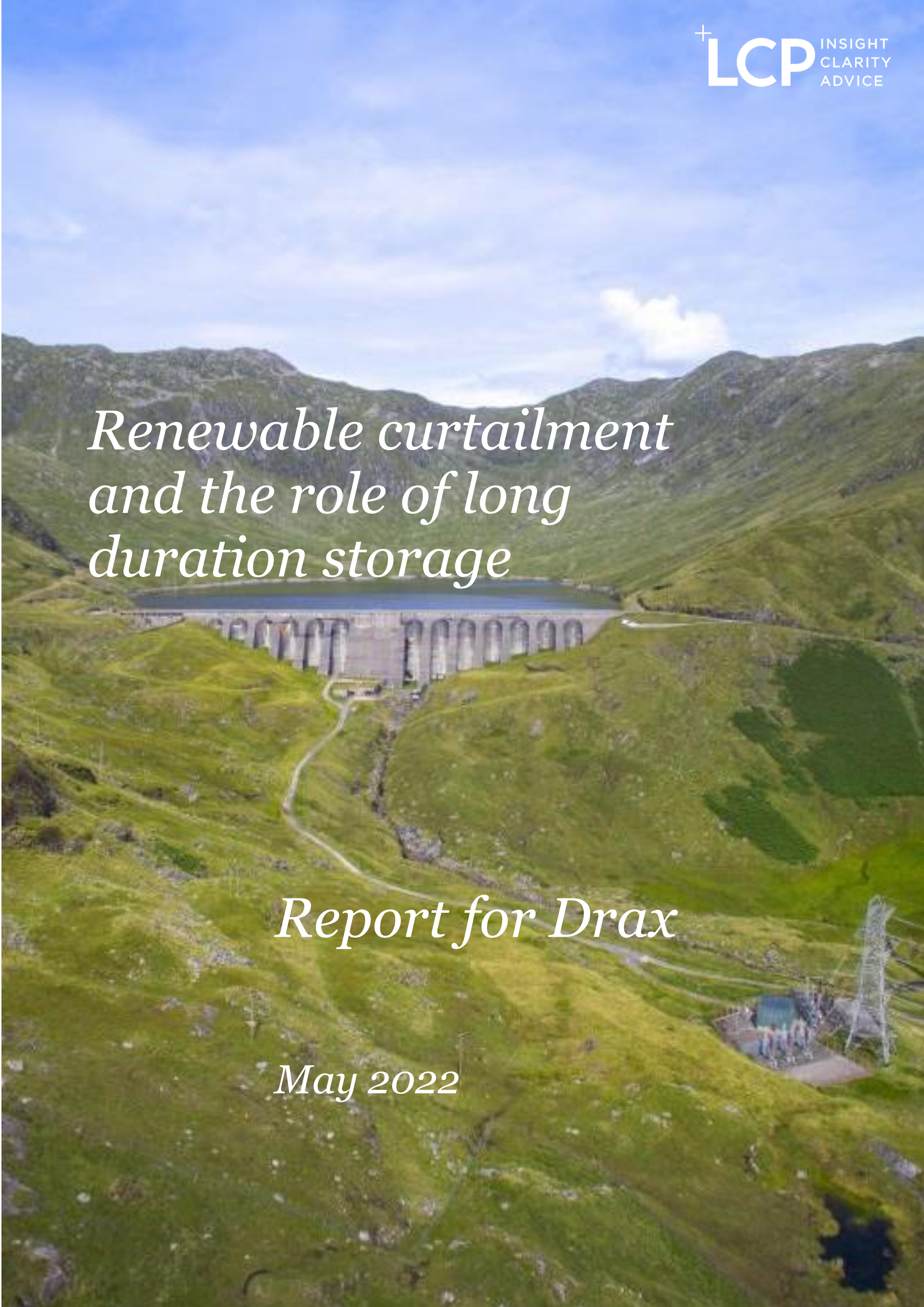


Renewable curtailment and the role of long duration storage

Report for Drax

May 2022

Contents

Executive Summary

- ***5.8TWh of wind curtailment due to system actions*** *across 2020 and 2021. Enough to power* ***800,000*** *homes.*
- ***88% of wind curtailment*** *is in Scotland.*
- ***£806m of associated consumer costs*** *in 2020-2021, with* ***£200m in November 2021*** *alone.*
- ***2% of total power sector CO_2 emissions*** *are due to this curtailment, the equivalent of 500,000 extra cars on the road.*

The curtailment of renewable generation, and in particular wind generation in Scotland, is a significant issue for the GB power sector. When renewable energy is unable to be transported to the final consumer, due to issues such as network constraints, carbon-intensive gas generation typically needs to be turned up to compensate, resulting in higher carbon emissions and higher costs to GB consumers. This report quantifies the level of curtailment across 2020 and 2021, and the cost of this curtailment to GB consumers. It also looks at the role that long duration electricity storage could play in reducing this curtailment.

In 2020, there was a total of 3.5TWh of wind generation curtailed due to system constraints in Great Britain. Wind curtailment in 2021 dropped to 2.3TWh due to unusually low levels of wind output and demand bouncing back with the loosening of Covid restrictions. Across 2020 and 2021 this curtailed wind generation would have been enough to power 800,000 homes each year. The decrease in 2021 reversed a general trend of curtailment increasing rapidly over recent years, and with the UK government's ambition for 50GW of offshore wind capacity by 2030, curtailment volumes and the associated costs will increase further unless there is significant investment in transmission infrastructure and system flexibility.

This wind curtailment has resulted in a significant cost to GB consumers. The analysis in this report estimates that wind curtailment cost GB consumers £299m in 2020, and £507m in 2021. Cost increases in 2021 were mainly due to the impact of high gas prices at the back end of 2021, which saw the costs of turning plant up to compensate for wind curtailment rise dramatically, with costs of over £200m in November 2021 alone.

Scottish wind represented the vast majority of these curtailment and costs, with 88% of the total wind curtailment volume in 2020-21 and 82% of the associated consumer costs.

As the UK government works towards its ambitious carbon reduction targets, the curtailment of generation counteracts these efforts with over 1 million tonnes per year of carbon emissions added due to wind curtailment across 2020-2021. This represents 2.0% of 2020 total power sector emissions, with carbon-intensive generation (mainly gas-fired CCGT) turned up to compensate for curtailed wind generation. The average annual cost to society of the additional emissions that result from wind curtailment (carbon appraisal) is calculated at £248m per year across 2020 and 2021.

Though there are many options for mitigating these curtailment costs and emissions, large-scale long duration electricity storage is one of the most attractive. In 2020 and 2021, 58% of periods with significant wind curtailment lasted more than 3 hours. This points to the need for longer duration electricity storage, which can store excess renewable generation and discharge the power in later periods, reducing GB's reliance on gas.

Drax's Cruachan Expansion represents the development of a new pumped storage power station at the existing site, located in the constrained Scotland region – where our analysis shows 82% of wind curtailment costs stemmed from over 2020-21. The expansion would allow the combined Cruachan site to provide around 9 hours of storage capacity if operating at full capacity or longer if some of the units are utilised for system services to the ESO.

Glossary

Balancing Mechanism (BM)

Used by the ESO to balance electricity supply and demand in each half hour of the day in real-time. It is used for energy balancing (ensuring GB supply and demand balance) and to ensure all system constraints are satisfied. Units submit bids and offers to deviate from their scheduled generation for each half hour.

Bid

A bid (in the context of the BM) is a price and volume that a unit submits to the ESO to reduce their output (or increase their demand). Bid prices from supported low-carbon units such as wind are often negative as the unit needs to be paid to turn down to cover its lost support payments. Bids for other units are typically positive as they are willing to pay the ESO to reduce their output, as still receive wholesale revenues and no longer need to pay running costs (such as fuel and carbon).

CCGT

A Combined Cycle Gas Turbine. These power stations make up the majority of gas-fired generation in Great Britain and are typically more efficient than OCGTs or gas engines. CCGTs can ramp their output up and down and are very active in the BM.

CfD

Contracts for Difference are a form of low-carbon support first allocated in 2015, which almost all new wind farms receive. Under a CfD, generators are guaranteed a ‘strike price’ for their electricity. Volume that is accepted in the BM is not eligible for a CfD but still receives the wholesale price and any BM revenue. They are administered by the Low Carbon Contracts Company (LCCC).

Carbon appraisal price

The UK Government has placed a price for greenhouse gas emissions in terms of the monetary value that society places on one tonne of carbon dioxide equivalent. This is different to the carbon price paid by the market, which is driven by the UK ETS and carbon price support. The carbon appraisal price is used in government policy appraisal to allow for an objective and consistent approach to cost-benefit analysis.[1]

Constraint

The ESO manages constraints on the transmission system which occur when power cannot be transmitted to the location of demand. This can occur due to a limitation on circuit capacity, or due to system management requirements such as inertia, voltage and stability (not considered for the purposes of this report). This leads to paying units to generate that would otherwise not be required from a pure supply and demand perspective.

Curtailment

Curtailment occurs when units are required to reduce their output, often in response to system constraints. A typical example is when wind farms in Scotland must turn down as they are producing more electricity than transmission capacity across the English border can carry. Curtailment actions occur through the BM and those that happen for constraint reasons can be identified by an ‘SO-flagged’ bid.

Day-ahead price

The wholesale price settled in the day-ahead markets which settle a single price (on each exchange) for each hourly period that generators will be paid. This forms the market reference price used for CfD-supported intermittent generators.

Electrolysers

[1] https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

Electrolysers use electricity to split water into hydrogen and oxygen – termed ‘green hydrogen’ as fossil fuels are not required (provided the source of the electricity is 100% green). They are currently only in limited commercial operation but are expected to come online in the next decade as hydrogen capacity is rolled out. They could be a potential source of flexible demand for excess wind generation.

ESO/SO

The Electricity System Operator / System Operator manages the electricity system and is responsible for balancing supply and demand as well as shaping the future energy system. In Great Britain, this role has been performed by National Grid but it has been recently announced that the ESO responsibilities will fall under a new public body to form a new, fully independent ‘Future System Operator’.

Flexible generation

Units with the capability to respond to fluctuations in the supply or demand of the electricity system (this can also mean responding to system requirements such as voltage). Historically, this has typically been provided by gas-fired power stations but increasingly this role will need to be filled by renewable generation sources including pumped storage.

HVDC bootstrap

High Voltage Direct Current transmission lines. In the context of Great Britain, these are being built undersea to connect Scotland to sources of demand further south, e.g a proposed 4GW bootstrap from Peterhead to Drax Power Station comprising two cables each stretching 440km along the east coast of Great Britain.

Inertia

Inertia is the kinetic energy stored in spinning generators that is important for system stability, minimising the impact of sudden changes in frequency. Conventional power stations provide inertia but most renewable sources of generation currently do not, which means that the ESO must carefully manage this constraint as renewable penetration increases.

Interconnectors

Interconnectors are high voltage cables between countries, enabling excess power to be exported. Great Britain currently has 7.4GW of electricity capacity connecting it to France, Belgium, the Netherlands, Northern Ireland, Norway and the Republic of Ireland with an additional 8.5GW to be operational with the next 5 years[2].

Large-scale, long duration electricity storage (LLES)

According to a recent BEIS call for evidence on LLES[3], ‘large-scale’ refers to projects of at least 100MW and ‘long duration’ refers to the ability to store and discharge energy for over 4 hours.

OCGT

Open Cycle Gas Turbine. A less efficient form of gas-fired power than CCGTs, there are only a handful of these operational in the UK.

Offer

In the context of the BM, an offer is the opposite of a bid. Units submit a volume to increase their generation (or decrease their demand) and a corresponding price. A positive offer price means the unit is being paid for its increase in output.

ROC

Renewable Obligation Certificates are a form of renewable subsidy that preceded CfDs, which are no longer available to new capacity. Suppliers must purchase these from RO generators so they can demonstrate they

[2]

[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003841/large-scale-long-duration-electricity-storage-cfe.pdf

have purchased a sufficient proportion of their electricity from renewable sources. Revenue received by generators through ROCs is typically additional to that received in the various available markets.

Scarcity Pricing

In the electricity market context, this occurs when the market price escalates above the marginal cost of the marginal unit. This occurs when margins between electricity supply and demand become tight. This was witnessed in the GB market in late 2021 when factors such as low wind generation and plant unavailability led to tight system margins in periods of peak demand.

Short duration storage

This is typically in the form of lithium-ion batteries with a discharge duration of up to 4 hours. They charge when prices are low and discharge when prices are higher, particularly in frequency markets where rapid response times are required.

SO-flag

As the System Operator (SO), National Grid takes balancing actions for different reason. Actions that are taken due to transmission constraints are 'SO-flagged'.

Strike price

A strike price for a CfD is the guaranteed price that generators will receive for their output on a per MWh basis. This means receiving a top-up payment when the day-ahead price for a period is below the strike price and paying back (indirectly) to the consumer when the opposite is true.

Turn down / Turn up

In the BM, units bid to turn down and offer to turn up their output. When this report refers to turning up or down, this means having bids or offers accepted in the BM to alter their output in either direction.

1. Curtailment volumes

Background

The Balancing Mechanism (BM) is used by National Grid Electricity System Operator (ESO) to balance electricity supply and demand in each half hour of the day in real-time. Generating units make bids to turn their generation down or offers to turn their generation up. For every half-hourly period, units can submit a price and volume and the product of these is the cost to the ESO (eventually passed on to consumers) of taking that balancing action.

As well as balancing supply and demand across the country, the ESO must take account transmission capacity constraints and other system requirements. Transmission capacity constraints often arise when there is too much generation on the system for the network to handle. For example, excess renewable generation in Scotland can mean that the amount of electricity needing to be transported to demand centres in the south exceeds the network's capacity.

Why does curtailment occur?

Energy balancing:

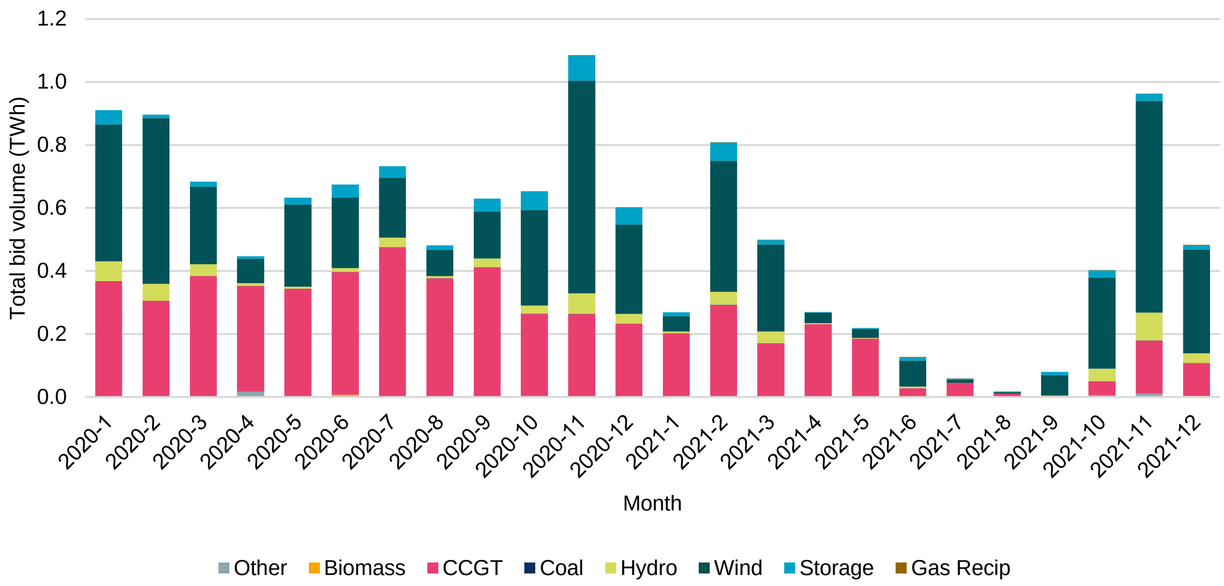
- *Turn up and down generation to balance overall GB supply and demand*
- *Often required due to uncertainty in wind and demand forecasts*
- *Rarely results in wind curtailment, as more expensive generation will be turned down first*

System balancing:

- *Required to resolve transmission network constraints*
- *Or other system stability reasons such as low system inertia or voltage levels*
- *Results in significant volumes of wind curtailment*

If an action is taken in the BM due to transmission constraints or other system stability reasons such as maintaining adequate system inertia, it is given a System Operator (SO) flag. For the purposes of this report, we calculate curtailment as the sum of SO-flagged bid volumes.

Figure 1: *SO-flagged accepted bid volumes split by technology*



In total, Combined Cycle Gas Turbines (CCGTs) and wind plant made up 45% each of SO-flagged bid volumes across 2020-21. Hydroelectric power made up 5% and biomass around 0.1%. All other renewable bid volumes are negligible.

In general, SO-flagged bid volumes were higher in 2020 than in 2021. This is likely due to two main reasons:

- Wind output across GB was unusually low in 2021, around 14% lower than in 2020.

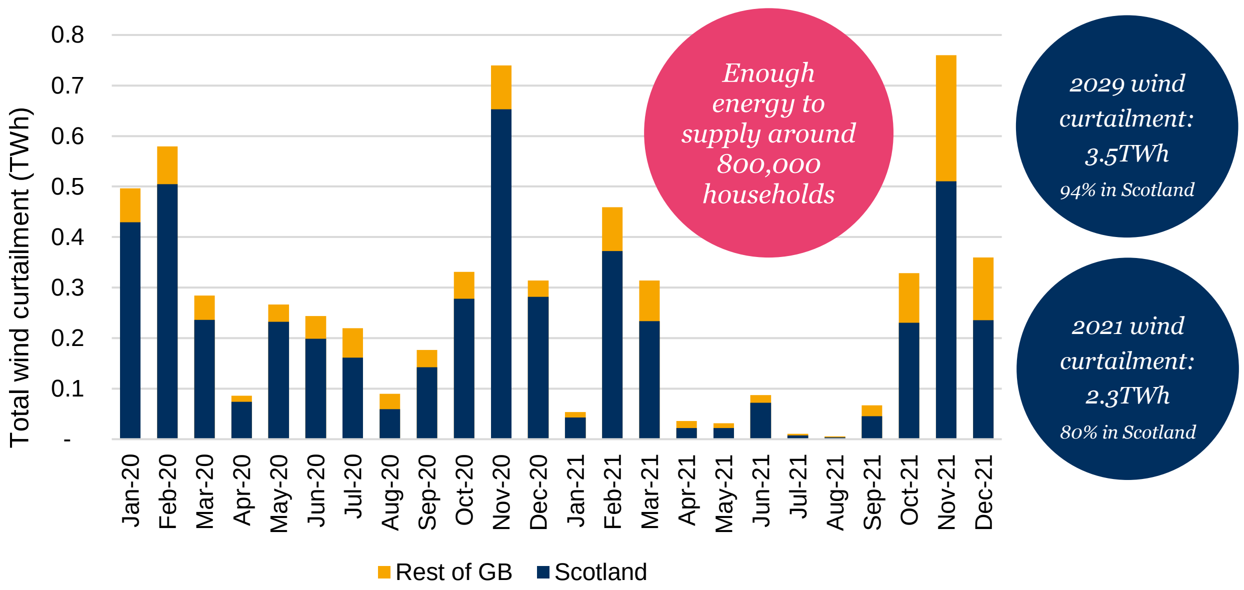
- 2020 saw low demand due to Covid restrictions (particularly over the spring-summer period), resulting in higher levels of curtailment.

We do not anticipate this trend to continue, and SO-flagged bid volumes are likely to increase year-on-year as more renewables are deployed to the system.

Wind curtailment volumes

Wind makes up the vast majority of renewable curtailment, representing around 90% across 2020-21. Most of the remaining renewable curtailment (SO-flagged accepted bids in the BM) is hydroelectric, much of which is flexible generation, which can be saved for a later period and is not completely lost. As a result, wind curtailment is the focus of this analysis. Much of the existing wind fleet is located in Scotland, and capacity constraints on the network prevent this energy from being transported south (to regions of high demand) during times of high wind output.

Figure 2: *Total wind curtailment by month, GB and Scotland*



As a result of these constraints, and the high proportion of wind plants located in Scotland, Scottish wind made up around 94% of total GB wind curtailment in 2020 and 80% in 2021. Though further expansion and reinforcements of the network are planned over the course of this decade, there are also significant levels of new wind capacity planned in Scotland, with 24.8GW of Scottish offshore wind capacity gaining option agreements in the ScotWind leasing round in January 2022.

The curtailed GB wind generation across 2020-21 represented an average of 2.9TWh of wasted electricity per annum, enough energy to power 800,000 households[4].

Historical levels of curtailment

Based on the 2020 and 2021 results, it may appear that there is a downward trend in the levels of wind curtailment over time. However, 2020 was an anomalous year in many ways and the significantly lower levels of electricity demand due to Covid-19 lockdowns (with demand in March 2020 dropping to lowest levels since 1982[5]) meant record curtailment volumes, particularly over the spring and summer lockdowns. In addition, in 2021 there were unusually low levels of wind output (around 14% lower than 2020).

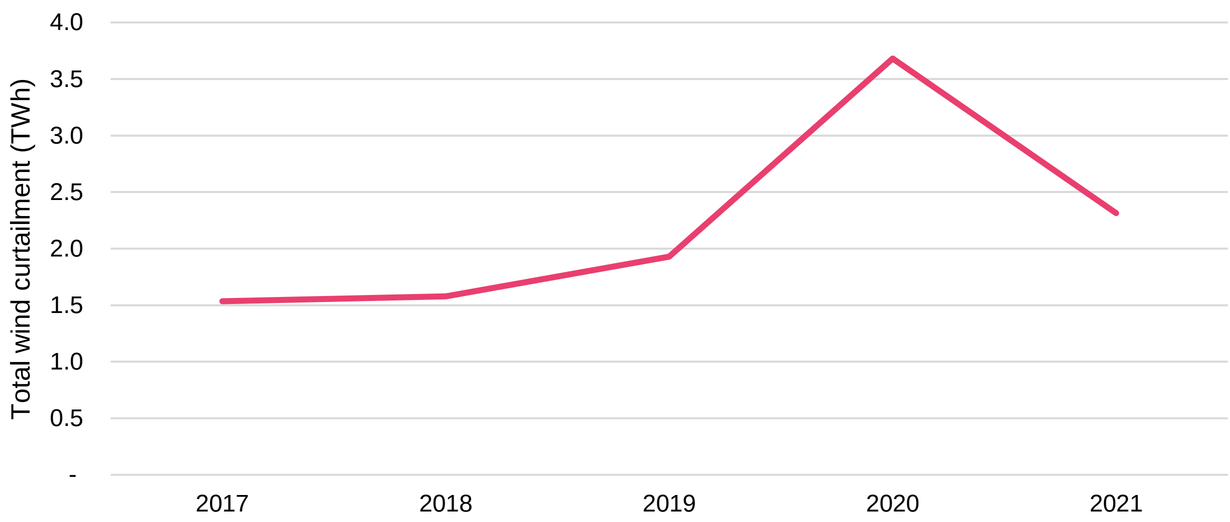
[4] Assuming an average household consumption of 3.73MWh per year

[5] https://reports.electricinsights.co.uk/q1-2020/under-lockdown/#more-78

Hence, we would not expect this reduction to continue in future. Offshore wind capacity in GB is set to scale up drastically from 10GW in 2020 to meet the new government target of 50GW by 2030. The Scottish government is targeting 11GW by 2030 (increasing from 1GW of existing capacity in 2020)[6], and the ScotWind auction in January 2022[7] exceeded expectations by awarding option agreements to 25GW of Scottish offshore wind projects. The transmission infrastructure investment is expected to lag behind this wind capacity deployment, and there is likely to be a corresponding increase in wind curtailment. National Grid ESO's modelling shows a significant increase in network constraint costs through to the end of the decade[8], and this analysis was produced prior to the government's new ambitions being announced, which are likely to increase costs further.

Looking back at wind curtailment volumes over the past 5 years, there is an upwards trend, with 2021 volumes higher than 2017-19 despite the low levels of wind output, due to the increases in installed wind capacity. Overall, there was a total of 11TWh of wind generation curtailed across the 5 years (2.2TWh per year) – enough, on average, to power 590,000 households.

Figure 3: *Total wind curtailment 2017-21*

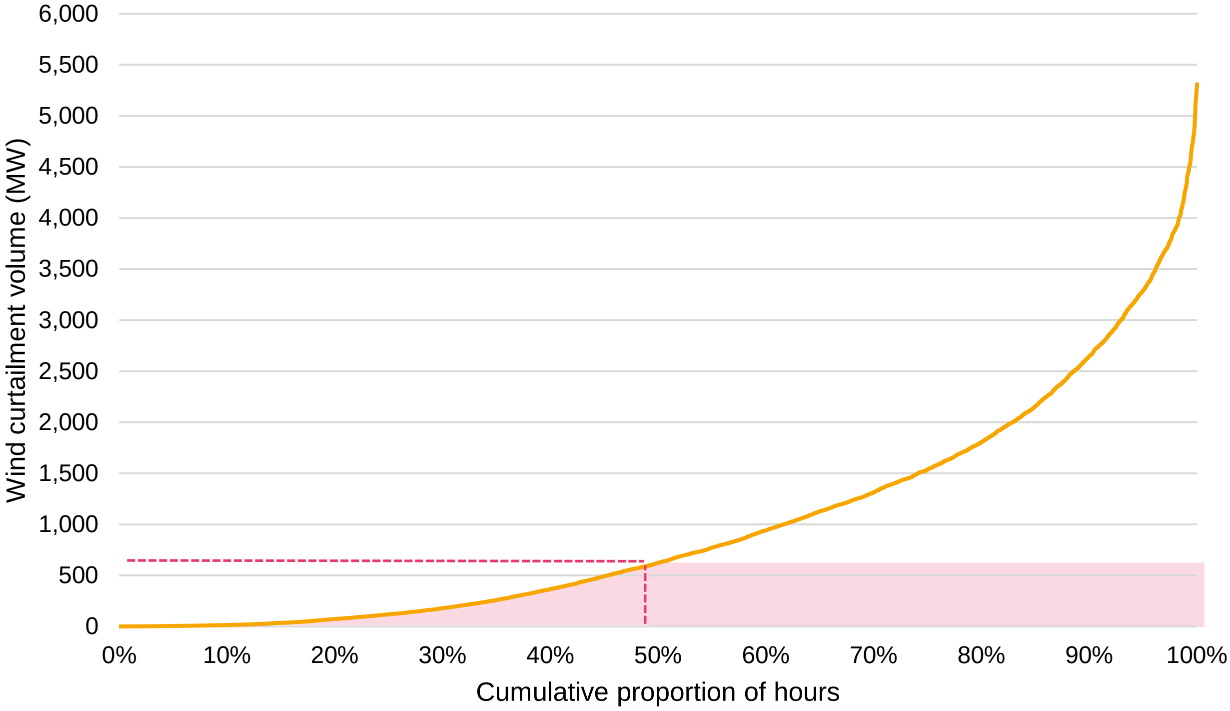


Distribution of curtailment

To understand the impact that flexible technologies could have, it is useful to examine whether the curtailment volumes were from frequent small events or rarer but high-volume curtailment periods which could not be fully mitigated by, for example, an extra 1GW of storage capacity.

6 https://www.gov.scot/news/increased-offshore-wind-ambition-by-2030/
7 https://www.crownestatescotland.com/news/scotwind-offshore-wind-leasing-delivers-major-boost-to-scotlands-net-zero-aspirations
8 https://www.nationalgrideso.com/document/194436/download

Figure 4: *Distribution of wind curtailment volumes in 2020-21*

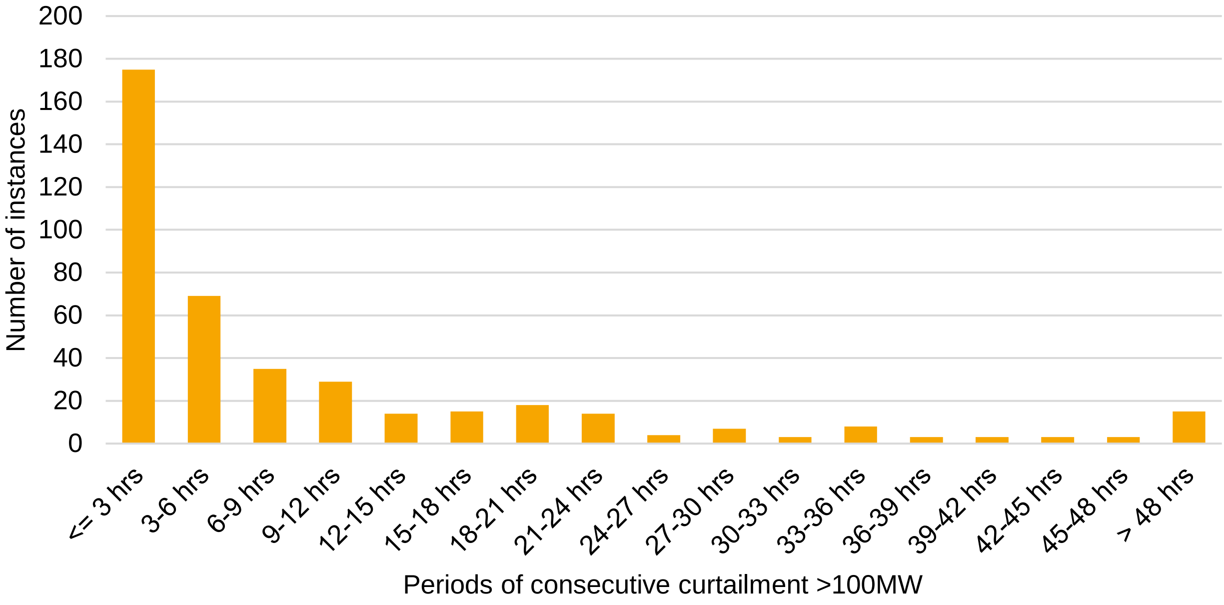


In the periods in 2020-21 where wind curtailment takes place, 49% of these periods see a total curtailment volume of less than 600MW[9] (show by the dashed lines on chart above). This means 49% of the curtailment periods could potentially be completely resolved by 600MW of storage or other demand-side flexibility. Similarly, 39% of the total 2020-21 curtailment volume could theoretically have been avoided given 600MW of storage capacity with unlimited duration – this is shown by the shaded area on the chart.

However, given that many of these curtailment volumes occur over periods of many consecutive hours, the ability of storage to help mitigate will be dependent on its duration, with longer durations able to provide more potential for curtailment reduction. Below we look at the distribution duration of curtailment periods.

[9] The proposed capacity of Drax's Cruachan 2 unit

***Figure 5:** Hours of consecutive wind curtailment of more than 100MW in 2020-21*



More than half (58%) of consecutive periods of significant wind curtailment (defined here as at least 100MW of curtailment) lasted for more than 3 hours, indicating that longer duration storage would hold an advantage in reducing curtailment. 67% of these consecutive wind curtailment periods were for 9 periods or less and 74% were for 12 hours or less.

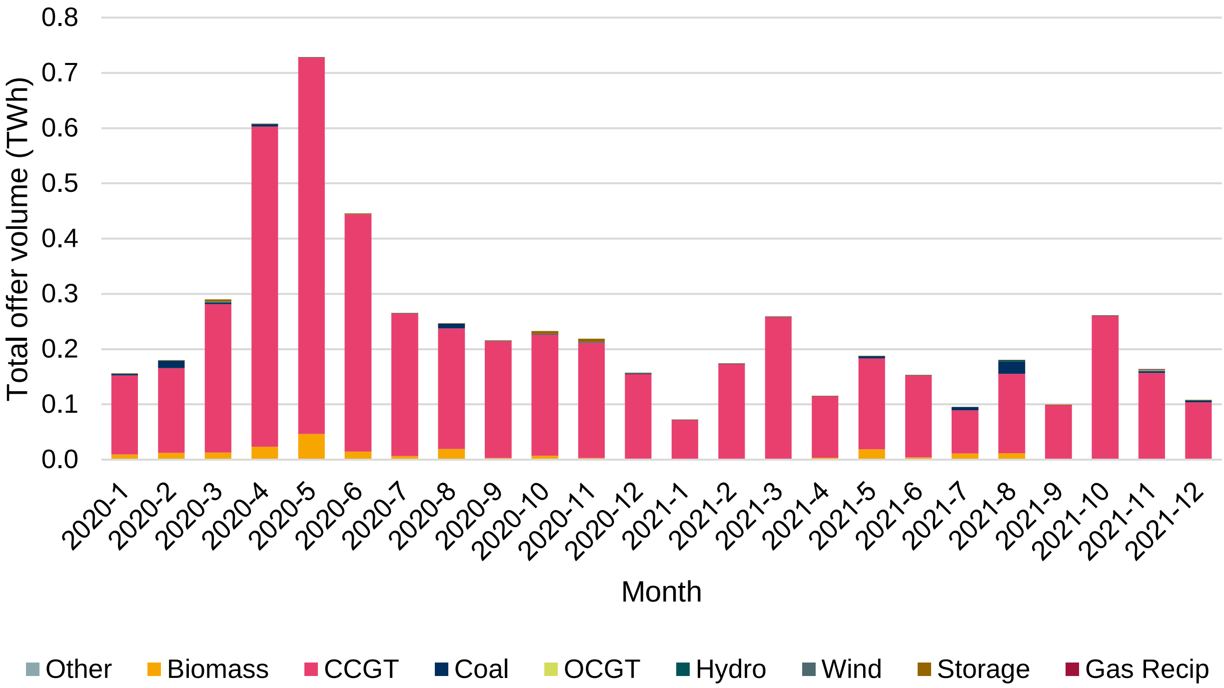
However, note that while most periods of consecutive curtailment lasted for less than 9 or 12 hours, the levels of curtailment volume – and therefore volume that could potentially be utilised by storage – was significantly higher as the length of curtailment events increases.

Turn-up volumes

When turning down wind generation to relieve transmission constraints or for other system stability issues, an equivalent volume of generation must be turned up elsewhere. In many instances this means that wind generation must be turned down in certain locations and high-carbon gas generation must be turned up in other locations.

It is not possible in the historic data to directly match which generation is turned up to compensate for the wind generation turned down, so instead we look at the average technology mix of SO-flagged accepted offers (i.e. turn-up actions) and apply this to the wind bid volumes.

Figure 6: *SO-flagged accepted offer volumes split by technology*



As shown on the chart above, the vast majority (94%) of SO-flagged turn-up volumes in the BM in 2020-2021 were from CCGTs (i.e. gas generation). In what follows, we assume the generation turned up to offset the wind volumes curtailed has the same distribution as the SO-flagged accepted offer volumes (matched on an individual period by period basis), allowing an estimate of the costs and emissions associated with these actions.

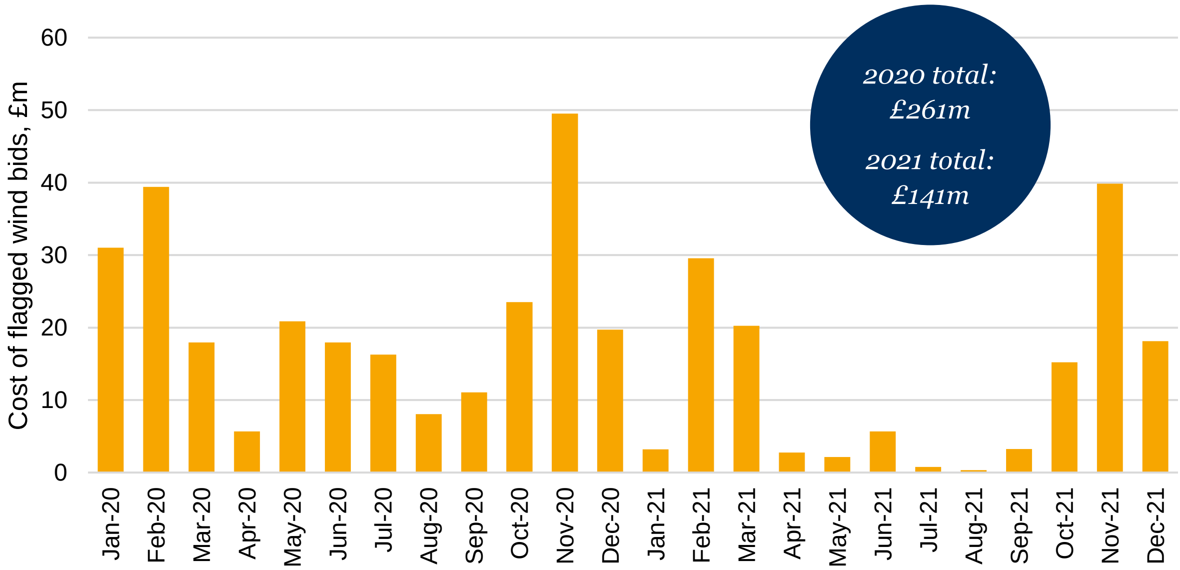
2. The costs of curtailment

The consumer costs of curtailing wind can be broken down into the cost of turning wind plant down (bid costs), the consumer benefit arising from the non-payment of low-carbon support payments to curtailed wind plant, and the cost of paying generation to turn-up (offer costs) to replace the lost wind generation. In this section we quantify each of these components in turn, and then calculate the total consumer cost of wind curtailment across 2020 and 2021.

Cost of turning wind plant down

The costs of turning wind down have been calculated at a unit level based on the bid prices multiplied by corresponding bid volumes for SO-flagged accepted wind bids. Wind bids are typically at negative prices – meaning they are paid to turn down – as wind plant need to recover their lost support payments (more on this in the next section). This means that wind turning down results in a net cost to the ESO and ultimately to the consumer.

Figure 7: *Costs of SO-flagged accepted bids from wind*



The total cost of paying wind plant to turn down was **£402m** across 2020-21. This roughly follows the same pattern as wind curtailment volumes in Figure 2, but with the average bid cost per MWh reducing in 2021. In the high price periods experienced in 2021, we see some CfD-supported wind plant in fact paying the ESO to turn down (e.g. a positive bid price), in order to avoid their CfD repayment in periods where the day-ahead price exceeds their strike price.

Benefit from policy support not paid

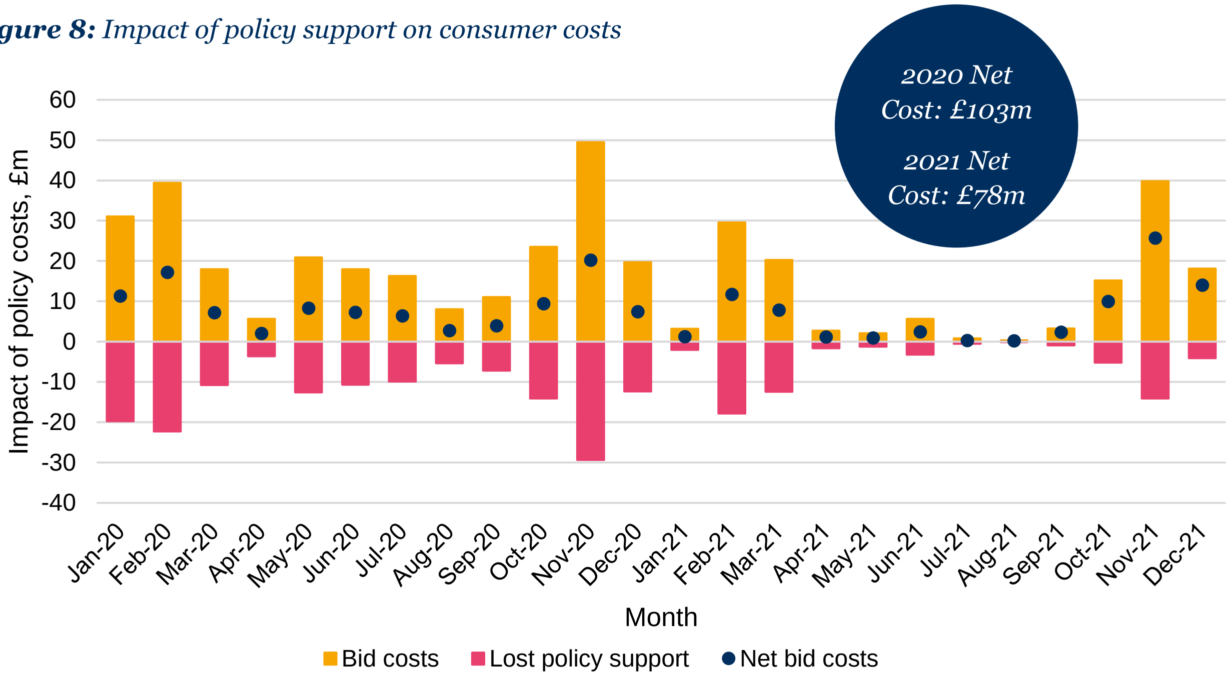
When wind plants are turned down in the BM, they lose their policy support payment, which are paid based on actual output. This represents an avoided payment to the consumer. For large-scale wind plant, this will either be in the form of a ROC or a CfD:

- ROC – the entire support payment is not paid, resulting in a reduction in the cost to consumers (relative to a situation where the curtailment had not occurred)
- CfD – the ‘top-up’ to the strike price is not paid, again resulting in a reduction in the cost to consumers (relative to a situation where the curtailment had not occurred). However, in situations where the day-ahead price is greater than the strike price (which occurred more frequently in late

2021), generators have to pay-back (rather than being topped up), and if they are turned down in the BM they avoid making this payment. Therefore, we have seen wind plant bidding at positive levels during higher price periods.

As a result of the above dynamics, wind plant typically allow for any lost ROC or CfD support payments in their bids, which means they are often negative. In calculating the costs to consumers due to wind curtailment, we have taken into account the avoided consumer cost of support payments. This reduces the net cost to consumers of curtailing wind, as seen below.

Figure 8: *Impact of policy support on consumer costs*

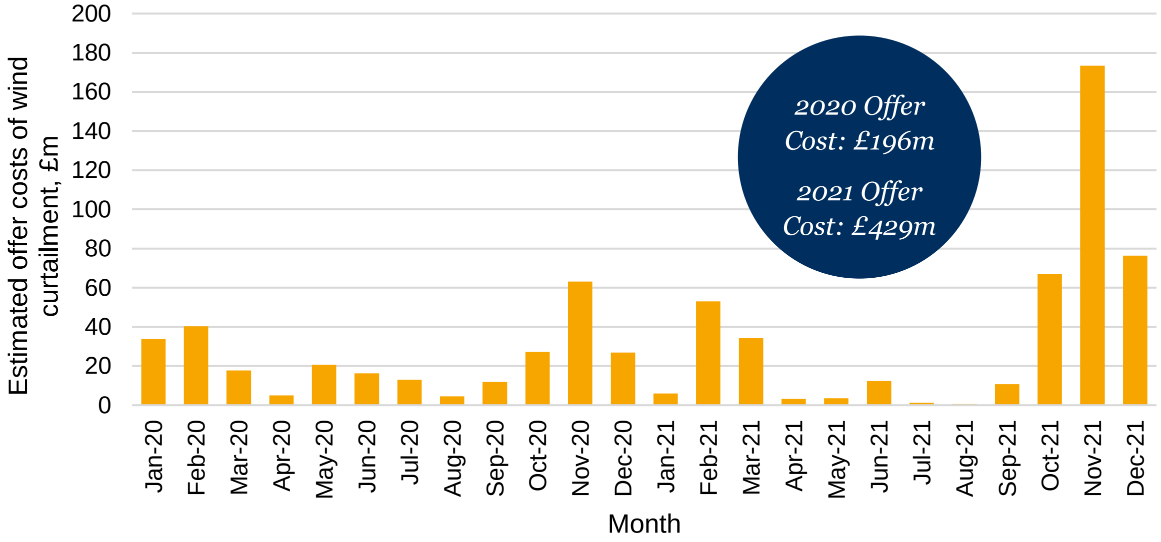


With the policy support lost by wind generators netted off from the cost of turning the plant down (bid costs), the net cost to consumers was **£181m** across 2020 and 2021.

Cost of turning generation up

Given that we don’t know exactly which turn-up actions relate to wind turn-downs, we assume in our analysis that all offers to match wind bids are from the volume-weighted average generation mix of all SO-flagged offers (see Figure 6). This weighted average technology mix has been applied to the volume-weighted average of SO-flagged offer prices in the BM for each half hour. Multiplying these prices by the total wind curtailment volume in each half hour gives an estimate of the total cost of paying units to turn up.

Figure 9: *Estimated costs of turning plant up to compensate for wind curtailment*

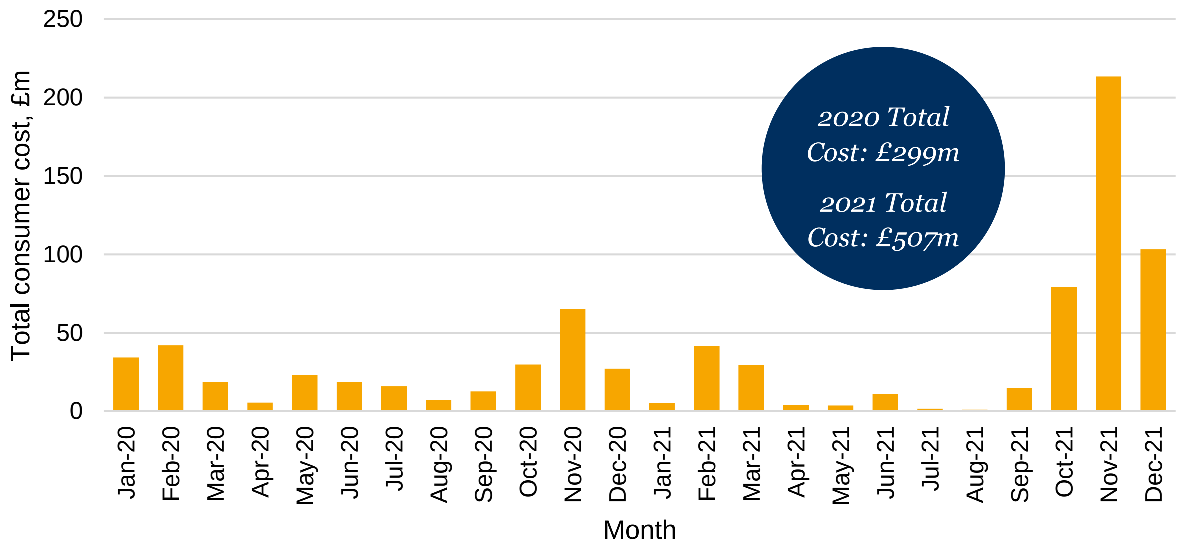


The costs of generation turn ups (offer costs) increased significantly in late 2021, with costs in November 2021 alone reaching over £180m. This is a result of high offers prices in the BM due to very high gas prices and scarcity pricing in a tight system (with some accepted BM offers as high as £4,000/MWh).

Total cost to consumer

Adding together the three elements outlined above – the bid costs of turning plant down, the policy support payments no longer paid to generators and the offer costs of turning plant up – we can estimate the total cost to consumers due to wind curtailment across 2020 and 2021.

Figure 10: *Total consumer costs due to GB wind curtailments*



In total, the cost to consumers due to wind curtailments across 2020 and 2021 was **£806m**, with an increase of 70% from 2020 to 2021 due to the higher costs of turning up generation. With gas prices remaining high in 2022, and wind curtailment forecast to increase, these higher costs are likely to continue.

This cost is the equivalent to an additional £15 from every GB household per year (though the costs will be spread amongst domestic, commercial and industrial consumers, meaning domestic households' direct share will be around £5 per year).

Figure 11: *Total consumer costs due to Scottish wind curtailment*

The total cost of Scottish wind curtailment comes to **£663m** across 2020 and 2021, which constitutes 82% of the total cost of wind curtailment. This illustrates the need for flexible technologies in Scotland specifically.

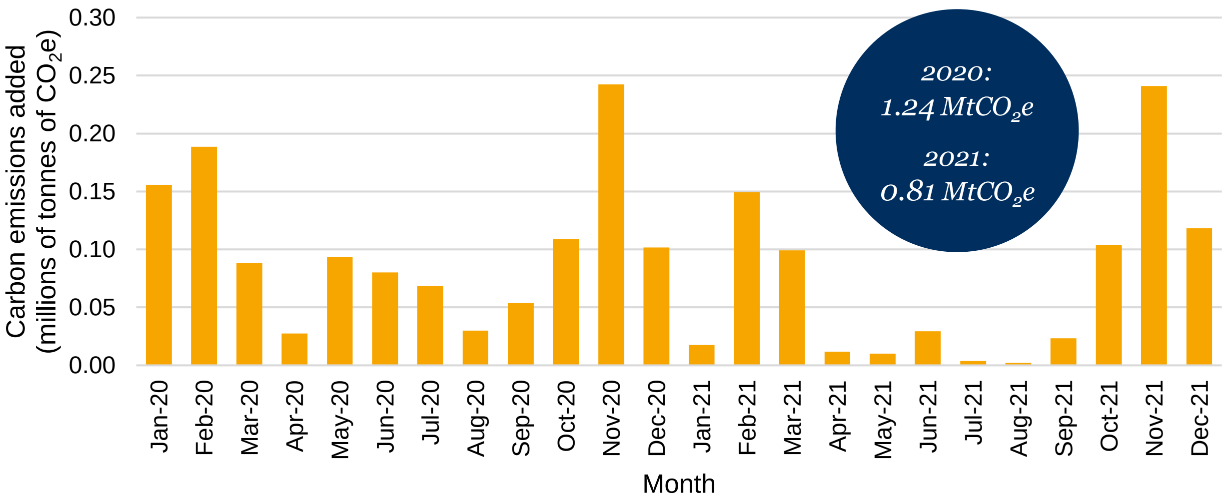
3. CO_2 impacts

The majority of turn up actions made to replace the curtailed wind are currently provided by CCGTs (i.e. gas generation), which represent the dominant source of flexible generation in the current system. This means, in addition to the consumer costs outlined in the previous section, zero-carbon wind generation is being replaced with unabated fossil fuel generation, increasing CO_2 emissions. In this section we quantify this impact.

Carbon emissions

Assuming as before that wind curtailment is met by a weighted average of all SO-flagged offer volumes, we then apply an assumption for the carbon intensity of the generation turned up in each period. CCGTs, which make up the vast majority of the turn up volumes (see Figure 6), have an average carbon intensity of around 360gCO_2e/kWh.

Figure 12: *Total carbon emissions resulting from generation turned-up to replace wind curtailment*



Wind curtailment resulted in an additional 1.02 Million tonnes (Mt) of CO_2 equivalent emissions per year across 2020 and 2021. This represents the equivalent of an additional 497,000 cars on the road[10], or 2.0% of total 2020 power sector emissions (50.1 Mt, the latest year full figures are available for[11]).

Carbon costs

BEIS have published an appraisal price for carbon emissions of £241/tCO_2e for 2020[12], increasing each year into the future. The appraisal price represents the price that carbon emissions would need to be priced at to achieve decarbonisation targets, and is the value recommended in carbon policy appraisal and evaluation. It allows us to calculate an average annual cost to society of the additional emissions that result from wind curtailment. This cost equates to **£248m** per year across 2020 and 2021.

[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1040514/env0201.ods
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1077409/veh0101.ods

[11] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2020

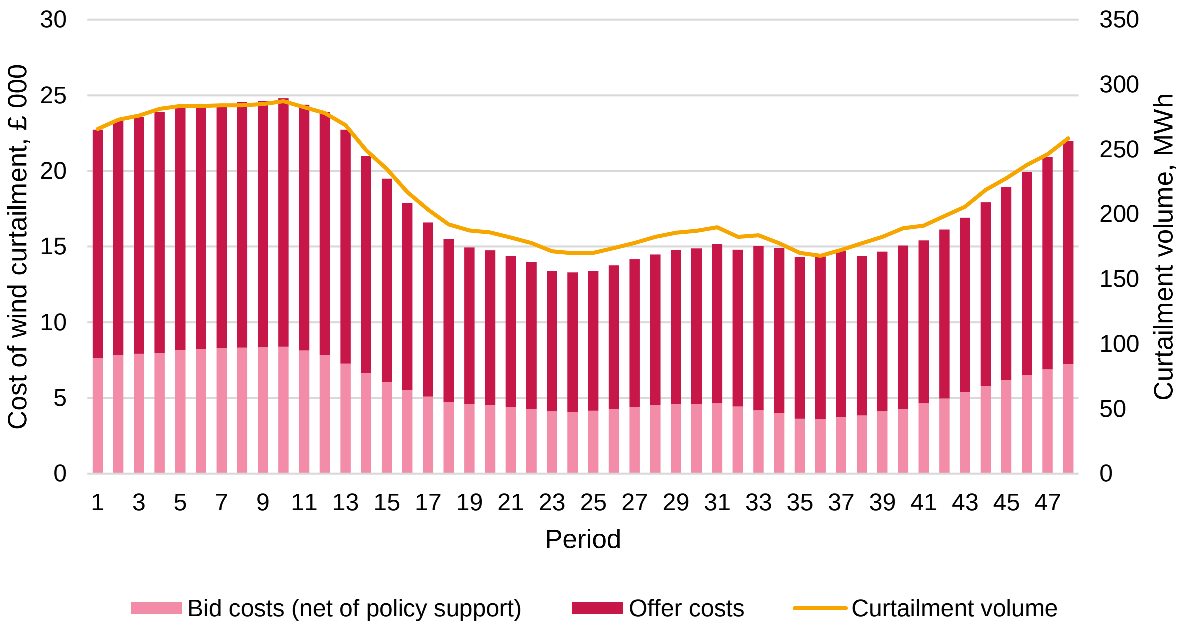
[12] https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal

4. Example days

Having looked at the aggregate figures across 2020 and 2021, this section drills down to individual days to examine intraday patterns of curtailment.

Average 2020 day

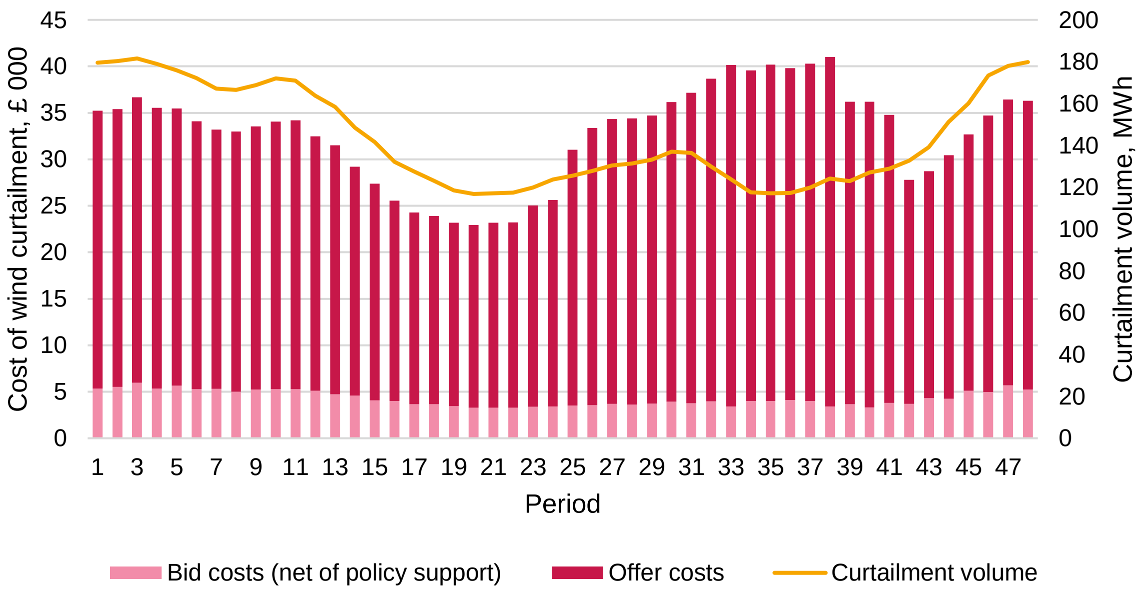
Figure 13: *Average wind curtailment costs and volumes by period on average in 2020*



In 2020, the shape of net consumer cost follows the shape of wind curtailment volume very closely. We see a peak in curtailment volume overnight when demand is at its lowest.

Average 2021 day

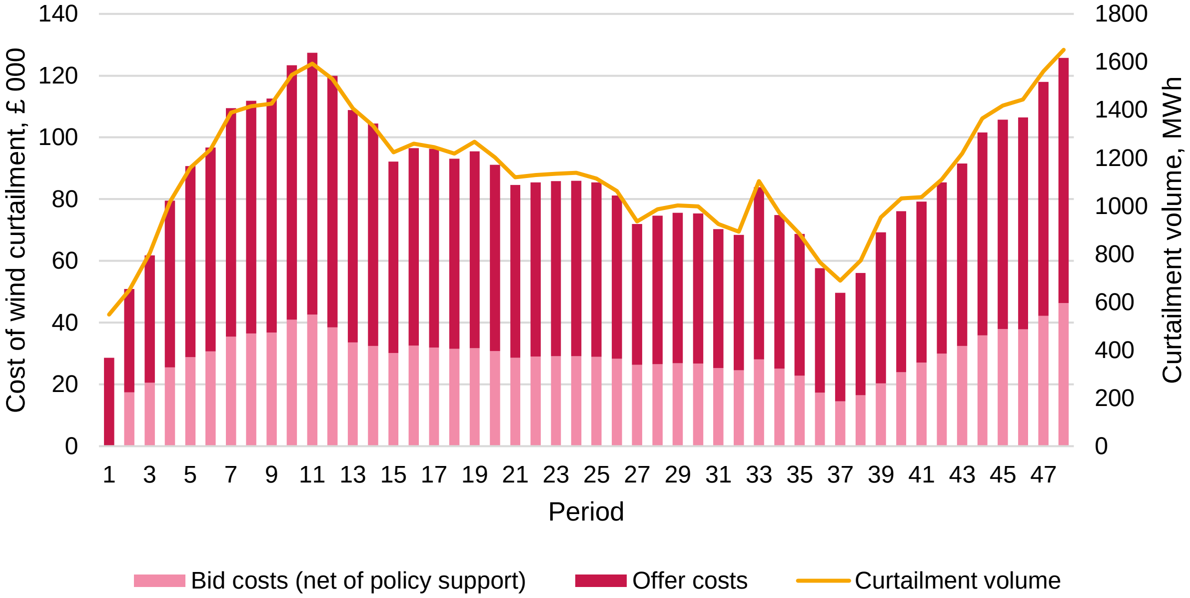
Figure 14: *Average wind curtailment costs and volumes by period on average in 2021*



The average day in 2021 shows a stark contrast to 2020. The highest costs fall in the peak demand hours of the day despite this being when wind curtailment volumes are lowest on average. Offer costs (i.e. the costs of turning up generation to replace the curtailed wind) represent a much larger proportion. This is due to the high prices experienced towards the back end of 2021, particularly over the evening peak, and this led to the extremely high offer costs seen above.

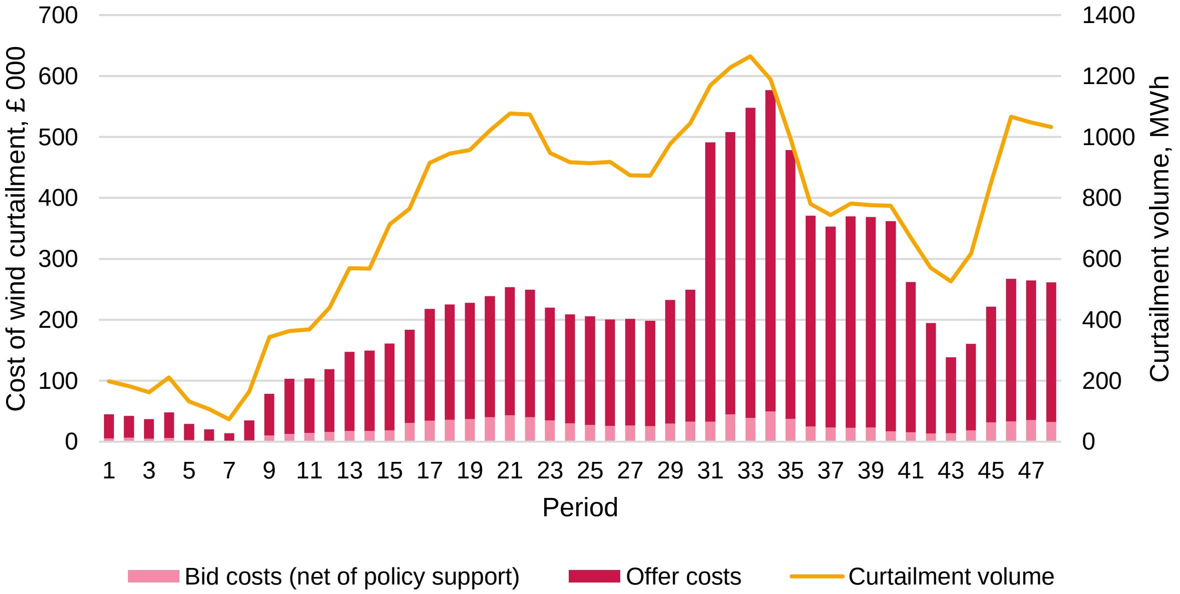
High curtailment day examples

Figure 15: *Wind curtailment costs and volumes on 3rd February 2020*



3rd February 2020 sees a total consumer cost of £4.2m. There is wind curtailment in every period of the day, ranging from around 550MWh in the first every half-hour period of the day to over 1600MWh. The curtailment costs follow the shape of curtailment volume closely, with a peak in the early morning and again in the late evening when demand is low. The periods of peak demand around 6-7pm see a drop in wind curtailment but this is still well above the average level from Figure 13.

Figure 16: *Wind curtailment costs and volumes on 14th November 2021*



This day in November highlights the impact of high power prices seen in late 2021. As CCGTs make up the majority of offer volume, the costs of curtailing wind is subject to high gas prices which can drastically increase consumer costs across the day. Over the evening peak, costs are particularly extreme, due to the high scarcity pricing seen in the power market in late 2021. Costs over this 5pm-7pm peak period average over £450 per MWh of wind curtailed. Compared to 2021, the level of wind curtailment here is not as high as the sample day in 2020 yet the total consumer cost comes to £10.6m, almost twice that of our 2020 day.

5. Mitigating the impacts of curtailment

Mitigation options

There are a number of potential ways in which wind curtailment and the associated costs identified in this report could be mitigated:

- **Network reinforcements.** Major reinforcements (such as HVDC bootstraps) are planned to increase the amount of power that can flow from Scotland to England. However, with the long lead times currently required and the pace of renewable deployment, other solutions are likely to be needed.
- **Short duration storage.** Storage technologies such as lithium-ion batteries can charge when there is excess renewable generation and discharge when there is no excess, typically offsetting gas generation in the discharge period. This has the potential to reduce overall curtailment and costs, and there is already a large amount of battery storage capacity in the pipeline, with around 3.3GW clearing in the 2022 T-4 capacity auction[13]. However, as seen in the analysis, many of the periods of curtailment last for long periods (58% last longer than 3 hours), which will limit the effectiveness of shorter duration storage in reducing wind curtailment.
- **Long duration storage.** Like short duration storage, longer duration storage can store energy when there is excess renewable energy and then release this energy back to the grid when there is no excess, typically reducing gas usage in the discharge period. However, longer duration storage has the advantage of being able to "charge" for many more consecutive periods, and therefore can be more effective given the long periods of consecutive hours of curtailment observed across 2020 and 2021 (which are likely to only increase going forwards).
- **Demand side flexibility**. Being able to shift demand to a different time of day (when wind is high) could help mitigate wind curtailment. Currently most demand is relatively inflexible, but it will be important for new demand sources such as electric vehicles and heat pumps to provide much more flexibility.
- **Additional demand sources.** Locating new sources of demand in constrained regions can also help reduce curtailment. This includes electrolysers, which can use the excess renewable generation to create green hydrogen. Electrolysers are not currently in full commercial operation, though are expected to come online this decade, with the new government energy security strategy targeting 5GW by 2030.
- **Interconnector exports.** Interconnectors to other markets can allow GB to export when there is excess renewable generation and import when there is not. The effectiveness of this in reducing wind curtailment relies on the generation patterns in the connected market not being highly correlated with GB's, which is why a hydro-dominated market like Norway is particularly attractive.

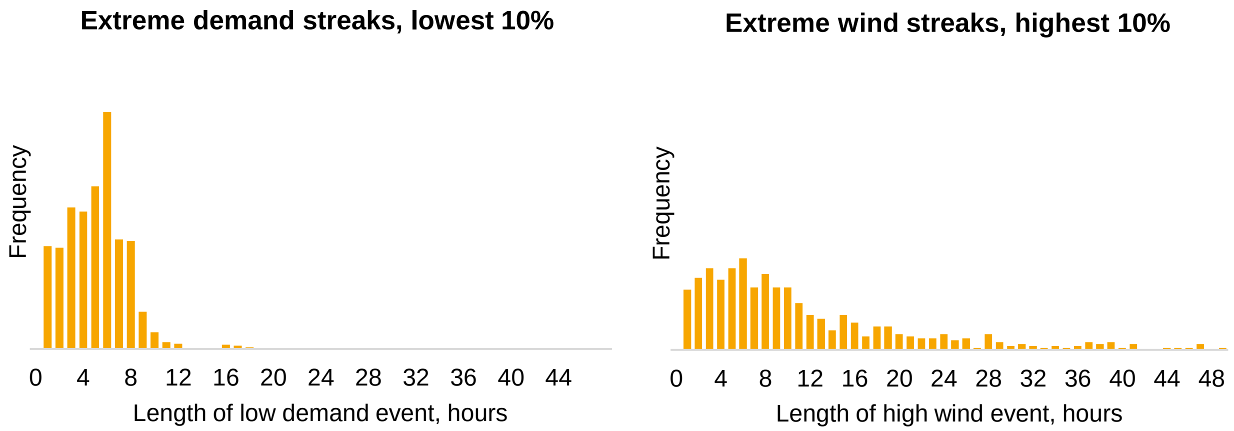
Long duration storage and Cruachan Expansion

Though all of the mitigations outlined above have potential (and can be deployed in parallel), long duration storage is particularly attractive. As shown below, unlike periods of low demand, periods of high wind often

[13] https://www.current-news.co.uk/news/t-4-capacity-market-clears-at-record-high-of-30-59-kw-year-marking-watershed-moment

last for 8, 12, 24 or more consecutive hours. As we move forward and renewable penetration increases, periods of high wind will increasingly result in wind generation curtailment.

Figure 17: *Drivers of periods of wind curtailment (2010-2020 GB data)*



This reinforces what has already been highlighted in earlier sections of this report - that wind curtailment in GB often occurs across long consecutive periods, and this is likely to become even more of a feature as wind penetration increases.

It is important to note that while long duration storage can play a key role, this does not necessarily mean that all of the costs of curtailment can be avoided. While the ESO does not have to pay wind to turn down when that energy is stored, the costs of paying plant to turn up elsewhere in the country are still incurred. However, when storage discharges in other periods it is likely to displace expensive carbon-intensive generation such as CCGTs, though there is a round-trip efficiency loss in utilising the storage. Overall, the cost savings to the consumer as a result of long duration storage are likely to be similar to the costs we have calculated in the curtailment periods (excluding the payments made to the long duration storage itself), and the carbon saved is also likely to be similar.

Despite the potential benefits, there are currently only limited numbers of long duration storage plant in commercial operation or planned. Though many new technologies show promise, pumped storage hydro represents the most established and commercially viable large-scale long duration electricity storage technology. These projects have their own challenges. They require a suitable physical site to keep costs down and have long construction lead times. This lack of locational flexibility means the sites may not always correspond with where the system most needs flexibility to reduce curtailment.

Drax's Cruachan Expansion project overcomes many of these potential hurdles. It will provide an additional 600MW of capacity to the existing Cruachan pumped storage scheme. As much of the current Cruachan capacity (440MW) is utilised providing system services, the additional capacity can allow the site to maximise its potential in reducing wind curtailment costs by operating as long duration storage, with the expanded Cruachan pumped storage hydro station providing around 9 hours of storage capacity if operating at full capacity or longer if some of the units are utilised for system services to the Grid.

Cruachan is located in the constrained Scottish region, where our analysis shows 82% of 2020-21 wind curtailment costs stem from. It can be deployed by 2030, enabling it to support interim climate and renewables generation targets for both Scotland and the UK.

However, projects such as Drax's Cruachan Expansion, face significant investment barriers to deployment. As identified in a recent UK Government call for evidence on large-scale, long-duration electricity storage,[14]

[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003841/large-scale-long-duration-electricity-storage-cfe.pdf

intervention in the market is likely to be required to support investment in these technologies. The lack of a framework for these technologies means that private investment is very difficult to secure for new pumped storage hydro (and other LLES) projects, with no new plants built anywhere in the UK since 1984. As the deployment of offshore wind continues at pace to meet the UK government's target of 50GW of offshore wind by 2030, curtailment volumes and costs will continue to increase unless the UK government addresses these investment barriers. Project developers currently await the outcome of the call for evidence with a hope that it will address these investment barriers to facilitate the deployment of projects such as Drax's Cruachan Expansion.

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