Operability Impact of Distributed Storage and Electric Vehicles

A System Operability Framework document

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nationalgridESO

Executive Summary

There is an increasing trend of storage and electric vehicles on the electricity network. The high penetration of these devices would alter the demand seen by ESO control centre and impact the system operability. With appropriate market and framework design, storage and electric vehicles will be able to support electricity system operation and be enablers to the decarbonization transition.

Background

In our Future Energy Scenarios (FES) document, all scenarios have an increase in distributed storage[1] in future as shown in Fig. 1 [1]. Storage could either inject electricity into or absorb electricity from the electricity network. It is a highly effective source of flexibility which can provide fast frequency control, manage network constraints and maximise the value of intermittent sources.

Electric vehicle (EV) batteries can be treated as a form of storage in electricity network, while their behaviour would be different, as they are not always connected to the electricity network. The time and magnitude of its demand is driven by human behaviour, or market/ system signals if smart charging is applied. Figure 2 shows the increasing trend of EVs in future, where the majority adopt smart charging [1].

The benefit of storage increases when more and more intermittent renewable generation is connected. Most storage is likely to be installed on the distribution network, co-located with distributed generation like solar and wind. EVs are key to the decarbonization of transportation and they will be mostly charged on the distribution network. The ESO has limited observability and controllability of distributed storage and EVs. Therefore we are planning to improve our forecast capability.

The high penetration of storage and EVs will impact how ESO operates the system. One typical example is the herding behaviour, for example when large numbers of storage and EVs charge or discharge at the same time. This report analyses how the behaviour of storage and EVs would impact system operability.

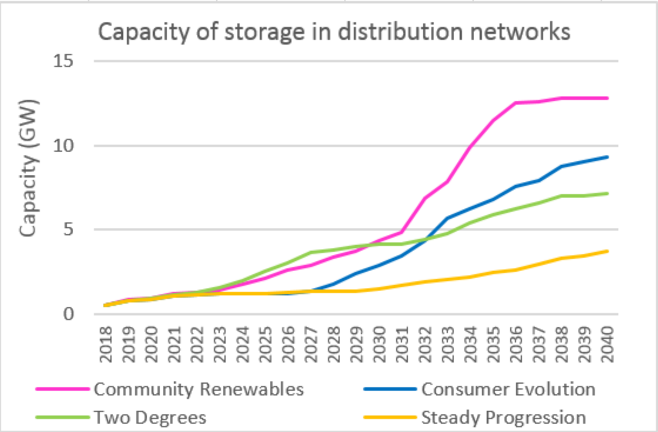

Fig. 1 Capacity of storage in distribution networks

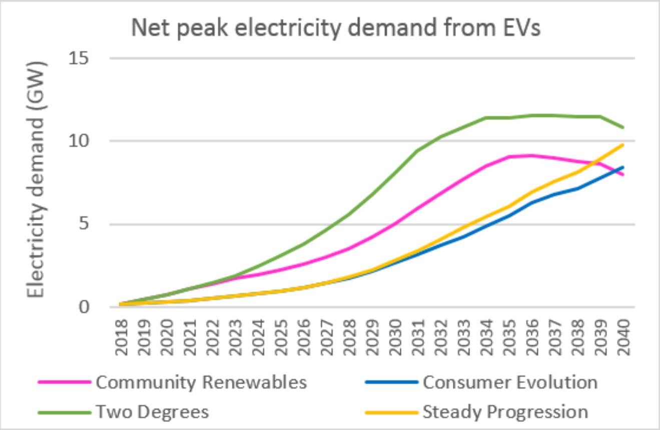

Fig. 2 Net peak electricity demand from EVs

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[1] Distributed storage refers to the storage connected to the distribution network. 'Storage' used in this report all refer to distributed storage.

Behaviour of Storage and EVs

- Demand behaviour of storage is complicated and uncertain.
- EV demand is affected by the usage of the car and the way of charging.
- Smart charging would be used by some storage and EVs to increase revenue or reduce costs.

Storage

The demand behaviour of storage is complicated; for any two identical storage installations, there are several ways they might respond to a number of different requirements or drivers, thus their impact on the electricity system and how it is operated may be quite different. Our work with the Carbon Trust identified 12 use cases for storage as shown in Appendix A [2]. Storage could behave towards providing grid service, maximizing revenues/reducing costs, or supporting renewable generation/EVs.

Electric vehicles

Without smart charging, EV demand is driven by usage of cars and time when chargers are connected. In a typical day, there are two periods where you would expect there to be a peak requirement to re-charge EV batteries; a smaller peak following morning commute when people charge at work and a second larger peak after the evening commute when people charge at home. Figure 3 shows a historic weekday EV re-charge demand profile with no smart charging [1].

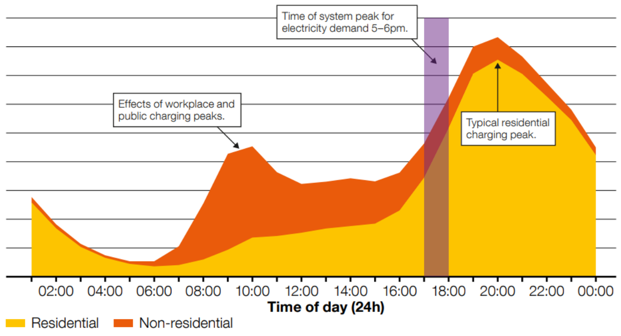


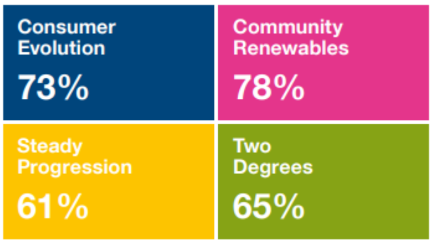
Fig. 3 EV re-charge demand in a typical day

Smart charging

Smart charging refers to charging units which have the ability of shifting the charging time following either internal or external signals [1]. Similar to storage, EVs have the flexibility to alter their demand by adjusting the time of charge and charging power level. Smart charging can be used to both storage and EVs.

A simple example is delaying charging from when they are first plugged in at 18:00 to around 01:00. At 18:00 system demand is high with high price of electricity, while at 01:00 the demand will be lower with a lower electricity price. In this way, an EV altering its charging pattern can save money, reduce carbon impact and be beneficial to the system. While low carbon intensity generation, like wind and solar, in a region does not always sit at low national demand periods; more sophisticated smart charging with two-way communication ability can shift the demand to maximize the utilization of low carbon intensity generation by considering both national and regional information.

FES forecasts that the majority of EV consumers would adopt smart charging in all the four FES scenarios in 2050 as shown in Fig.4 [1]. Figure 5 shows an example of demand profiles of an uncontrolled EV and a smart charging EV which responds to market price.



Consumer Evolution 73%	Community Renewables 78%
Steady Progression 61%	Two Degrees 65%

Fig. 4 EV consumer participation levels for smart charging in 2050

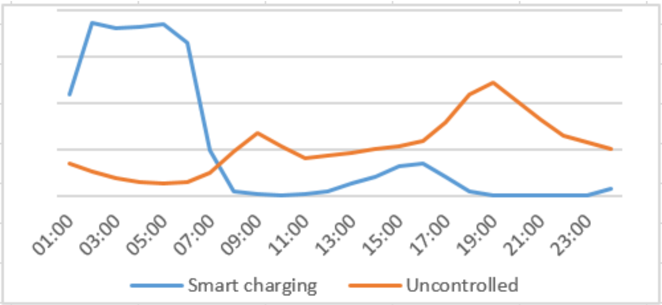


Fig. 5 Uncontrolled and smart charging EVs demand profiles

Vehicle to grid (V2G) is similar to smart charging but takes it one step farther. It can export the energy stored in the vehicle battery to the system to support system operation or sell the energy for revenue.

Operability Impact/ Opportunities

- Storage and EVs with smart charging are enablers to decarbonization by shifting demand towards low carbon intensity periods.
- Storage and EVs could alter demand peak and minimum, impacting demand forecasting.
- Storage and EVs could increase demand ramp rate, requiring faster frequency response and more dynamic reactive power support.
- Markets need to be well designed so that storage and EVs could support system operation whilst maximizing profits.

ESO has limited visibility of storage and EVs connected to the distribution network, but sees the transmission network demand, i.e. the net of the gross demand (from home and industry), generation and storage on the distribution network. As the amount of storage and EVs increases, the demand seen by ESO control centre would look very different. This demand change would impact how we operate the system. In order to analyse the impact of storage and EVs on system operability, we compared the transmission network demand in the following cases in Table 1.

Table 1 Study cases in this assessment

Case	Details
Base	Assume no storage and no EVs are used in the future network.
EV_only	Assume only EVs are used and no storage is used in the future network.
Close-to-reality	'EV_only' + storage behaviour is defined by the storage tool[2] based on FES scenarios [2]
Economic idealization	'EV_only' + storage behaviour is defined based on BID3 economic dispatch[3].

In this assessment, EV demand profiles come from the EV charging innovation project [4], and they contain both uncontrolled charging and smart charging. The 'EV_only' case only considers the impact of EVs assuming there is no storage used.

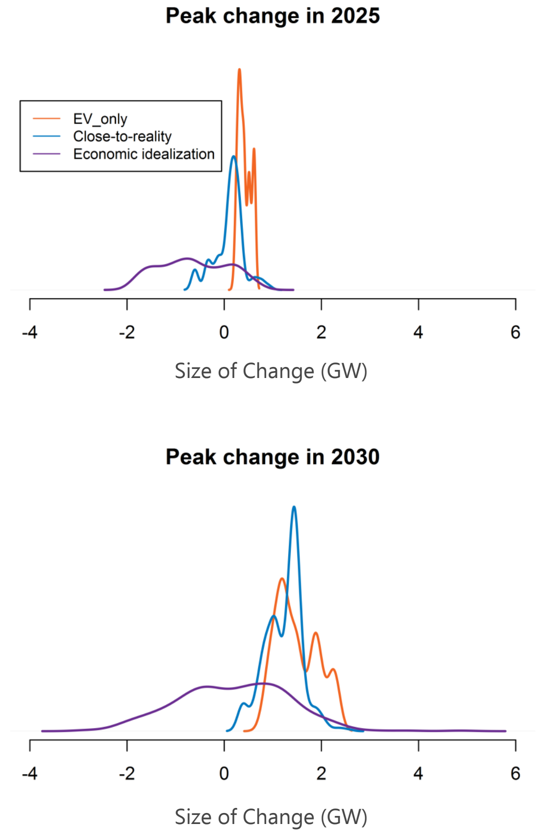
In 'Close-to-reality' case, the storage behaviour is defined by the storage modelling tool[2]. As FES scenario information was used to define the parameter values in the modelling tool, this case is supposed to be close-to-reality. The storage modelling tool has limits; the storage behaviour is not always aligned with the changes of market and system through the whole year. For example, storage, designed to provide service to the ESO, might discharge to provide Firm Frequency Response (FFR) earlier or later than when FFR is required. Thus, 'Close-to-reality' could be treated as a case where the market is not well aligned, or there is delayed response of storage.

In 'Economic idealization' case where storage is an optimized participant in the wholesale market, BID3 tool is used to dispatch storage and generators in an economic manner. Groups of storage would respond to a market signal in the same way, leading to herding behaviour; 'Economic idealization' is a case where herding of storage is modelled.

The behaviour of storage and EV is complicated and uncertain, so none of the cases in Table 1 would perfectly reflect the future scenario, but they help us to understand future impacts. This assessment analysed the impact of storage and EVs in terms of variations of transmission demand peak/minimum and ramp rate changes.

Demand peak

Demand peak is the point in a day where the maximum demand is seen. Fig. 6 shows the density distribution of the daily demand peak change compared to the 'Base' case in 2025 and 2030. The


Peak change in 2025

Peak change in 2030

Fig. 6 Demand peak changes in 2025 and 2030

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[2] This storage tool was developed in an innovation project with the Carbon Trust to model the storage demand behaviour [2].

[3] BID3 is an economic dispatch model used by National Grid ESO. Details are provided in the Network Options Assessment [3].

details of a density plot is illustrated in Appendix B.

In 'EV_only' case, the demand peak is always increased as only the charging mode of EVs is considered; EVs are always seen as demand. If 'V2G' is considered, the results could be different.

In 'Close-to-reality' and 'Economic idealization', storage could either charge or discharge so the demand peak could either increase or decrease in the cases with storage included. Storage will typically be exporting power to the system at peak time when electricity price is high and will help operability during these hours. While the high volume of demand from EVs make the demand peak increase in the majority of 2025, and always increase in 2030.

In 'Economic idealization' case, the demand peak varies in the widest range as a large amount of storage behaves simultaneously following market changes - herding behaviour. While the peak reduces more times compared to other cases, this illustrates how storage with appropriate control could potentially help to reduce the demand peak.

Demand Minimum

Minimum demand is the point in the day where the lowest demand is seen. As shown in Fig. 7, in 'EV_only' case, the increase of demand minimum is higher than that of demand peak in Fig. 6, because EVs with smart charging are more likely to be charging in periods of low system demand, low carbon intensity and low energy cost.

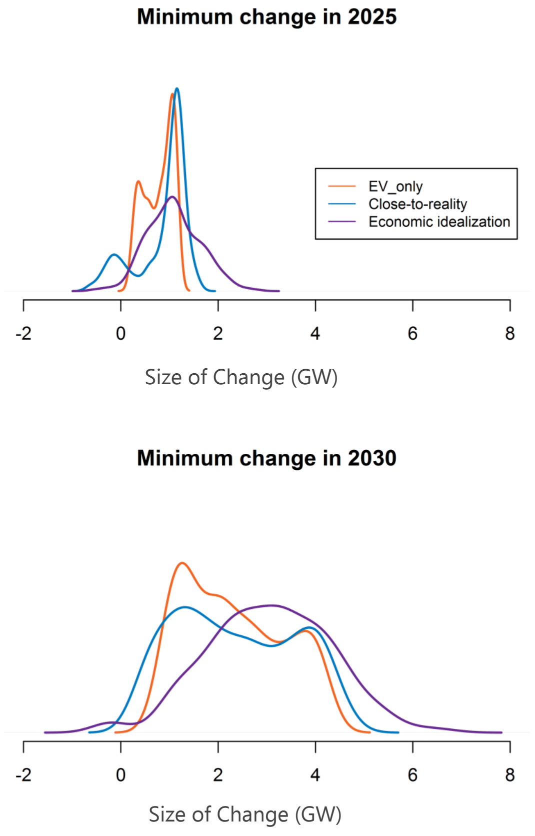

Fig. 7 Demand minimum changes in 2025 and 2030

Storage is expected to be charging during low demand and low carbon intensity periods when prices of energy are cheaper. The demand minimum increases in the majority time when storage is used as shown in Fig. 7. This will support the system operation. For example, a storage co-located with solar would mainly be charging when the solar generation is high, which is a period of low demand and low carbon intensity.

From 2025 to 2030, the ranges of variations of demand peak/minimum increase in all the cases in Fig. 6 and Fig. 7. This shows as more storage and EVs are connected, the variations would increase. Demand peak and minimum are critical to demand forecasting. The increased variability of demand peak/minimum could affect the accuracy of demand forecasting, which could incur additional cost to operate the system. ESO is planning to include storage and EVs in our demand forecasting development strategy to improve the accuracy.

Ramp rate

Ramp rate refers to how fast demand changes. The system impact of large ramp rates is that they can lead to an imbalance of both active and reactive power. In active power the ESO needs to have enough response and reserve in place to ensure these swings in power can be managed without any frequency disturbances. For reactive power enough dynamic voltage support are required to ensure that any swings in reactive power can be compensated.

Figure 8 shows the box plot of the transmission demand ramp rate in 2025 and 2030 for all the cases. The horizontal line in the middle of the rectangle

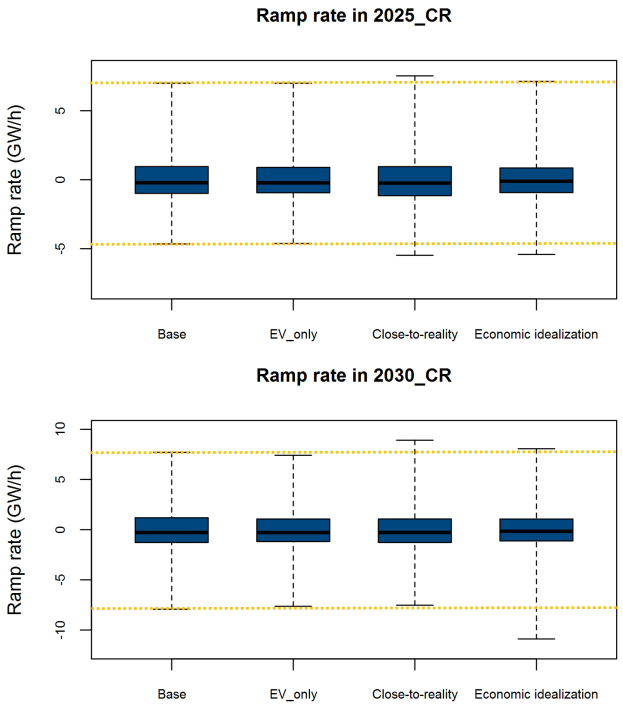

Fig. 8 Box plot of transmission demand ramp rate

represents the median value of the ramp rate throughout the year, while the box range is from the first quartile of the ramp rate to the third quartile (25-75%). The top whisker represents the maximum value reached and the bottom whisker represents the minimum value.

Compared against 'Base' case, the 'EV_only' case has similar and even lower range. EVs with smart charging are more likely to be charging in low demand period, reducing the demand peak-minimum difference and then the ramp rate. With storage considered, the ranges of the ramp rate are increased in 'Close-to-reality' and 'Economic Idealization'.

Faster frequency response and more dynamic reactive power support are required to facilitate high ramp rates in transmission demand. In Response and Reserve Roadmap [5], we have set out our plans for reforming our frequency response and reserve services. A key priority in this roadmap is to develop faster-acting frequency response services to support our operational needs. We also have launched Regional Development Programmes [6], Stability Pathfinder project [7] and Power Potential project [8] to innovatively secure new sources of either or both of flexibility and dynamic voltage support.

Smart charging and control

Storage and EVs are manageable; with smart charging, they would be vital part of the system operability solution. It has been recognized that smart charging of EVs and storage could help to minimise peak demand and network congestion, and reduce the ramp rate of system demand. In order to realize these benefits of smart charging, the market needs to be well designed so that smart devices are able to receive and send information on time; they can adjust the charging power/direction dynamically following the system change.

Without complete information and timely response, the storage could discharge in low demand period, lowering the demand minimum in Fig. 7 and charge in high demand period, raising demand peak in Fig. 6. Although the yearly ramp rate range is reduced in 'EV_only' case, EVs might cause higher ramp rate in an individual day. Fig. 9 shows an example, where EV and storage raise the demand peak and ramp rate.

Storage and EVs increase the variability of demand peak and minimum as discussed; actually they are re-shaping the demand. Smart charging of storage and EVs provide flexibility from the demand side. They can shift demand towards periods of low carbon intensity and low energy price, and maximize the utilization of low carbon intensity generation. This flexibility in demand side increases as more storage and EVs are adopted in our system in future. With the flexibility from demand, the demand shape would become less driven by consumer behaviour, but follows the availability of low carbon intensity generation. The electricity system would be able to accommodate more intermittent renewable generation at a faster speed. Storage and EVs could significantly facilitate our system operation, reduce environmental impact and enable the decarbonization transition.

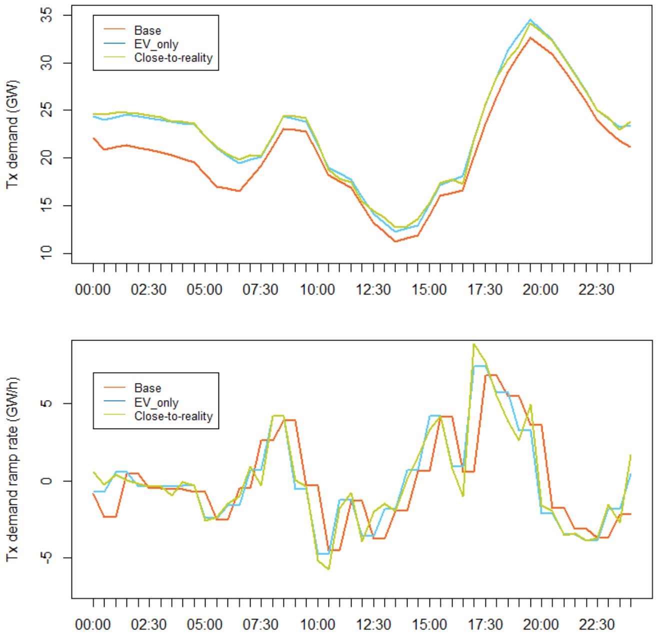

Fig. 9 Profiles of demand and ramp rate in a typical day

Herding behaviour is a typical example of simplistic control. If a large numbers of storage and EVs start to charge or discharge at the same time after receiving the same control signal, this can alter the demand significantly, cause high ramp rate and stability issues for system operation. This could also lead to constraints in local distribution networks. To address this issue, it has been proposed to include a requirement that all chargepoints have a function that randomly delays how quickly it responds to a signal over a period of time. ESO has actively engaged in the development of this delay function. The herding of interconnectors could cause similar issues; it has been discussed in our SOF 2016 publication [9].

Conclusions

As part of the transition to net zero, EVs and storage are key enablers to decarbonize electricity. Through careful market development and policy decisions, storage and EVs are vital part of the solution to operate a zero carbon network.

The demand behaviour of storage and EVs is complicated and uncertain in the future. The high penetration of storage and EVs in the electricity network would dramatically change the transmission demand seen by ESO control room, impacting the system operability.

Storage and EVs could impact system operability by causing:

- Increased variability of transmission demand, especially lower demand minimum and higher peak. These would impact the demand forecasting, incurring additional cost to operate the system.
- Higher ramp rate. Faster frequency response and dynamic reactive power support would be necessary to facilitate the fast changing demand.

The above are most likely to occur when markets are not designed with consideration to system operating costs. Smart charging of storage and EVs enables flexibility in demand side. This demand side flexibility would significantly facilitate our system operation and enable the decarbonization transition. Storage and EVs with smart charging can shift the demand towards periods of low carbon intensity and low system demand to increase utilization of low carbon intensity generation and meet system needs while their owners could maximize profits.

To deal with increased variability of demand, the existing demand forecasting needs to be improved to include storage and EVs.

- ESO is planning to include storage and EVs in the short term demand forecasting development strategy to improve the accuracy.

More sources of flexibility and dynamic voltage support are necessary to facilitate faster changing demand. ESO has published the Response and Reserve Roadmap [5], which set out plans for reforming frequency response and reserve services. One of the priorities is to develop faster-acting frequency response services. Besides, the ESO has launched the following projects:

- Several Regional Development Programmes in cooperation with DNOs to develop new ways to facilitate system operation, including developing new sources of flexibility [6].
- The stability pathfinder project to seek for economic solutions/products to provide dynamic voltage support, short circuit current and system inertia [7].
- The Power Potential project to obtain voltage support from distributed energy resources [8].

References

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3. Network Options Assessment - https://www.nationalgrideso.com/publications/network-options-assessment-noa
4. EV Charging NIA Innovation Project - https://www.smarternetworks.org/project/nia_ngso0021
5. Frequency and Reserve Roadmap - https://www.nationalgrideso.com/document/157791/download
6. Regional Development Programme - https://www.nationalgrideso.com/insights/whole-electricity-system/regional-development-programmes
7. Stability Pathfinder Project - https://www.nationalgrideso.com/publications/network-options-assessment-noa/network-development-roadmap
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9. System Operability Framework - https://www.nationalgrideso.com/publications/system-operability-framework-sof

Appendix A

Our work with the Carbon Trust identified 12 use cases for storage as shown in Table 2.

Table 2 Use cases identified

Use Case No.	Name	Description
1	Providing flexibility to the DNO/ DSO	Providing flexibility services to the DNO/DSO (not the ESO).
2	Providing flexibility to the DNO/ DSO with reserves for lowering peak demand	UC1 + discharging during times of peak demand.
3	Providing flexibility to the ESO (e.g. FFR)	Providing flexibility services to the ESO.
4	Providing flexibility to the ESO with reserves for lowering peak demand	UC3 + discharging during times of peak demand.
5	Demand Turn Up	A specific service contracted by the ESO to increase demand at specific times. This can include charging storage assets.
6	Manage demand to avoid network peak prices (DUoS)	Storage system has been implemented to supply a demand load during network peak charges to reduce the overall energy bill.
7	Co-located with solar/wind to avoid peak energy prices	A demand user with generation is using storage to increase self-consumption of on-site generation (Solar/Wind), but weighted towards high commodity/delivery charge periods.
8	Co-located with solar/wind to maximise use, but not price sensitive	A mode where a demand user with generation is using storage to maximise self-usage of on-site generation, but is not sensitive to high/low price thresholds (i.e. domestic solar with a flat electricity import tariff).
9	Shift co-located generation times to benefit from export prices	Using energy storage co-located with generation to time shift energy from a low to a higher price period.
10	Store power to overcome grid constraints and shave peak demand	Using energy storage co-located with generation, but diverting a proportion of the generation into storage, to bypass grid export constraints. For purposes of modelling (to differentiate from UC8), excess (stored) generation is discharged as soon as capacity becomes available (i.e. no price signal).
11	Electric Vehicle (EV) Charging support and grid services	Storage connected alongside EV charging points to support fast charging and provide balancing services and arbitrage services.
12	Vehicle-to-Grid (V2G) operation	EV batteries used for grid balancing or meeting peak demand on site.

Appendix B

Figure 10 below gives detailed explanation of a density plot.

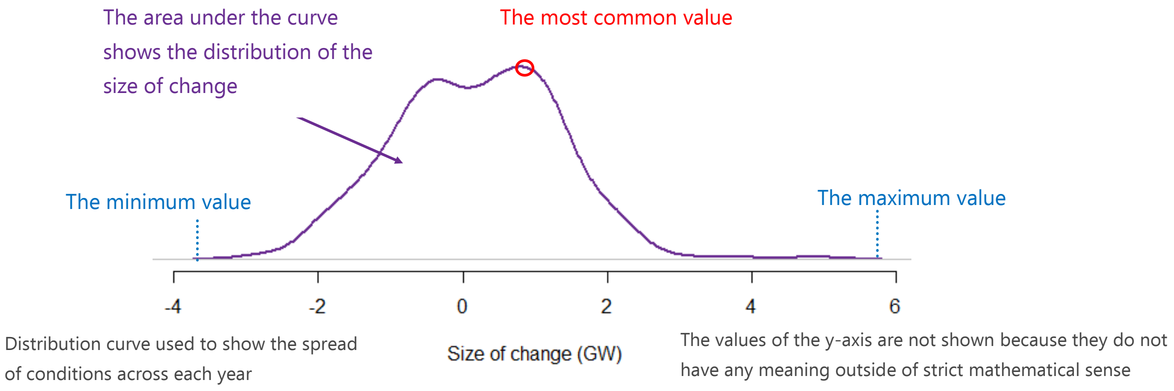

Fig. 10: Detailed description of a density plot

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