National Trends and Insights

A System Operability Framework Document

March 2021

nationalgridESO

Contents

Background

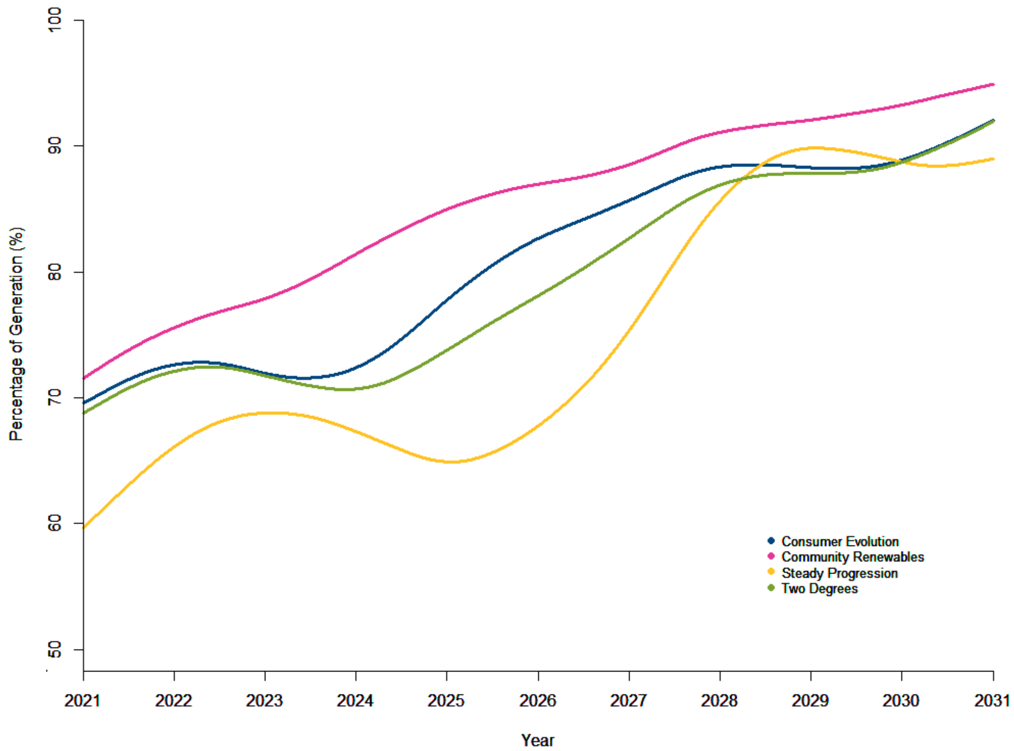
This National Trends and Insights (NTI) document is published by National Grid ESO. It should be considered in tandem with our Operability Strategy Report [1], which set up a plan for specific topics for future System Operability Report publication.

This report used latest Future Energy Scenario 2020 [2] data and latest output from the Electricity Ten Year Statement (ETYS) [3] and Network Options Assessment (NOA) [4], applied engineering analysis to predict the future system performance trend and assess impact on operability with the network boundary constraints. We identified three key areas for secure future operation of the system and describe the initiatives underway to address these challenges. These are:

- Storage - this new technology presents exciting opportunities but needs appropriate market designs.
- Interconnectors - the large increase of coupling to Europe allows cost benefits for all European consumers and enhanced mutual support between System Operators. However, there is an impact on local thermal limits, stability and voltage control. We describe the impacts and how we are working with European partners following the EU-UK Withdrawal Agreement.
- Short Circuit Level (SCL) and System Inertia - with the move away from a reliance on large thermal power generation and the rapid deployment of solar, wind and interconnectors (Figure 1), there is a decline in synchronous generation. This means the management of SCL and inertia requires more careful consideration. We describe Pathfinder projects intended to address these concerns and the creation of auctions for Enhanced Frequency Containment.

We have already started to address these operability challenges through industry groups, innovation projects and our future balancing services program. There are known technological and commercial solutions to the issues we’ve highlighted here and known risks and benefits to use them. Please read our Network Development and Product Roadmaps [5] and Operability Strategy Report [1] for information on how we plan to bring these forward. For more information please contact us: sof@nationalgrideso.com.

Figure 1: Annual proportion of electricity generation from low carbon sources



Storage

We have been growing our experience of operating with new forms electricity storage over the past few years and have already seen significant benefits flowing from the flexibility provided by storage technology. This section looks at how storage technology's integration into the energy market could impact on electricity system operation.

Figure 2 below illustrates a potential electricity generation mix on a sunny day for future years. Increasingly, storage absorbs active power overnight and during the solar peak, when transmission demand dips - and exports power in the morning and evening. The storage is also used to meet peak demands and smooth the solar ramping.

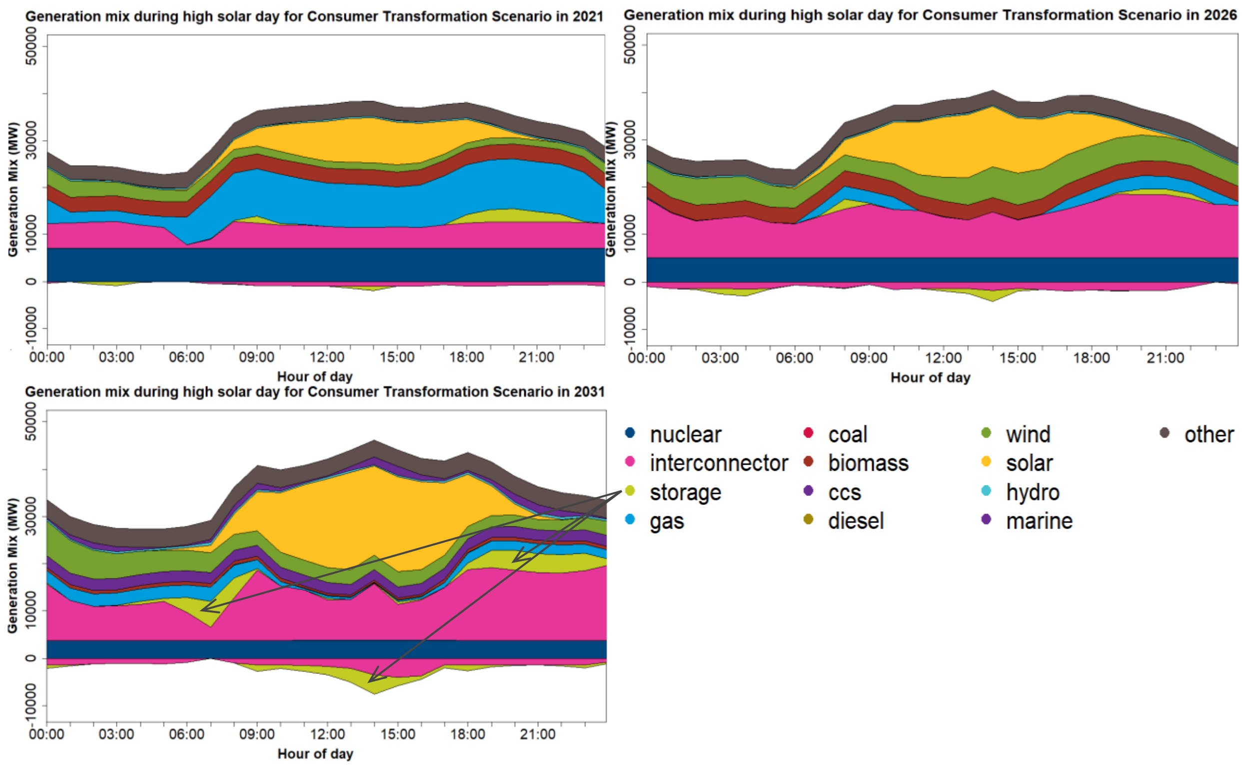
The effect of storage behaviour in Figure 2 is beneficial to operability. This behaviour relies on having a good view of the available solar output during the day to manage energy balance in the storage unit. If the forecast is not accurate and visible, the storage could be at full capacity when it should be absorbing or at zero capacity when it should be generating.

Any imbalance would have to be met by the System Operator. Therefore, there is a benefit to continue improving the accuracy and visibility of forecasts.

We have been developing an energy forecast for each Grid Supply Point (GSP in the network) using a newly developed deep-learning AI algorithm. The Half-Hourly (HH) resolution enabled more accurate analysis for any periods of the day, and for better coverage of any areas of interest. The learning from this work will feed into the development of the ESO's facilities for demand forecasting known as the Platform for Energy Forecast (PEF). The forecast data can be used to generate market information.

As the storage industry (pumped storage excepted) is relatively new, the technologies and the commercial frameworks need to be kept under review to understand their operational impact. There is a risk that the actual operation of storage in the market will not always provide a beneficial effect. If extreme price signals were seen, and storage changes its flow to respond, the energy balance could fluctuate by too much too quickly for the market to keep up and may require additional action from the System Operator.

Figure 2: ***Generation dispatch by fuel during high solar day—Community Renewable Scenario***



The behaviour of storage responding to price signals in the market could be a challenge to operability as storage can change its output very quickly. If all storage units are responding to the same price signal, it is possible that there will be a large swing in power as all the storage moves in the same direction, at the same time.

There are large benefits for operability that can be realised from storage if the following risks are managed:

- markets potentially causing storage to operate at times not helpful in achieving an energy market balance
- difficulty in storage operators managing their energy balance based on forecasts of the market
- herding behaviours causing disruptive power swings as multiple storage units respond to the same price signals.

These operability challenges are dependent on markets for storage develop. The technical impact on operability must be accounted for in market design and operation. The detail has been described in SOF paper Operability Impact of Distributed Storage and Electric Vehicles [6].

To address these challenges, operability needs to be considered when the market rules and mechanisms for storage are designed and implemented. We have published the Response and Reserve Roadmap [7], which sets out plans for reforming frequency response and reserve services. One of the priorities is to develop faster-acting frequency response services including services required to mitigate the effects of fast ramping.

Interconnectors

Interconnectors facilitate the sharing of energy between GB and other countries giving great benefits from an economic and environmental perspective. Figure 3 shows a potential generation mix in the coming years – with a decrease in gas generation (blue) and an increase in wind (green) and solar generation (yellow). This is alongside large interconnector imports into the GB system (pink).

In 2021, GB normally imports energy from Europe even on a windy day. In 2026, GB exports wind to Europe in high wind month such as January and February. Exported wind energy increases in other months. The diagram for 2031 demonstrates this trend continues for future years. As levels of intermittent renewable generation increase, interconnectors play an increasingly important role in providing flexibility for all net zero scenarios [10].

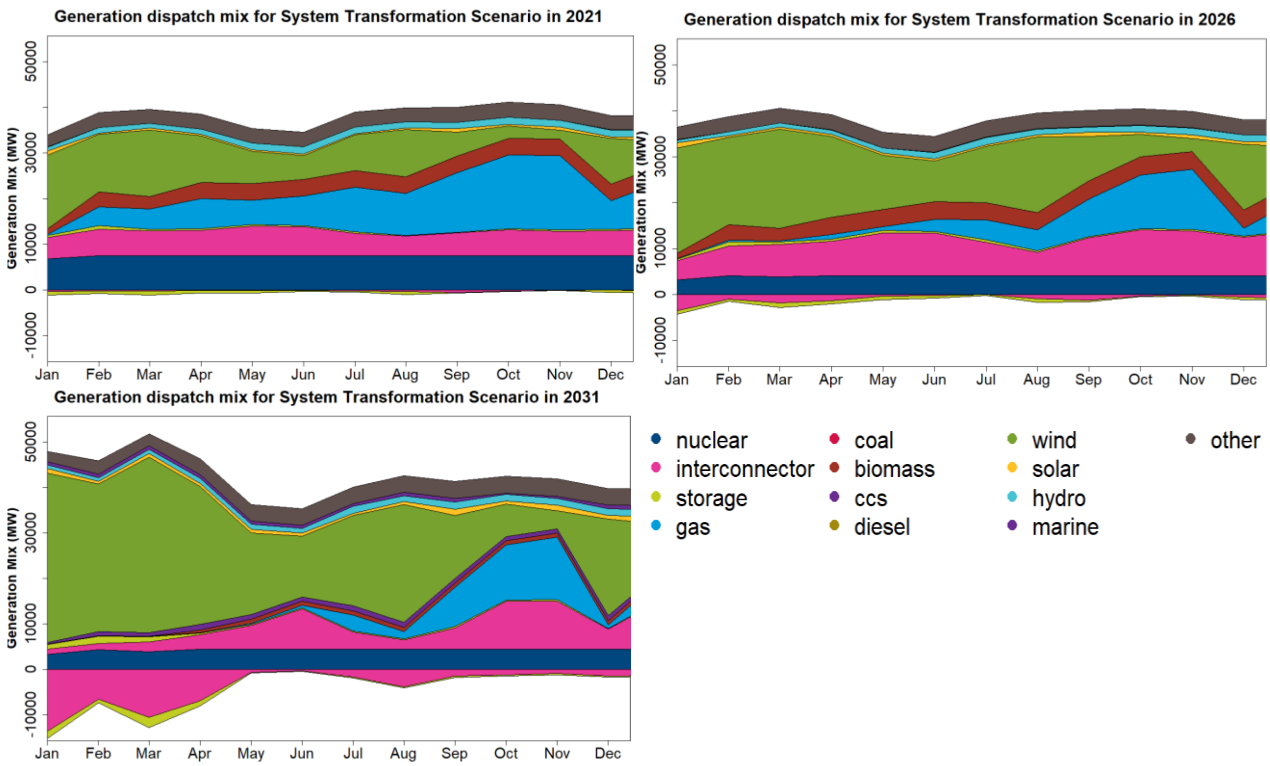
The operation of the interconnectors is driven by commercial concerns. GB imports energy from Europe when the price is cheaper in Europe, and exports to Europe when the price is reversed. Interconnectors are based on High Voltage Direct Current (HVDC) technologies which can be highly flexible.

HVDC devices can provide frequency control for one of the transmission systems which are linked by the interconnector. The frequency of a system can be controlled by modulation of the active power of the HVDC. HVDC devices have the capability to do this quickly and can provide fast acting frequency response in a similar way to the Dynamic Containment (DC) frequency control product described later in this document.

The impact on rate of change of frequency (RoCoF) of the interconnectors is complex. Increased levels of import can displace conventional plants which were contributing to system inertia and lead to increased system RoCoF. An interconnector exporting power may result in additional synchronous generation on the system and therefore reduce system RoCoF. More analysis is presented in the section on System Inertia.

Control mechanisms built into HVDC technology can enable it to contribute the local short circuit level (as described in the following section) and to support system inertia. The contribution depends on control modes, operation points and control strategies and is limited in theory only by the design of the control system and safe rating (essentially the size) of the equipment involved. Widespread adoption of 'grid forming' control techniques for HVDC has the potential to mitigate or eliminate many of the challenging aspects of the HVDC equipment installed today.

Figure 3: ***Generation dispatch by fuel type in a whole year — Community Renewable Scenario***



Another issue that must be addressed is the ramping of interconnectors – a HVDC device can ramp very quickly in response to price changes in a similar way to storage. As the interconnectors ramp, following the results of commercial auctions, large frequency deviations could result. As more interconnectors go-live the effect of several interconnectors ramping at the same time further exacerbates the control of system frequency.

After our withdrawal from the European Union many of the older EU codes no longer apply within GB. Some elements have been retained in GB law via several statutory instruments. However, the main agreement detailing our relationship with Europe is the EU-UK Trade and Cooperation Agreement (TCA) [8].

The TCA describes how GB will establish a Memorandum Of Understanding (MOU) covering how we will work with European Transmission System Operators (TSOs). After the establishment of an MOU all TSOs are instructed to develop detailed working arrangements.

The TCA covers arrangements on capacity calculation, new trading arrangements over the interconnectors and how we coordinate to maximise trade while also ensuring operational security. National Grid ESO is taking a leading role in the development of these new arrangements as we shape our new relationship with Europe.

These functions will facilitate auctions on interconnectors to achieve the best value for consumers while also ensuring the system is operated in a secure manner.

Quite often interconnectors represent the largest loss on the system, therefore under those scenarios NGESO has to curtail interconnectors to reduce the largest loss and the effect of a trip on RoCoF [9]. We are taking actions seeking to minimise curtailment in the futures, which include:

1. The running of the Accelerated Loss of Mains Change Programme [10] under which initiative the electricity distribution companies are updating settings for the RoCoF loss of mains protection relays from 0.125 to 1Hz/s, with a definite time delay of 500ms.
2. Providing a new Dynamic Containment service to enhance system stability.
3. As recommended by the Frequency Risk & Control Report (FRCR) consultation [11], applying the wider limit of 49.2Hz (It is 49.5Hz currently) to all infeed losses.

These measures will significantly reduce operational costs.

Short Circuit Level

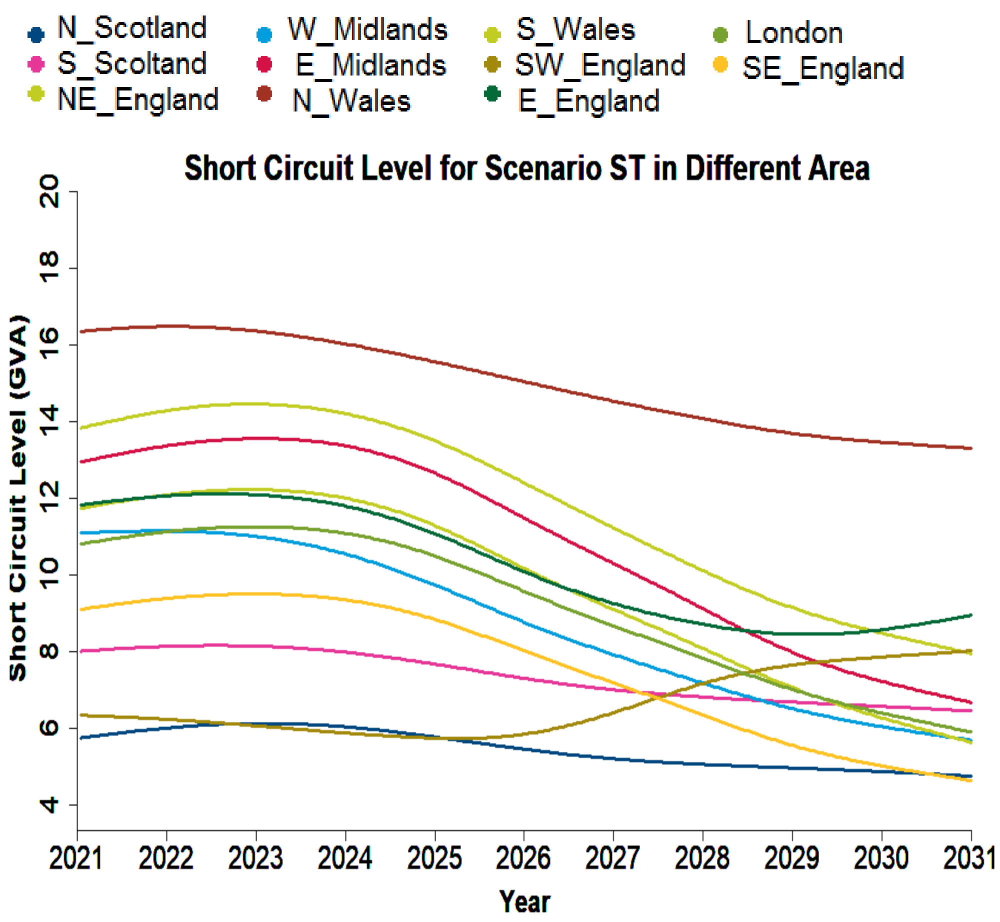
In previous SOF reports we have looked at the impact of the changing short circuit level (SCL) on the network [12]. Protection on the transmission network relies on the large current flowing in the system during a system fault. The protection sees these large currents and opens circuit breakers to protect the system and equipment.

During a fault, a lower SCL results in lower retained voltage levels across the network which can compromise a generator's ability to ride through the fault conditions. Lowering fault levels means that the voltage magnitude and angle will respond to a disturbance to a greater extent, there will be less dynamic damping available and voltage recovery will be slower. Therefore, the SCL provides a measure of how strong the system in dealing with system faults, and how resistant the electricity system is to voltage change. It provides a benchmark that designers of the equipment connecting to the system need to account for to ensure the equipment can operate and remain stable under all future conditions.

Having less synchronous generation dispatched will result in reducing short circuit levels on the transmission system. This is due to the synchronous generation being replaced by non-synchronous generation which has a lower and less predictable fault infeed [13]. The trend of reduction varies with location, largely depending on the local mix of the generation. Figure 4 gives the mean SCL trend for scenario System Transformation (ST). It shows that the east-midlands has most significant decline in SCL. In addition, Figure 5 indicates that the short circuit level for scenario ST drops from 16GVA to 7.5GVA in this area from 2021 to 2031.

The combined impact of these lower SCL means that operating the system may require increasing levels of intervention, over the decade, for every scenario. With the decline in synchronous generation, SCL could become an operability constraint over certain periods.

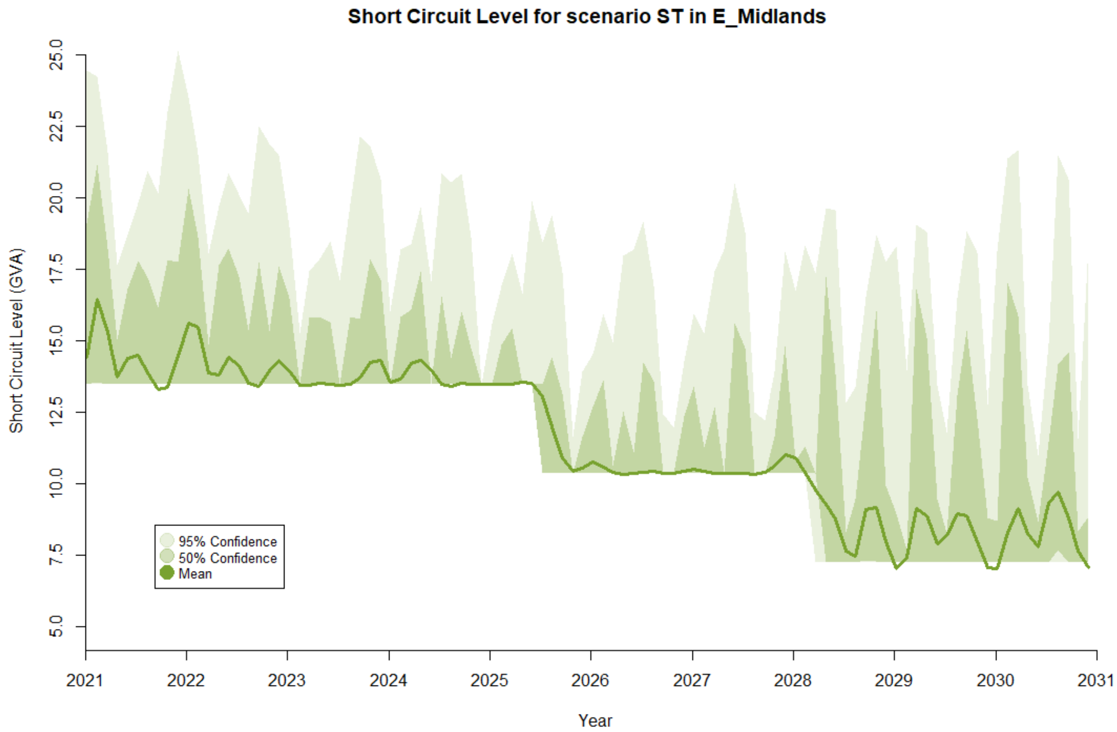
Figure 4: ***Mean Short Circuit Level for scenario System Transformation in different areas***



Our Network Development Roadmap sets out proposals to identify the best solutions by comparing potential network and market-based solutions. We have taken a 'learning by doing' approach, establishing pathfinding projects that aim to run competitive tenders for system needs such as SCL.

We envisage two routes to meet the need for short circuit Infeed as part of our requirement for stability support: a close to real time market (a short-term market) and a long-term tender/network owner solution via the stability pathfinders. The aim of the Stability pathfinders is to compare network owner solutions and commercial solutions for long term stability needs. Development of the close to real time market is still in an early stage. The stability pathfinders are in progress and are described further in the inertia section below. Developers and TOs will be able to bid in this year in the stability tender for Scotland. All technologies that can meet the performance requirements will be able to participate.

Figure 5: ***Short Circuit Level for scenario System Transformation in East Midlands***



System Inertia

System inertia is a measure of how much energy is available in the rotating mass of all machines that are directly coupled to the system to instantaneously balance any surplus or deficit in power. The rate at which frequency changes following a loss of generation or demand depends on the total system inertia. When inertia is low due to less energy being stored in rotating masses, the frequency changes faster and it is harder to manage.

Figure 6 shows the trend of the average inertia in the next 10 years based on FES 2020 data. With the changing energy mix, the traditional fossil-fuel generators have been replaced by interconnector imports and the renewable generators such as wind and solar to provide clean energy for GB consumers. This change is resulting in a reduction in system inertia. New technologies could in theory reverse this trend. For example, synthetic inertia and grid forming control philosophies have been developed for convertor-based generation (eg wind turbines, batteries, HVDC and photovoltaics) and could provide inertia support.

Figure 7 shows the annual distribution of system inertia for different scenarios and how it varies over future years. The inertia values are based on FES 2020 scenarios which have been explained in Appendix A.

The declining trend of the inertia is across all scenarios. The system inertia directly links with the Rate of Change of Frequency (RoCoF) for any sudden change in generation and demand. The decline of the inertia means that frequency will move faster for any power imbalance on the system. The effect of low inertia on loss of mains RoCoF relays is well documented and illustrated in SOF 2020. Currently some loss of mains protection relays used by distributed generators are set to the RoCoF limit of 0.125Hz/s. When RoCoF exceeds this limit, the relays could operate, and distributed generators will be disconnected from the system. The orange dash line in Figure 7 indicates the current minimum national inertia requirement of 140GVA.s which is recommended in Frequency Risk and Control Report [11]. For scenario LW, if the limit of inertia is 140GVA.s, the inertia is above this limit only for 55% of time in 2021. This number reduces to 45% in 2026 and further reduce to 15% in 2031.

We are currently working with the electricity distribution companies to update settings for the RoCoF loss of Mains protection relays from 0.125 to 1Hz/s, with a definite time delay of 500ms, under the Accelerated Loss of Mains Change Programme [10]. Once this is complete, there will still be a need to ensure that fast falling frequency does not cause inappropriate tripping of low frequency demand disconnection [14]. We have recently introduced the first of our new frequency control products called Dynamic Containment (DC) which will help manage this risk. DC is described further in our frequency response and reserve product roadmap [7].

Figure 6: ***Inertia trend to 2031***

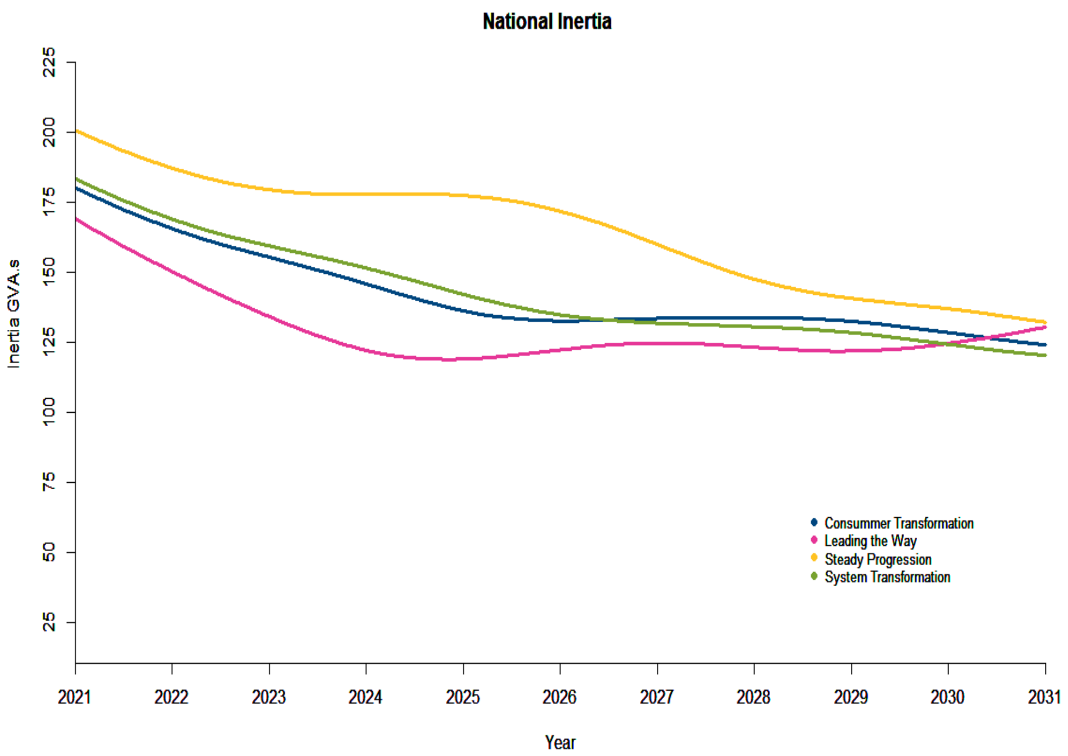
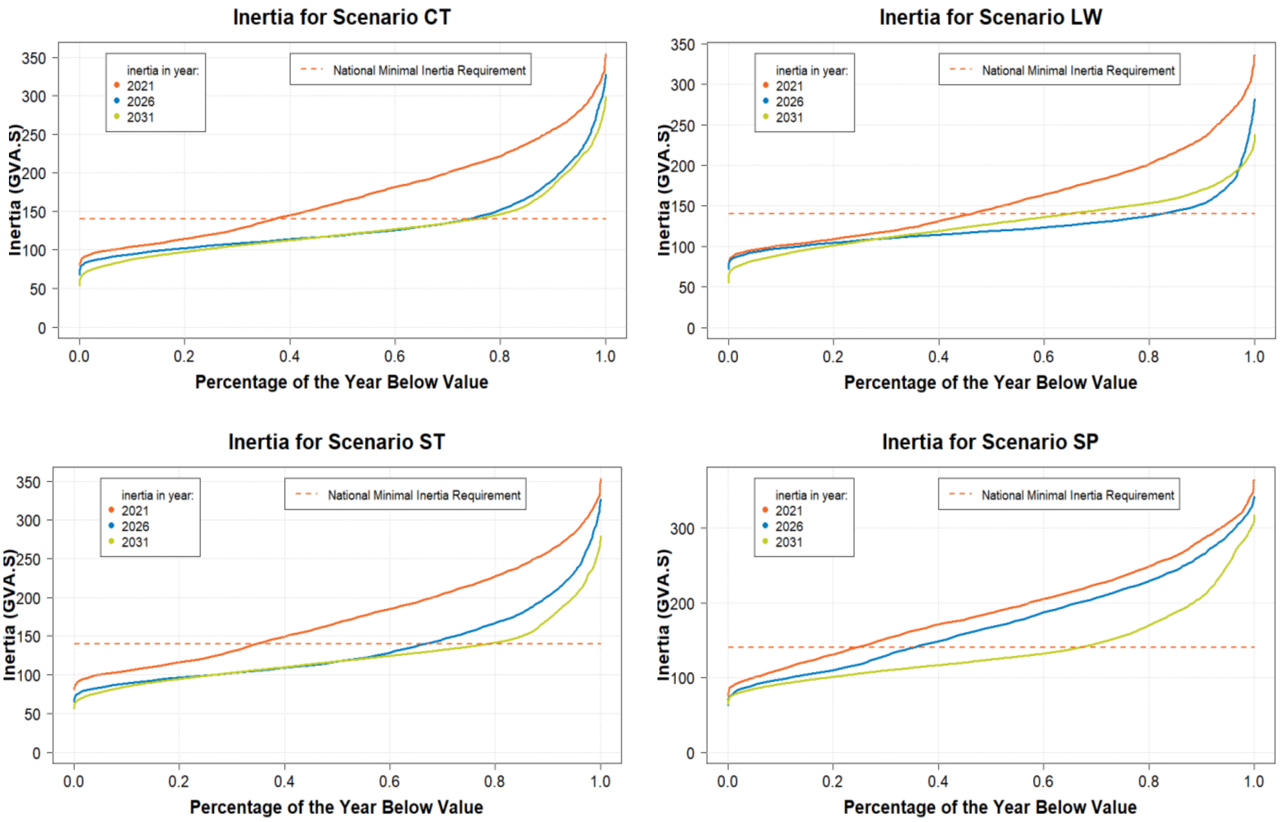


Figure 7: ***Annual distribution of the inertia***



Our stability pathfinder phase one is designed to support our national stability needs. The phase 1 tender was completed in April 2020. National Grid ESO awarded 12 tenders to 5 providers across 7 sites, securing 12.5GVAs of inertia until 31st March 2026. Phase 1 now in the service delivery phase with contracts signed with the successful providers.

We are also currently exploring under stability pathfinder phase two, which is about to move into the feasibility study stage with potential providers. We have defined a minimum technical specification, which is intended to encourage the broadest range of provision across all available technologies, provided these options are sufficiently mature to be delivered to the timeframes outlined.

The stability pathfinders will help bridge the gap between our inertia requirement and that inherently provided by the market. In parallel, we will examine the potential to reduce our inertia requirement (by making use of Dynamic Containment for example) through a regular Frequency Risk and Control Report process.

Conclusions

We see from our data that the GB power system is expected to see several continuing trends in generation and demand over the next decade. The results of these trends are that the market is dispatching in a way that requires increasing actions to be taken by the System Operator.

The dispatch will lead to several operability challenges:

- The amount of electricity storage is expected to increase over the next decade. Storage will help to balance out generation and demand and improve operability. But if storage is inappropriately incentivised through the market it could result in storage absorbing or generating at unhelpful times or causing large swings in power. However, with appropriate market and framework design, storage will be able to support system operation and be enable the decarbonization transition.
- The impact of interconnectors on system operability is currently mixed. Their capability to provide the frequency control, voltage control and system restoration capability etc. will be beneficial to system operability. However, more supplies from interconnectors will displace the contribution of synchronous generators meaning that the level of additional benefit provided by interconnectors is hard to quantify with certainty.
- Our analyses show that there is a system trend for a decline in the amount of synchronous generation in the market is dispatching. This will cause SCL and inertia to decline and means less support for the system during a fault. This in turn will impact operability as actions will need to be taken to prevent the system becoming less stable. We are also running stability pathfinder projects. These are designed to support our national stability needs, which cover inertia, fast acting dynamic voltage and short circuit level.

The above operability challenges are expected to increase over the decade based on what the market will dispatch. This means that on a day in the control room in 2031 we will need to take significant intervention to ensure a secure and stable system. We foresee a need to work with the industry on a continuing basis to make sure the level of our intervention is appropriate.

As it has been mentioned, we have already started to address these operability challenges through industry groups, our innovation projects and our future of balancing services program. There are known technological and commercial solutions to the issues we've highlighted here and known risks and benefits to using them. Please look out for our Network Development and Product roadmaps [5] and the Operability Strategy report [1] for information on how we plan to bring these forward.

References

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Executive summary

The UK's transition to a low carbon economy is bringing many new challenges and opportunities to how National Grid ESO operates the GB electricity system, with flexibility becoming an increasingly valuable characteristic. As the Electricity System Operator, we are continuously working with industry stakeholders to transform our operations and delivering the right market solutions at the right time to benefit the end consumer.

This document takes the output of National Grid's ETYS and NOA processes in 2020 and looks further into the technical issues which may need to be addressed for the successful operation of a low carbon electricity system.

Appendices
Background and Method

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Background and Method

Background

As the Great Britain system operator, we ensure that the system is operable now and in the future.

In SOF 2016, for the first time, we provided year-round insight into operability for the next decade with reference to the Future Energy Scenarios (FES). We developed an approach that combined historical data, projections from the FES and a simple representation of balancing requirements. In this report, we have updated the assessments from SOF 2016 with the latest FES data and an updated methodology using our economic dispatch model, BID3.

Every year National Grid Electricity System Operator publishes an overview of the future trends on the power system, based on input from our stakeholders, in our FES. These scenarios cover both electricity and gas. They are based on the energy trilemma (security of supply, sustainability and affordability) and provide supply and demand projections to 2050. The 2020 FES is summarised in Figure A1 and covers a broad range of economic prosperity and green ambition possibilities. This is a brief summary and we encourage you to read the FES 2020 or FES in five minutes for further insight.

Using the FES data, it is possible to simulate how generation will dispatch for every hour and every scenario for the next ten years.

In our analysis we used BID3, which is an economic dispatch optimisation model used by National Grid Electricity System Operator in its long-term market and constraints modelling. It includes demand, supply and infrastructure, and balances supply and demand on an hourly basis. It models the hourly generation of all power stations on the system, taking into account fuel prices, historical weather patterns and operational constraints. BID3 has been developed to support the System Operator's annual Network Options Assessment (NOA). You can read more about BID3 on our website [15].

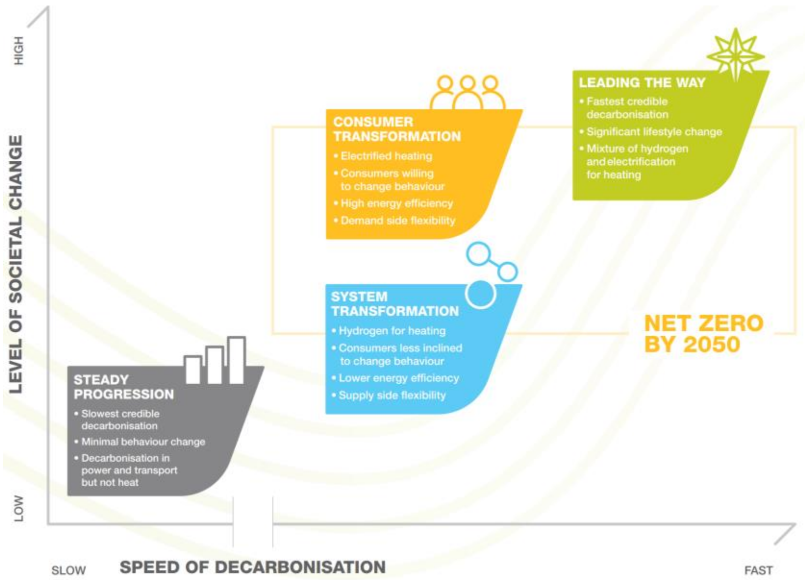
Although FES is normally completed in June, the Bid3 will not be available until NOA is finished, which is in December. Therefore, we still use FES 2020 in this paper.

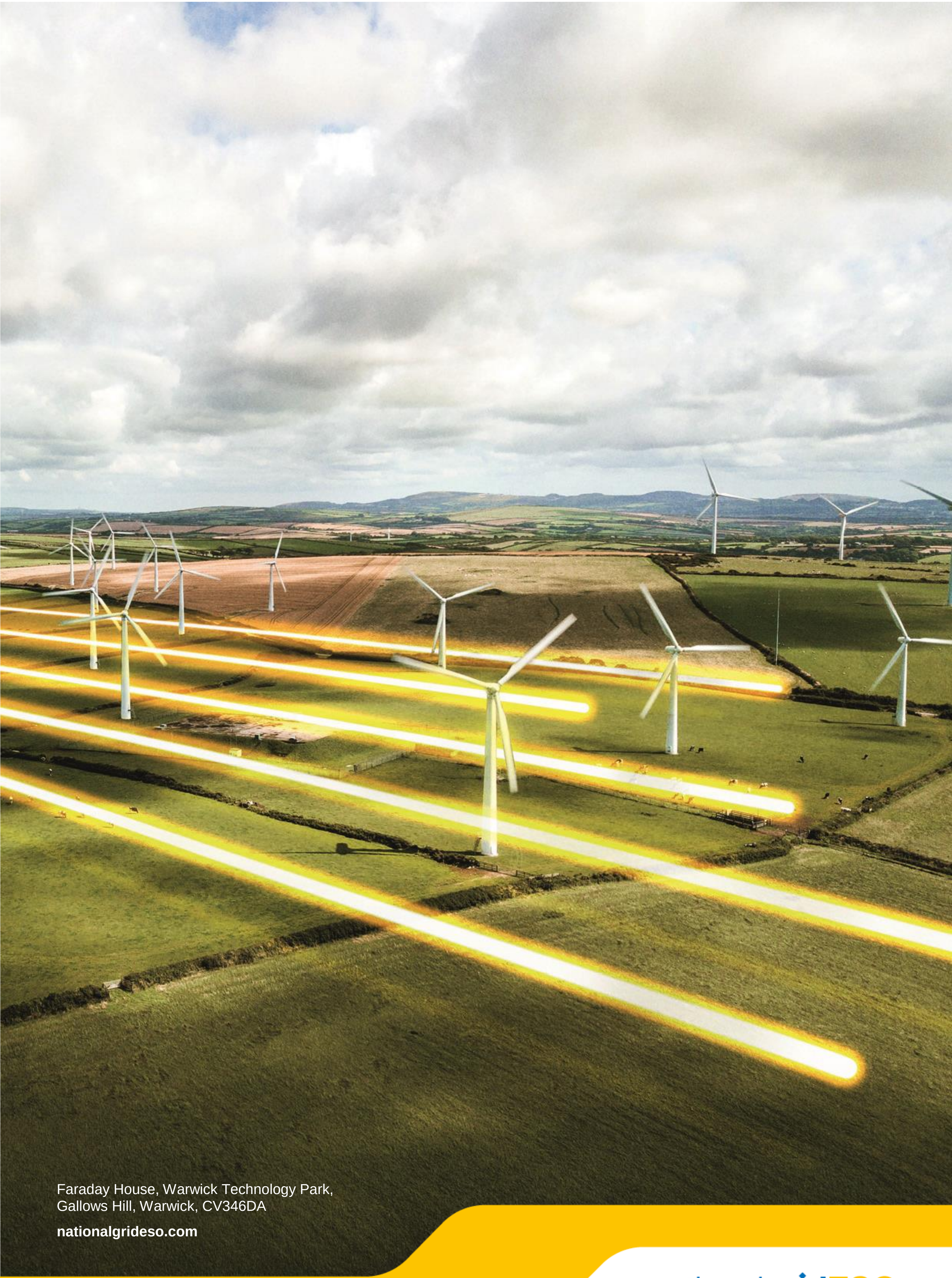
Method

We used the economic model and the FES datasets to produce hourly values for demand and generation for each generator on the system in this report. From this data, we can observe trends on the power system over the next 10 years that may have an impact on the operability of the system.

The economic dispatch we use in this analysis includes actions taken to solve thermal boundary constraints and reserve requirements. This is before any additional action has been taken to solve other operability conditions such as: ensuring a suitable voltage profile and ensuring stable operation. Trends highlighted in this document are independent of any solutions yet to be decided. In its estimation of storage, interconnectors and other flexible distributed energy resources, this dispatch calculation assumes the "perfect foresight" of the next day's weather conditions. This is to inform the operation of those flexible resources across the day.

Figure A1: 2020 Future Energy Scenarios





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