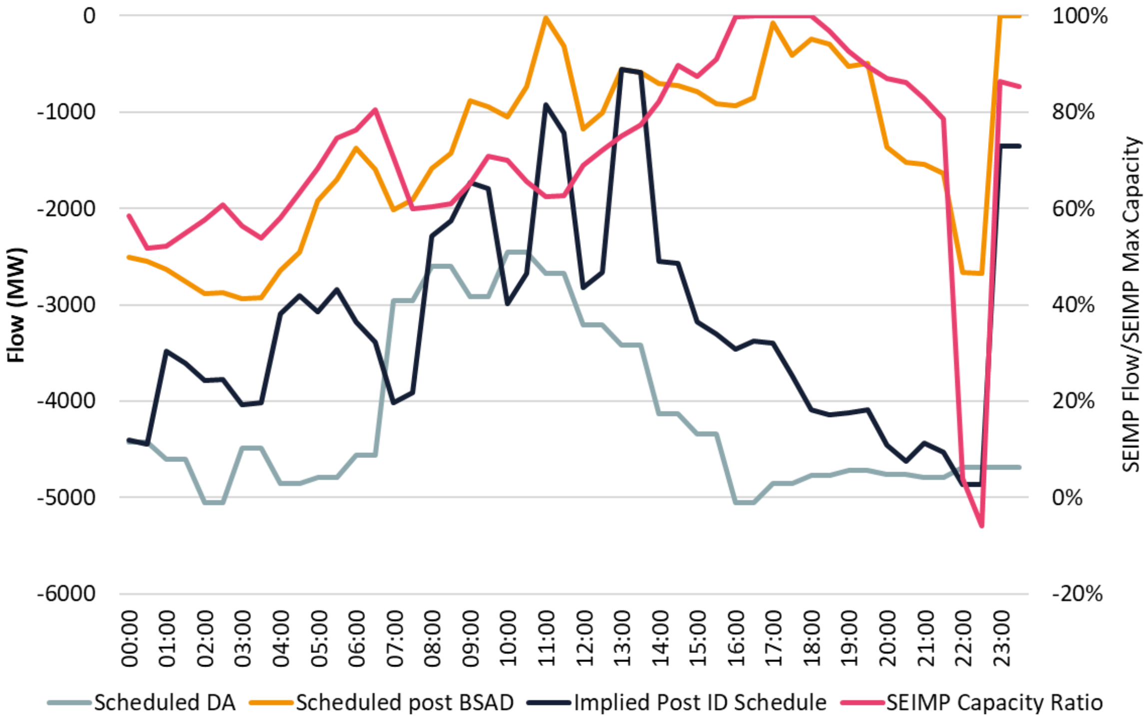


Source: LCP analysis of BSAD actions

Example 6, 20/07/2022 – Exports reduced within-day to manage SEIMP import constraint at high cost

Transmission outages meant the transfer capacity across the SEIMP boundary was significantly lower than usual. This led to the SEIMP boundary being import constrained (limiting flows south from the rest of GB over the SEIMP boundary) during the evening peak. Price spreads with continental Europe meant that GB was scheduled to net export around 5GW of power across interconnectors that land in the SEIMP zone around this time at the day ahead stage. To manage the SEIMP constraint, interconnector flows were changed through intraday auctions and BSAD interventions to reduce exports to France, Belgium, and the Netherlands at a cost of above £9,000/MWh for some actions.

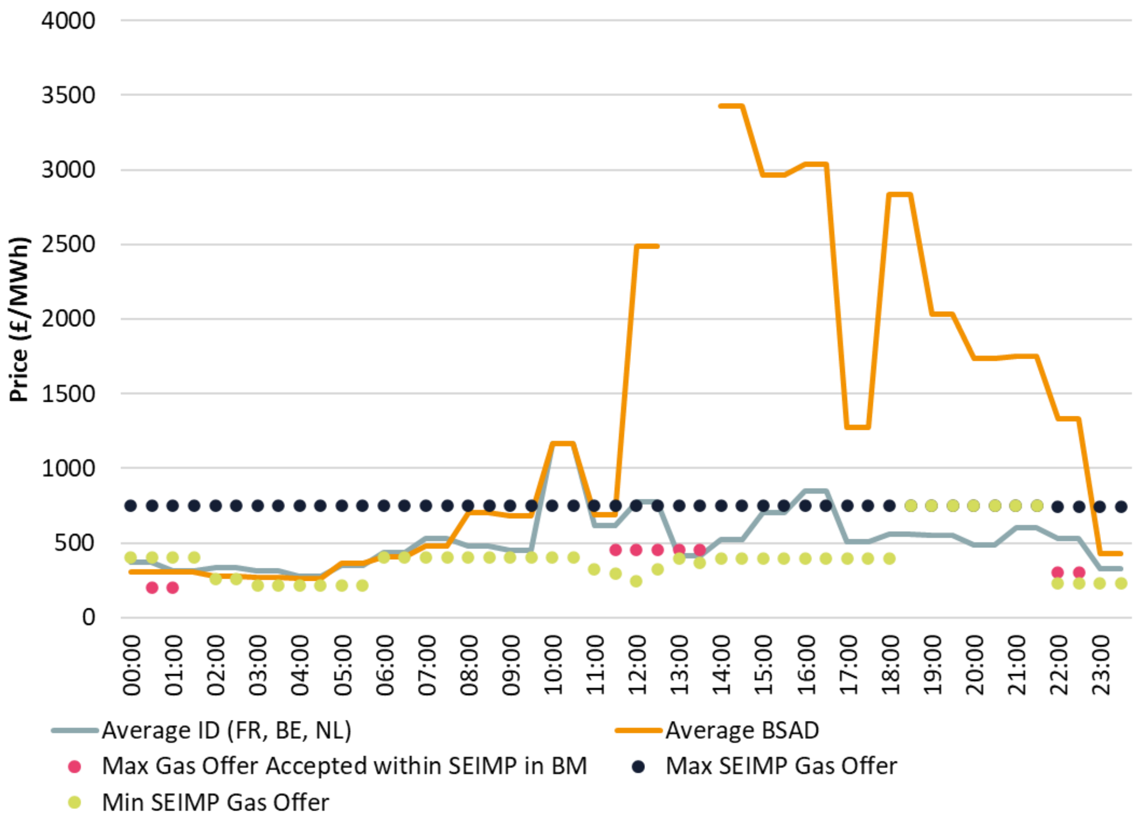
Figure 42 20/07/2022 – Net scheduled IC flows (IFA1, EL, Nemo, BritNed) and SEIMP flow as a proportion of interconnector maximum capacity



Source: LCP analysis

Prices in continental Europe were high, due to the low availability of the French nuclear fleet and high temperatures driving increased demand. But even in this context, BSAD trading to reduce exports was extremely costly, with the GB system having to pay above £9,000/MWh in some periods. Figure 43 below shows the weighted average BSAD intervention cost, which was above £3,000/MWh in multiple periods (well above the intraday price in the markets). This is an extreme example of the high costs that can arise from adjusting interconnectors to resolve locational constraints close to real time (1 to 4 hours before delivery in this case). Throughout the day, there were gas turn up offers not accepted in the BM despite the comparatively low price. However, the turn up capacities were an order of magnitude lower than the BSAD interventions.

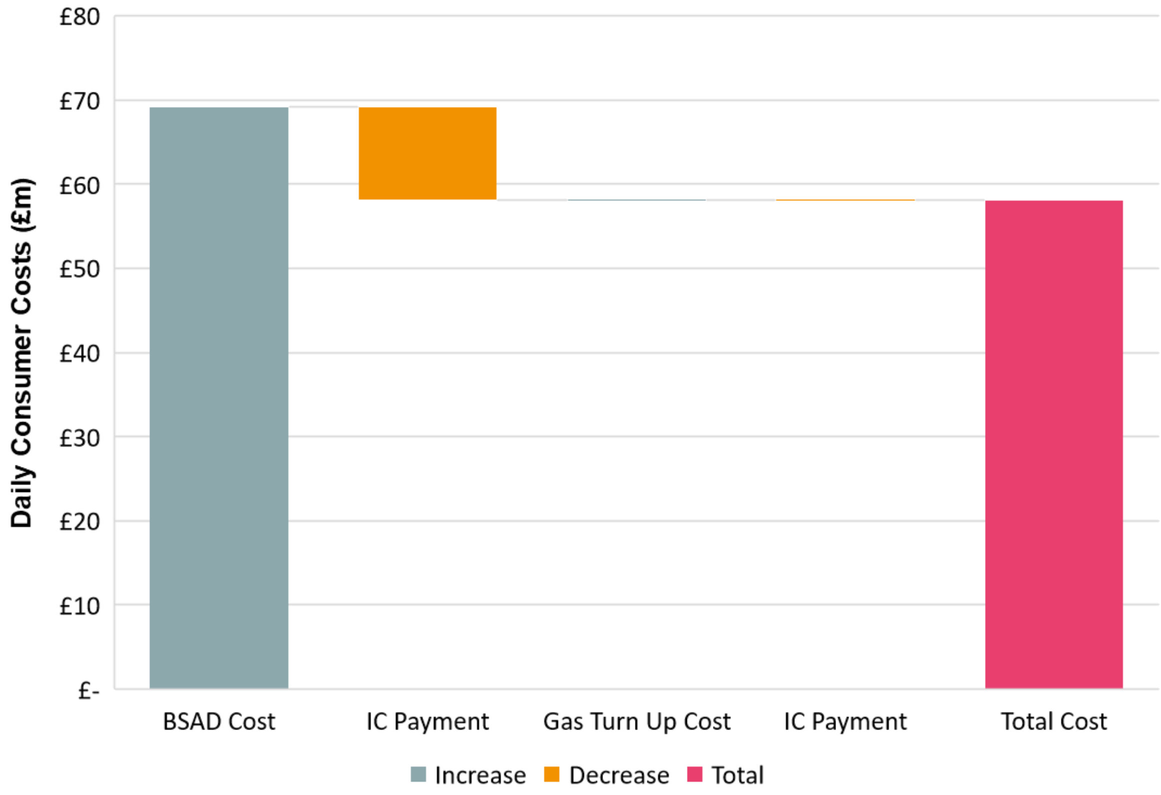
Figure 43 20/07/2022 – Intraday, BSAD intervention and offer prices



Source: LCP analysis of BSAD actions

On this day, there was limited availability of gas turn-up offers in the BM. This required costly interventions through BSADs. If flows on the SE interconnector were changed at the DA stage (or through ID prices) to remove the need for costly BSAD interventions and remove gas turn-ups during the evening peak, this would provide consumers with a large net saving – around £11 million based on DA prices.

Figure 44 20/07/2022 - Possible consumer savings from dispatching interconnectors more efficiently at DA stage



Source: LCP analysis of BSAD actions

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