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Moving to a smart future

Simulated Trials Summary Report

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Scottish & Southern Electricity Networks

Simulated Trials Summary Report

TRANSITION

Electricity North West Limited

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Executive Summary

This report summarises work done by TNEI Services Ltd (TNEI) to undertake a series of simulated flexibility trials for the TRANSITION innovation project, which is being delivered by Scottish and Southern Electricity Networks (SSEN) with support from Electricity North West Ltd (ENWL).

TRANSITION is a five-year Network Innovation Competition (NIC) funded project exploring the market and technology elements of flexibility within the electricity system. One of ENWL's roles in the TRANSITION project is to carry out a series of simulated trials using models of their networks in the Northwest of England. Whereas the physical trials are being held on SSEN's network in Oxfordshire, the simulated trials have been carried out using models of ENWL's network, including regions in Greater Manchester. The overall aim of the simulated trials is to explore and produce learning about questions and topics which cannot be reasonably tested within physical trials, such as the impacts of different sources of uncertainty and risk, and how sensitive the optimal or near-optimal decisions about procuring flexibility are to different inputs and market behaviours.

TNEI has supported ENWL and SSEN in designing, conducting, and analysing simulated trials of flexibility services. The simulation approach developed by TNEI and summarised in this report has been to synthetically generate sets of data, as though they were genuine observations and predictions being collected or estimated in real-time. These are then provided as inputs to tools which approximate the decisions a DNO will have to make about flexibility. In response, the tools will issue outputs – comprising of procurement and/or dispatch decisions - for different flexibility services.

The learning objectives for the work, and the learning generated against each objective, are summarised in Table 1

Table 1: Summary of learning generated for each objective

Topic	Objective	Learning
Operational verification	Simulating flexibility services under varying network conditions to verify their operation and benefits.	The use of flexibility services to manage thermal and voltage limits has been demonstrated throughout this work, for multiple use cases and several network models, under a wide range of operating conditions which represent generation and demand patterns out to 2035.
Price behaviour and market/ system interaction	High level insights about how price-forming behaviour in flexibility markets might impact DNO services and, ultimately, on the network, in situations with high liquidity and good availability of services.	The sensitivity analysis in Section 4.1 has demonstrated that some flexibility providers are more valuable than others, depending on where they are located, and that their services might usefully interact in a non-linear way. This section also demonstrated the potential benefit of flexibility from reactive power. Finally, this section considers the impact of simultaneously analysing many contingencies at multiple voltage levels, demonstrating that flexibility services are more valuable if they can relieve multiple constraints at once.
DNO Decision-making	Generating insight about the impact that varying flexibility services requirements might have for decision-making processes.	The results in Section 4.2 have highlighted how year-on-year variation in weather and customer behaviour introduces variation, uncertainty, and risk, in the magnitude of flexibility requirements. This has implications for many aspects of DNO decision-making, like the definition of price ceilings, risk sharing between DNOs and service providers, and the contribution of renewables. Consideration of this variation and uncertainty should be adopted into business-as-usual (BAU) flexibility decision-making processes.

Topic	Objective	Learning
Provider reliability	Exploring the impact on a network under potential conditions of lack of service provider availability or partial delivery, with such conditions likely to be difficult to control within physical trials.	The results in Section 4.3.1 show that the risks due to periods of partial delivery of a service are, in some ways, like those associated with periods of complete unavailability: both phenomena will introduce risk that network assets become overloaded. However, the risk of higher overloads will be greater with complete unavailability than with partial delivery. This means the latter may be more suitable to management through over procurement of the flexibility service.
Forecast accuracy	Exploring the impact of the inaccuracy in operational forecasts, alongside the tolerance of the flexibility response solutions to different types of forecast errors.	The results in Section 4.3.2 show that, if flexibility services are sized based on point forecasts, then forecast errors will introduce risk of overloads for the network. If these forecasts are unbiased then, in the simplest cases, the network will become overloaded approximately 50% of the time. However, if the spread of possible forecast errors is greater, then the risk of higher levels of overload will also be greater. This means greater forecast errors will be more difficult to manage with over procurement. In more complex cases, the *correlation* between forecast errors at multiple locations will also matter.

Key themes that emerge from the simulation results, include:

- **The importance of uncertainty and risk within flexibility decision-making.** The use of flexibility services changes the nature of the risks that DNOs (and their customers) are exposed to, and DNOs will need capabilities to manage this. Ultimately, DNOs will probably need to overprocure – paying for flexibility they probably won't need – to manage this risk. Opportunities for minimising this overprocurement should be considered in detail as flexibility is adopted into business as usual.
- **The potential benefits of highly decentralised flexibility services.** The simulation results have shown that flexibility services can be more effective if they are electrically distant from the network constraints, due to the reduction in losses. They have also shown that services are more valuable if they resolve multiple network constraints simultaneously. At the limit, this might mean it is most efficient to source flexibility from the high voltage or low voltage networks, although more analysis would be required to confirm this.
- **The benefits and challenges arising from increasingly complex flexibility decision-making processes.** The methodologies used within this work are already quite complex, but in many cases the results demonstrate the benefit and /or importance of that complexity. However, this complexity comes with costs and barriers, including computational challenges but also issues around transparency and explicability. Finding the right balance between complexity and tractability / scalability will be an ongoing challenge as flexibility is adopted into BAU.
- **The role of complex analysis tools within flexibility decision-making.** The simulated trials have relied on the integration of many sources of data within off-the-shelf software and bespoke algorithms. Implementation of flexibility into BAU is likely to be similar. Interoperability between different tools will through standards like the Common Information Model (CIM) reduce the reliance on any single software. Using live operational software, tools, and processes in further offline simulations could be helpful to inform the ongoing design of policies and practices relating to flexibility services.

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1 Introduction

This report summarises work done by TNEI Services Ltd (TNEI) to undertake a series of simulated flexibility trials for the TRANSITION innovation project, which is being delivered by Scottish and Southern Electricity Networks (SSEN) with support from Electricity North West Ltd (ENWL).

TRANSITION is a five-year Network Innovation Competition (NIC) funded project exploring the market and technology elements of flexibility within the electricity system. By developing two IT systems (a Neutral Market Facilitation (NMF) Platform and an associated Whole System Coordinator (WSC) tool), TRANSITION enables the advertisement of flexibility needs and running of a series of flexible events including DSO-Procured Services and DSO-Enabled services. These IT systems operate in conjunction with a forecasting tool and a power system analysis engine to facilitate decentralised flexibility services on the distribution network. The focal point of the project is a sequence of large-scale physical trials of several flexible services on SSEN's Oxfordshire network, coordinated by the novel flexibility platform and run by SSEN. The TRANSITION project also informs and collaborates closely with the ENA Open Networks programme, within which both SSEN and ENWL are heavily active.

One of ENWL's roles in the TRANSITION project is to carry out a series of simulated trials using models of their networks in the Northwest of England. Whereas the physical trials are being held on SSEN's network in Oxfordshire, the simulated trials have been carried out using models of ENWL's network, including regions in Greater Manchester. The overall aim of the simulated trials is to explore and produce learning about questions and topics which cannot be reasonably tested within physical trials, such as the impacts of different sources of uncertainty and risk, and how sensitive the optimal or near-optimal decisions about procuring flexibility are to different inputs and market behaviours.

TNEI has supported ENWL and SSEN in designing, conducting, and analysing simulated trials of flexibility services. The simulation approach developed by TNEI and summarised in this report has been to synthetically generate sets of data, as though they were genuine observations and predictions being collected or estimated in real-time. These are then provided as inputs to tools which approximate the decisions a DNO will have to make about flexibility. In response, the tools will issue outputs – comprising of procurement and/or dispatch decisions - for different flexibility services.

The assumptions made within the modelling process aim to maximise the necessary use of flexibility services (e.g., by taking a more conservative view of asset ratings than is typical within network planning and operation) and assert that there is widespread availability of flexibility services, with costs that are efficient. This is so the simulated trials can provide as much learning and insight as possible about how flexibility services might operate technically. This is an important enabler for understanding the impact of flexibility at scale in business-as-usual (BAU) operation, complementing the physical trials completed in Oxfordshire.

There are then several different study topics where the outputs of the simulations can be tested and analysed. For example, one option is to take ENWL's network model and treat it as if it is the real network, with outputs for line flows and voltages being treated as if they were real measurements being collected in the DNO's PI historian system. The impact of the decisions from these flexibility tools can then be evaluated in this simulated version of the real network. This is illustrated below in **Error! Reference source not found.** which shows the high-level architecture of the systems used for t he simulated trials. This highlights the separation between the ***tools and processes for flexibility decisions***, and the ***simulation environment***, which consists of an IPSA network model alongside data, models, and assumptions from which simulation parameters can be drawn.

The introduction of various sources of uncertainty and risk within the simulation environment may lead to problems on the network. For example, there is a risk that thermal ratings and statutory voltage limits are not complied with if providers fail to deliver the flexibility dispatches which they've been instructed to provide, or if the DNO over- or underestimates the levels of demand and generation in the network at that time. Within the simulated trials, these phenomena have been explored through probabilistic simulations.

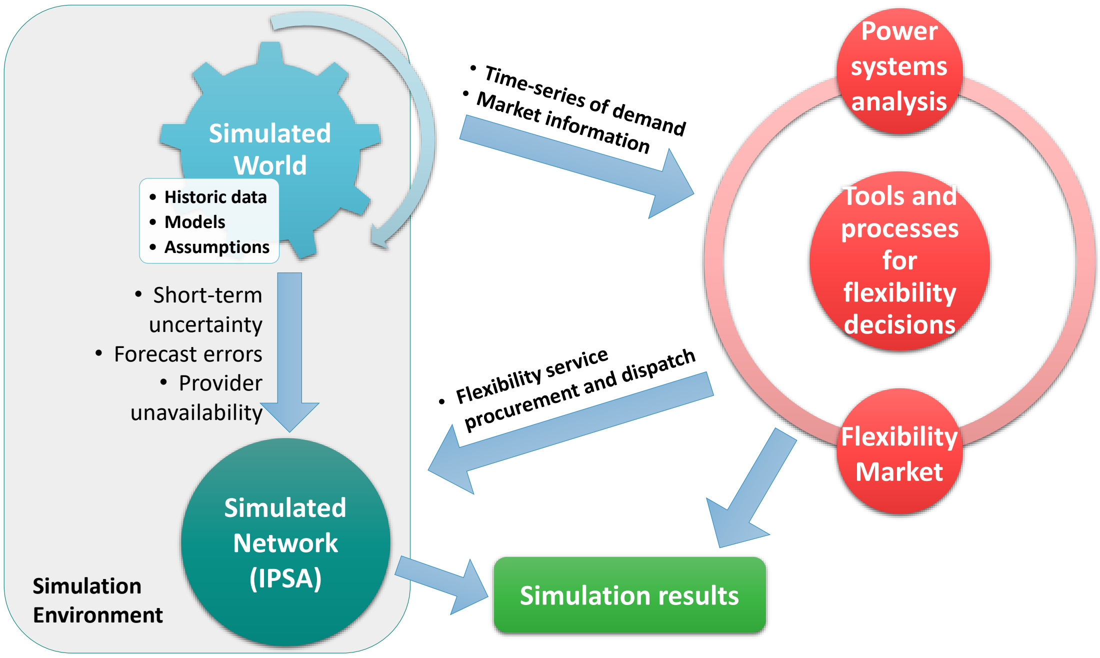

Figure 1: Overview of simulated trials approach

The simulated trials have also explored the long-run variation in flexibility requirements across many years under different Distribution Future Electricity Scenarios (DFES), and how this might change between typical years, low temperature years, years where peak demand is high but not due to low temperatures etc. This demonstrates the value of flexibility services under different scenarios, but also has implications for the strategies employed by a DNO and risk exposure at different lead-times.

It is also possible, with simulations, to explore how the decisions that DNOs might make about flexibility services are sensitive to different inputs. This includes the relative price of flexibility from different providers and the contingency scenarios that are considered.

1.1 Learning objectives

The following learning objectives for the simulated trials were developed through discussions between TNEI, ENWL and SSEN:

- **Operational verification** – Simulating flexibility services under varying network conditions to verify their operation and benefits.
- **Price behaviour and market/system interactions** – High level insights about how price-forming behaviour in flexibility markets might impact DNO services and, ultimately, on the network, in situations with high liquidity and good availability of services.
- **DNO Decision-making**– Generating insight about the impact that varying flexibility services requirements might have for decision-making processes.
- **Provider reliability** – Exploring the impact on a network under potential conditions of lack of service provider availability or lack of delivery, with such conditions likely to be difficult to control within physical trials.
- **Forecast accuracy** – Exploring the impact of the inaccuracy in operational forecasts, alongside the tolerance of the flexibility response solutions to different types of forecast errors.

2 Methodology

There are five key elements of the methodology used within the simulated trials.

1. Long-term demand trends: the statistical processing of recorded demand values. Historic ENWL primary substation demand data covering the 2017/18 to 2021/22 financial years has been used to inform the representation of demand patterns within the simulations. This must be processed to ensure that the simulations can account for long-term demand trends. The steps involved in this are: (i) account for the way that underlying patterns of demand have changed between 2017/18 and 2021/22, (ii) preserve the natural variability in demand patterns from one year to the next, that arise due to both weather and also randomness in customer behaviour, and (iii) represent future scenarios where there is less headroom in the network and, therefore, a more pressing need for flexibility services. The impact of COVID lockdowns on patterns of demand (particularly in 2020) presents a significant challenge to this, and data on the severity of lockdowns was used to try to correct for this.

   Demand has been scaled to represent ENWL's five DFES[1] in the years 2030 – 2035.
2. Network impacts: the simulation of network conditions to estimate impacts on the network. Power systems analysis models have been set up to provide simulated network conditions, which can be used as a proxy for the real network to inform network impacts. The approach is to treat the calculated power flows and voltages from these models as if they were actual measured power flows and voltages. TNEI's IPSA power flow analysis tool[2] has been used in most of the simulations of power flows and network impacts, supported by other tools, including commercial software like (DigSILENT PowerFactory[3] and Opus One DERMS Platform[4]) and bespoke algorithms) where necessary.
3. Flexibility decision-making: the simulation of DNO actions under evolving conditions. The simulations need a way to represent the evolving and responsive decisions that future DNOs will take - as network conditions and (imperfect) forecasts materialise – on when to procure and dispatch flexibility services (and how much). This representation of flexibility decision making should reflect both the details of the power systems analysis but also the operation of a flexibility market. Several options for how flexibility dispatches are generated have been considered for this within the simulated trials project, but most of the results have used an AC Optimal Power Flow algorithm implemented by TNEI.
4. Uncertainty in the short-term: representing short term uncertainties and investigating sensitivity to them. One of the central areas of investigation within the simulated trials has been the impact of sources of short-term operational uncertainty that may be present, including the influence of point forecast errors and the risk of less than perfect reliability from flexibility providers. Sensitivity analysis and Monte-Carlo simulations have been used

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[11] This work has used the 2021 iteration of the DFES, available at: https://www.enwl.co.uk/get-connected/network-information/dfes/archive/

[2] https://www.ipsa-power.com/

[3] https://www.digsilent.de/en/powerfactory.html

[4] https://www.opusonesolutions.com/

to explore the impact of these phenomena, with simplified probability models assumed that describe the nature of provider reliability, and the possible sizes of forecast errors.

5. Active learning: avoiding a very heavy computational burden by adopting a machine learning algorithm. One challenge affecting many areas of these simulated trials is the computational expense of undertaking a very large number of simulations. A methodology for result interpolation using a machine learning technique called active learning[5] has been implemented, which significantly reduces computational expense and running time.

2.1 Assumptions about flexibility

2.1.1 Alternatives to flexibility services

Within the scope of these simulations, it has been assumed that flexibility will be the most appropriate solution for managing constraints that arise in the network due to the projected growth in network demands. This implicitly assumes (within these simulations) that many of the other tools that a DNO might be able to draw on (such as operational switching, cyclic and dynamic ratings, and ultimately, network reinforcement) are either not available or are not as effective as flexibility.

In reality, this is unlikely to be a realistic assumption in every case, and it is expected that DNOs will need to be able to rely on all of these tools in combination to resolve network issues. This might even mean that many of the examples of network constraints presented in this report could be dealt with entirely by other operational means or based on other policies, meaning there would be no need for either flexibility or investment.

However, the aims of this work are focused on providing insight about the flexibility services that could be one of the many tools in this toolbox, rather than trying to consider all aspects of how a future DNO might operate its system. Therefore, the simulations have considered a very conservative set of worst-case assumptions[6] (e.g., *standard* rather than *cyclic* asset ratings, without options like operational switching) when determining requirements for flexibility and the resultant impacts on the network. This increases the extent to which flexibility is used in the simulations, with the aim of maximising the learning and insight generated about their technical operation.

2.1.2 Availability and price of flexibility services

The simulations rely on hypothetical sources of flexibility that have been made available (on an aggregate basis if necessary) at whichever location in the network requires them for a specific simulation, and at prices which are efficient compared to reinforcement. This assumes that the market for flexibility is liquid, with many possible providers offering competitive prices and no market power. For simplicity, we have assumed that all services are paid for their utilisation only, rather than the more sophisticated combinations of availability and utilisation payments that are being proposed for actual flexibility services.

When there is only one source modelled for providing aggregate flexibility, there is no need to make any specific assumptions about its offered price. The only general assumption is that it is more expensive to source flexibility from within the network than it is to source power from the external grid (as modelled at the transmission generator). This means that flexibility within the network is only

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[5] See https://modal-python.readthedocs.io/en/latest/content/overview/modAL-in-a-nutshell.html for an overview of the active learning technique, as part of a Python implementation called modAL.

[6] In general, this conservatism means that the reporting of a need for flexibility in the use cases presented in this project does not mean that there are any actual network security issues affecting ENWL's network, either under current conditions or projected for the future.

used when there are thermal (and in other cases, voltage) constraints that need to be managed, and that these local flexibility providers are not there to act as the primary supply of local energy demand.

When there are multiple locations from which flexibility can be procured, the *relative* price of flexibility between these locations is important – this is explored in detail in the simulations summarised in Section 4.1. But there are still no specific assumptions made about the *absolute* level of this price, other than it being more expensive than sourcing power from the wider energy system. However, the interpretation of these results can give some insight about things like market power – if a flexibility provider in a more favourable location recognises that they provide extra benefit to the network, they might offer the DNO their service at a higher relative price.

These assumptions – widespread availability, high liquidity, and low prices – are optimistic compared to the current level of maturity of distribution flexibility markets. In reality at present, the lack of available sources and the concentration of locational market power could impede the use of flexibility services in the short term and high prices may make it more cost-effective to simply reinforce the network. Nevertheless, the results of these simulated trials can provide insight about how a more liquid flexibility market might operate (in the long term) and, if interpreted cautiously, can also provide learning about markets in the short-term with more illiquidity.

3 Networks and use-cases

Simulations were carried out on a selection of network areas within ENWL's network licence area. Discussions with subject matter experts from across ENWL were held to help select appropriate areas of the network. The aim was to choose areas of the network which (i) were fairly representative of typical network topologies, (ii) which provided opportunities for new learning compared to the physical trials while still providing some overlap, and (iii) which were anticipated by ENWL to require some intervention (either through flexibility or conventional reinforcement) within the coming years. In addition, there was a desire within the SSEN and ENWL TRANSITION team to represent some urban and suburban areas of the network – this had been reflected in some of the early scoping documents which described an intention to use models of networks in Manchester and Greater Manchester.

Based on these discussions, two areas of the network were selected for analysis within the simulated trials. These are summarised in the table below.

Table 2: Overview of network models

	Kirkby GSP and Bold GSP	Harker GSP and-Hutton GSP
Geographic area	North-west of Manchester, near Wigan	Cumbria
Number of BSPs	4	11
Urban or rural	Urban and suburban	From densely urban (Carlisle) to smaller towns (Kendal) and very rural areas (Lake District).
Topology	Radial at 132 kV and mostly radial at 33 kV, with parallel redundant assets. Some 33 kV ring configurations. Normally open points between BSPs. GSPs separated during normal running arrangements. Some HV interconnection between BSP groups.	Heavily interconnected at 132 kV. Lots of 33 kV ring configurations. Some 33 kV interconnection between BSPs.
Voltage levels	From 275 kV NGET network to HV busbars in primary substations.	From 132 kV busbars in GSPs to HV busbars in primary substations. All 33 kV and 132 kV circuit included in the model
Flexibility Use Cases	Gidlow N-1 Pimbo and Willow-Hey N-2 (maintenance)	Kendal BSP with several overlapping-N-1 conditions

The Bold and Kirkby GSP model was considered to represent a fairly typical network, with some relatively simple use cases, while still providing opportunities to consider some more complex arrangements. This was the main model considered in the simulated trials.

The Harker-Hutton network provides opportunities for further learning, due to the complexities introduced by the ring and meshed topologies, although the size and complexity of the network does introduce some significant challenges. Some further focused simulations using this network have also been considered.

The Bold and Kirkby GSP and Harker-Hutton GSP were considered sufficient to satisfy the three aims for selecting a network described above without considering further models at this stage.

4 Results

4.1 The sensitivity to varying prices

4.1.1 Multiple service providers

The simulations have shown that, when there are multiple flexibility providers available, some of them can provide more benefit to the network than others due to technical factors (e.g., voltage drop and technical losses). In a simple N-2 maintenance case, the more beneficial provider is therefore the one that is the most electrically distant from the network constraint (in this case, at Pimbo primary), as long as it is contributing to the network constraint. This is because both providers have a single path to the constrained asset, but the more electrically distant provider will have a bigger impact on technical factors like voltage drop and losses. The increased value this provider gives to the system could give them a degree of market power: they could in principle increase their prices beyond their costs without diminishing their market share.

However, if the more beneficial provider's costs are too high, then it becomes more cost-effective for the DNO to pay for flexibility at the lower unit cost even if it is less effective. When the prices are closer to each other, the "optimal" solution for the DNO is to take some flexibility from both providers, rather than a "winner-takes-all" outcome. This is a consequence of the non-linear physics of the network, but simpler approximations of the power flow (particularly linear approximations) may not identify this.

This result is shown in the figure below, which plots how much flexibility is taken from each of the two primaries as the relative price between them changes.

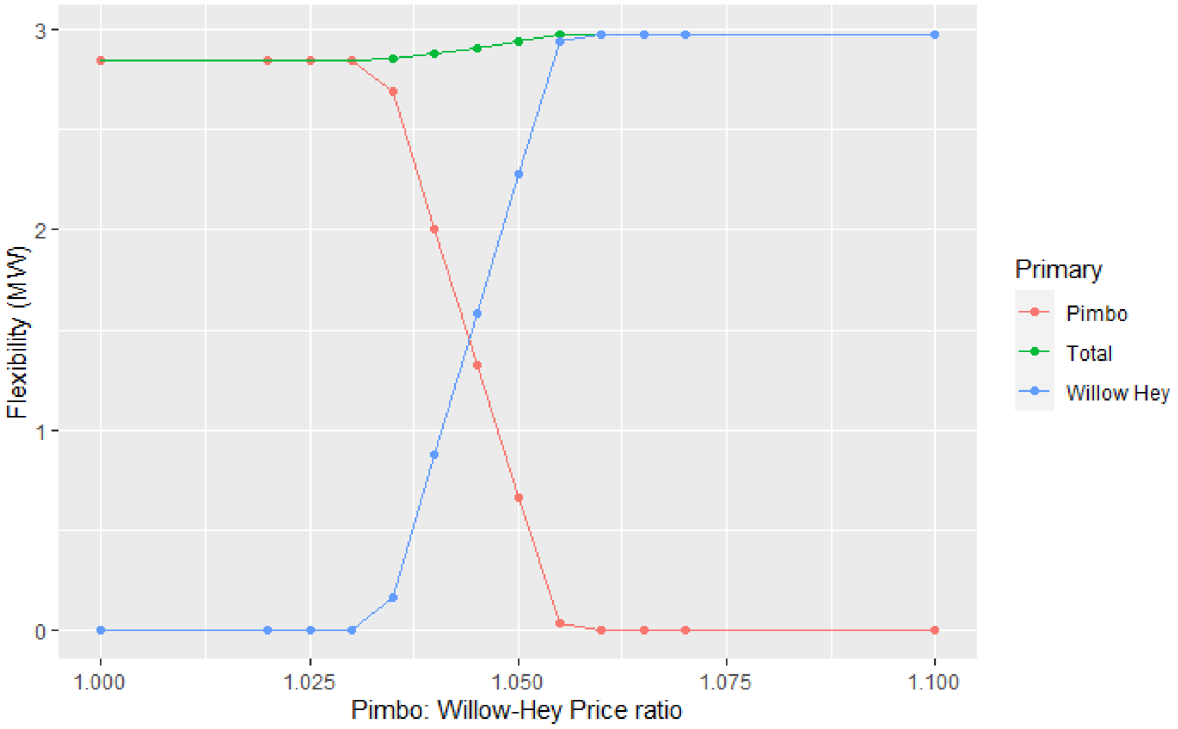

Figure 2: Flexibility for Pimbo and Willow Hey primaries, under varying prices

4.1.2 Flexible Reactive Power

The simulations have also shown that providing active power (MW) flexibility without changing reactive power (MVAr) loads can worsen the power factor of the net demand at the point at which the flexibility is provided, and of the power flowing in the network components supplying that point. This means that additional MW flexibility is required to manage this worsened power factor.

This has been explored within this set of flexibility simulations by setting dispatches for both MW and MVAr flexibility. The results show that providing MW flexibility with MVAr flexibility simultaneously could be more efficient than MW flexibility on its own, as this does not lead to the overall power factor being worsened. However, this depends on the cost of accessing the MVAr flexibility and how it is provided (e.g., can one provider offer both types of flexibility). Combinations of MW and MVAr flexibility can result in a lower overall MVA flexibility need. The optimum combination depends on the topology of the network, the power factor of the constrained network assets, etc, and on the nature of the costs incurred by the service provider(s) and the technology they are using to provide flexibility.

This result is illustrated in the figure below, which shows the lowest cost combination of Active and Reactive power flexibility and the total resultant Apparent power flexibility, and how this changes as the relative price of Reactive power flexibility is changed.

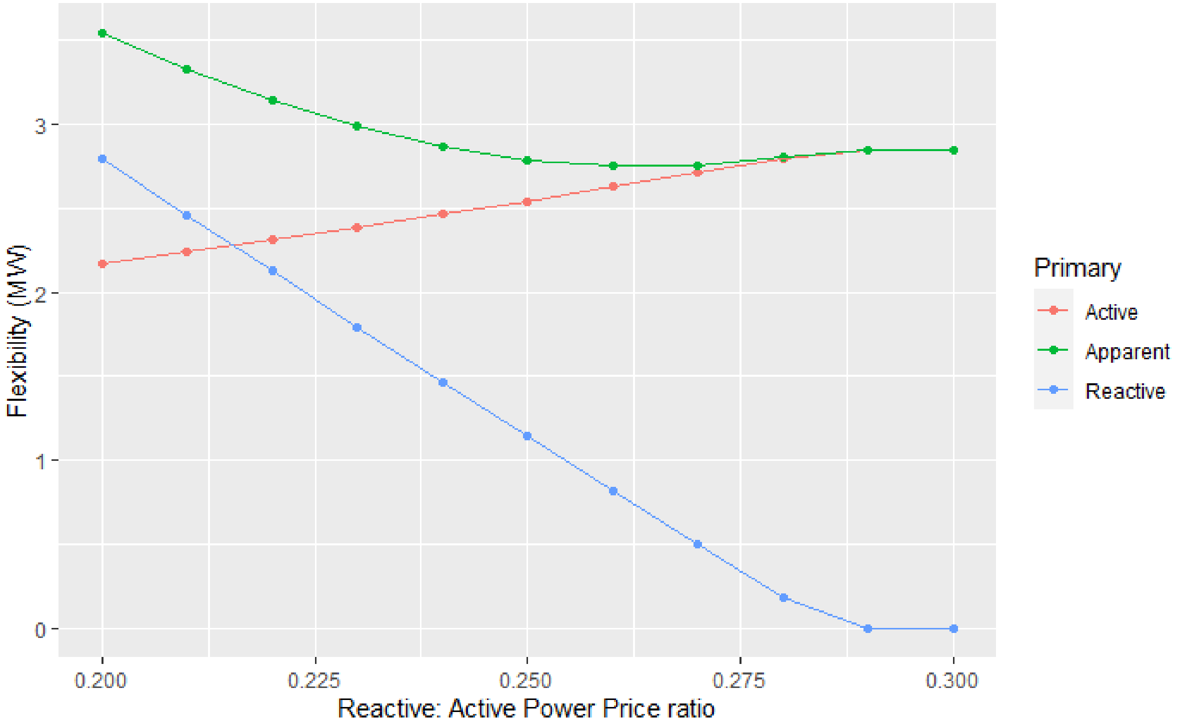

Figure 3: Flexibility under different active: reactive power price ratios

4.1.3 Overlapping security constraints

Additionally, the simulations have demonstrated that analysing many security contingencies is computationally expensive and time consuming. However, it may be necessary in some networks. The simulated trials investigated an example where assessing multiple contingencies in a single analysis will result in different outcomes than studying them separately and then attempting to combine the separate solutions. Some of these security contingencies demonstrated that it could be possible to use active power flexibility to resolve violations of steady-state voltage limits.

The flexibility simulations considered a case in the Kendal BSP network where there are constraints within the lower voltage levels of the network (e.g., 33 kV circuits and primary transformers) as well as the higher voltage levels (e.g., BSP transformers). This did not occur in the cases studied in the other network model. When resolving a higher voltage level (BSP) constraint using lower voltage level sources which all have the same cost, then it is optimal (in terms of losses and voltage drop) to distribute the delivery of flexibility throughout the network, rather than take it all from a single location. The presence of many constraints in the lower voltage levels of the network will also lead to flexibility being taken from distributed locations, although this will be biased towards the locations where there these constraints exist within the lower voltage levels.

If there is a single cheap source of flexibility at one location in the network, then it would be most cost effective to use only this source to resolve the higher voltage level constraint if analysing that constraint in isolation. However, if analysing many constraints, then the need to use decentralised flexibility distributed throughout the lower voltage levels is unavoidable, even if it increases the cost.

For this case, the total flexibility requirement for the BSP transformers exceeds the sum of the requirements from the lower voltage levels: including the high voltage level in the analysis means the flexibility needs to be “topped up”. However, this only requires a (relatively) small top-up, since the flexibility services for the lower voltage levels also provide benefit to the BSP transformers.

This finding is illustrated in the figure below, where hypothetical flexibility providers have been located at each primary in the network, and one has been located directly at the BSP, with a lower relative price. The Kendal BSP flexibility provider is not selected to resolve the 33 kV and Primary constraints since these are downstream of its point of connection. When only the BSP constraint is imposed, then the bulk of the flexibility is taken from Kendal BSP, although some is taken from the wider network to resolve some voltage issues. When the BSP constraint is included *alongside* these lower-level constraints, a small top-up is required, and this is taken from Kendal BSP, since this is the lowest cost. The more expensive flexibility must still be selected to address the lower level constraints, though.

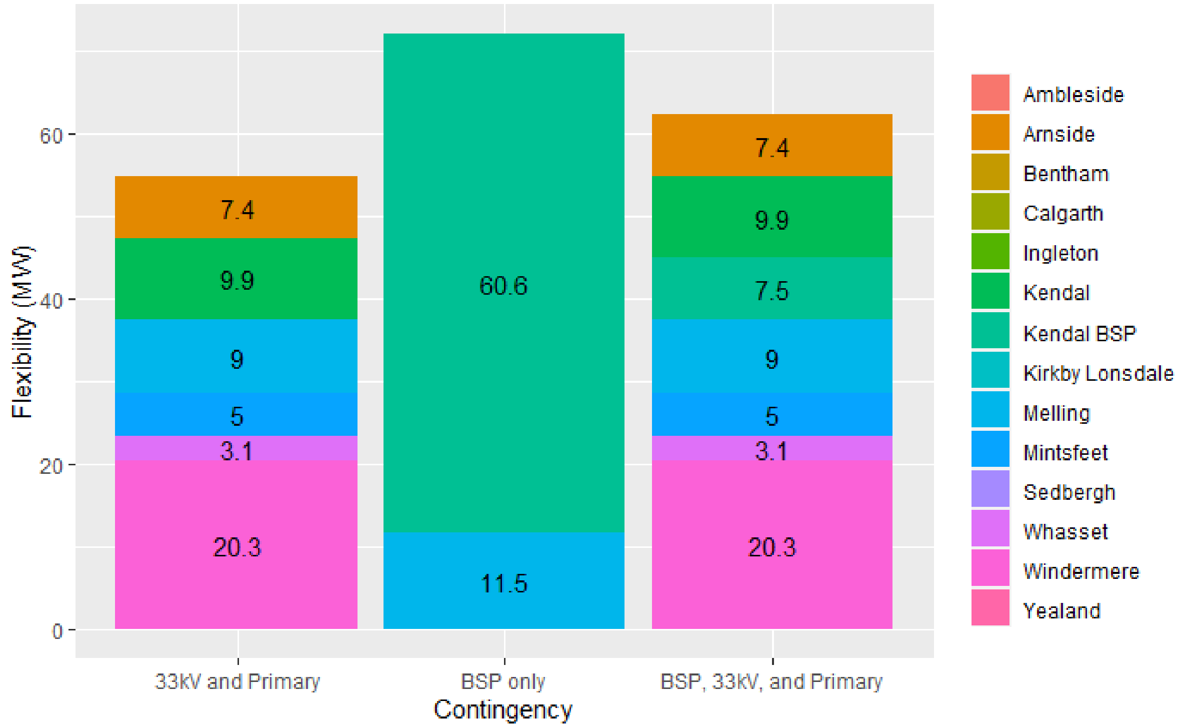

Figure 4: Flexibility required in the security-constrained analysis of the Kendal use case (right-hand column), compared to a security-constrained analysis which only considers 33 kV and primary transformer contingencies (left-hand column) or only the BSP contingency (middle column), with different prices across flexibility providers

4.2 Long-run variation in flexibility requirements

4.2.1 Variation and uncertainty in flexibility requirements

From appropriately rescaled time-series of future demand, considering different future energy scenarios, flexibility requirements can be identified using a network model and some kind of algorithm to identify flexibility dispatches[7]. In the simplest case, the capacity (MW) and utilisation (MWh) of the required flexibility services can be determined. Analysis of a primary substation N-1 use case shows that, without reinforcing the network, flexibility services can keep network assets in the primary substation within standard thermal ratings until at least 2035 under all five Distribution Future Electricity Scenarios (DFES).

But, randomness in the behaviour that affects electricity demand and in weather patterns (which in turn affect demand) mean there is uncertainty in the demand at each location in the network, including the timing and magnitude of the peak demand. The peak demand (and other quantities like the annual demand) can be described with an expected value, but also with a probabilistic predictive distribution.

The uncertainty in demand (due to random behaviour, weather etc) leads to uncertainty in the capacity and utilisation requirements for flexibility services. Like the peak demand, the required peak capacity of the flexibility service can be described probabilistically: e.g., there is a 90% chance that the flexible capacity needs to be at least 7.04 MW or, equivalently, if a DNO makes 7.04 MW available in advance, there is a 90% chance that it will end up needing to source more flexibility closer to real-time. The figure below shows, for 2034/35 under one DFES, the probability that the annual peak flexibility requirement must be greater than the value on the x-axis for a use case at Gidlow Primary.

Figure 5: Probability of exceeding different levels of maximum flexibility requirement, highlighting the expected value, for Gidlow Primary use case under Leading the Way scenario in 2035

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[7] In these simulated flexibility trials, an AC optimal power flow algorithm has been used with an implementation that is described in detail in Section 2 of the full report.

This risk in the required level of flexibility capacity means DNOs need tools and processes for managing risk. DNOs will need to define risk tolerances – how willing is a DNO to accept shortfalls in the available level of flexibility, and how does this change at different lead-times? To plan robustly, a DNO will need to have a view of the availability of other extra sources of flexibility in the future, and also what these might cost.

This uncertainty also affects the price that a DNO should be willing to pay for a flexibility service, since a price ceiling based on an expected utilisation or flexibility requirement may actually be breached around 50% of the time. The figure below shows the probability that the total expenditure on flexibility will exceed the value associated with deferring reinforcement as the price ceiling is varied, assuming a utilisation only price. For example, if the price ceiling is set based on *expected* (average) levels of utilisation of the service, and a contract is agreed at this price ceiling, then there is roughly a 50% probability that the total cost of flexibility will exceed the reinforcement deferral value.

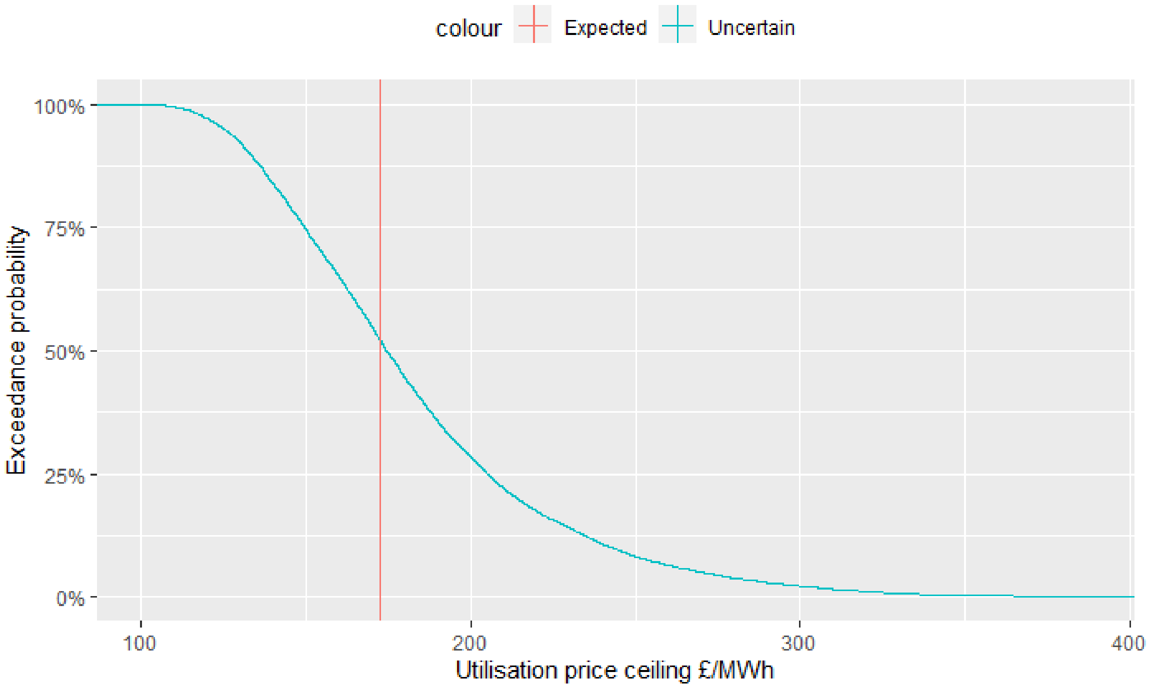

Figure 6: Probability of exceeding different levels of a flexibility service utilisation price-ceiling, for Gidlow Primary use case under Leading the Way scenario between 2030/31 and 2034/35

The need for flexibility (both capacity, and utilisation) and the levels of risk and uncertainty also change both by season and by time-of-day. There are some relatively predictable patterns in the expected levels of flexible capacity and utilisation, but the uncertainty appears to be less easy to explain deterministically.

4.2.2 Risk sharing between DNO and provider

The uncertainty in flexibility requirements (capacity and utilisation) means there is risk associated with using flexibility services. The nature of the commercial arrangement between the DNO and the flexibility service provider (e.g., the terms, and payment structure) define how this risk is shared.

Some options would leave the DNO to manage this risk – for example, paying for a service which is always dispatched within some window, such as winter evening peak periods, irrespective of what the requirement is, and always paying for the dispatch. This results in a fixed payment for a fixed level of service, but it means the DNO (and, indirectly, its customers) take the risk of paying for flexibility when it is not needed. The simulations show that, with this sort of model, the DNO could frequently end up dispatching flexibility services which the network doesn't actually need.

At the other end of the spectrum, a DNO might notify the flexibility services provider in real-time about whether the service needs to be dispatch, so that flexibility isn't delivered when it isn't needed. If the fee paid to the provider is per MWh of delivered flexibility, then this means the flexibility service provider is left managing a lot of risk.

The simulations show that, for one year of the same scenario within the winter evening peak period, the 90% predictive interval for the utilisation of the service varies from 668 MWh to 1,536 MWh as illustrated in the figure below, meaning that within this simulated example the hypothetical provider would be managing considerable risk about how much they need to be dispatched and how they would be paid for the service[8]. This might just lead to the provider increasing their cost. The DNO would then need to manage the risk that the requirement exceeds that which has been made available in advance.

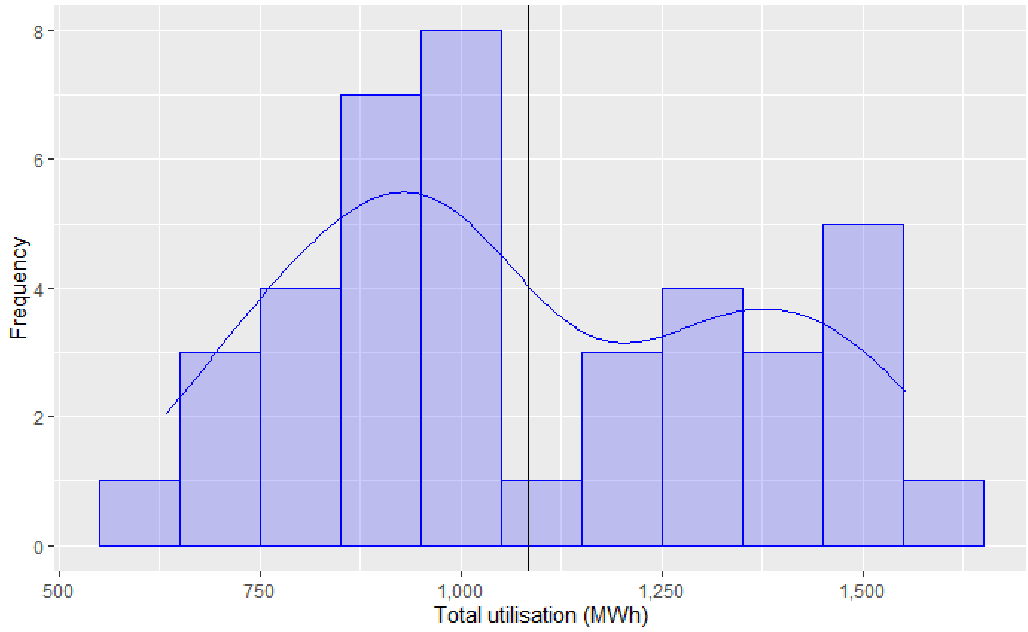

Figure 7: Histogram of the utilisation of the flexibility service requirement within a winter evening peak window, showing the variation across the 40 weather and demand years and the expected value, for Gidlow Primary use case in 2034/35 under the Leading the Way scenario

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[8] The DNO service with the longest procurement horizon is Sustain, and while this is planned to have utilisation only payments, this will be on the basis of a dispatch profile which is fixed in advance. Therefore, this would actually have very limited risk for the service provider – instead, the DNO manages the risk by paying for a service when it may not require it.

4.2.3 Inter-scenario variation

For a known Distribution Future Electricity Scenario, uncertainty in flexibility requirements can be quantified (at least with some degree of reliability and skill). However, in the longer-term, there is also uncertainty between DFES, and the variability between DFES may be greater than the variation within one. The simulation results show that, for some of the DFES, the variation (and therefore uncertainty) *between* the scenarios is greater than the variation and uncertainty within a given scenario.

The figure below illustrates the probability that different levels of annual peak flexibility requirement will be required under each of the five DFES in 2035 for the Gidlow use case, showing the considerable variation associated with the Leading the Way scenario.

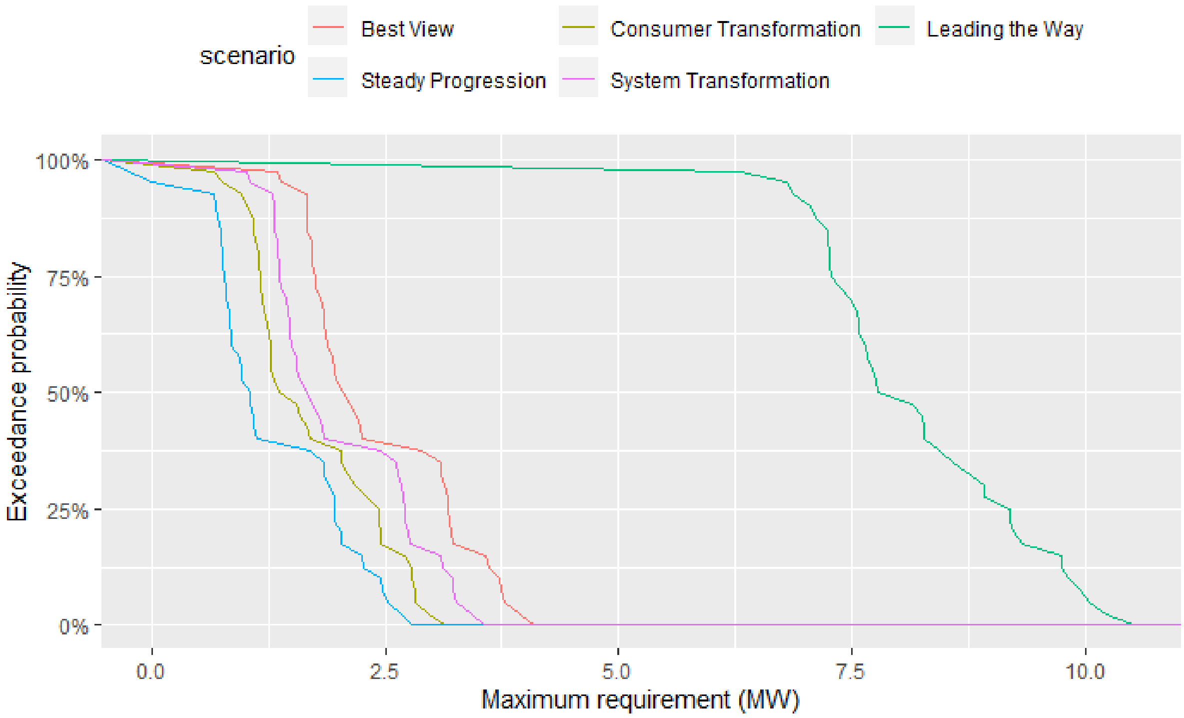

Figure 8: Probability of exceeding different levels of maximum flexibility requirement, showing the variation across the five different DFES, for Gidlow Primary use case in 2034/35

The uncertainty that exists between DFES is much harder to meaningfully quantify. Probabilities could be assigned to these scenarios, but these will be very subjective, and the actual out-come is unlikely to exactly match any single one of these scenarios. In general, the best approach for making optimal decisions subject to uncertainty between scenarios is not settled science. There is precedent in other parts of the energy sector, particularly the use of least-worst regrets analysis in NGESO's Capacity Market Analysis[9] and Network Options Assessment[10].

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[9] https://www.emrdeliverybody.com/Lists/Latest%20News/Attachments/116/Electricity%20Capacity%20Report%202017.pdf

[10] https://www.nationalgrideso.com/document/265621/download

4.2.4 Sourcing flexibility from variable, renewable generation

Variable renewable generation can contribute to requirements for demand flexibility (e.g., through a generation turn-up service), although this adds another source of uncertainty to the management of flexibility. This is similar to the concept of f-factors within the P2 planning standard. The simulated trials have looked at the demand and generation patterns for a specific substation within ENWL's network in a specific year, rather than using a generic f-factor.

The ability of the wind power to contribute to a flexibility requirement for demand depends on the installed capacity of the wind (as well as, of course, its location in the network relative to the network constraints). In the case analysed in this report, an increasing installed capacity of wind can fulfil an increasing proportion of the need for flexibility but, on its own, even a large wind farm won't fulfil the *entire* need for flexibility, and there is a risk that, in some periods, the DNO will need to source additional flexibility from other sources.

The simulation results also show that the likelihood that a DNO will need further flexibility in addition to the wind farm will also vary from year-to-year, depending on whether it is a "high wind" year, a "high demand" year, or both, and depending on the extent to which the timing of the wind output coincides with the timing of the peaks of demand.

In the long-run, this means there is a limit on the extent to which a DNO can rely on variable generation like wind power to meet the need for demand flexibility and, when planning reinforcements or putting long-term flexibility contracts in place, a DNO will need to take this into account in a way which is appropriate, given their risk appetite.

However, in operational timescales, a DNO can rely on the persistence of wind output. If the wind output has been higher in recent periods (e.g., over the last day), then the simulation results show that it is likely that it will remain high in subsequent periods. This might allow a DNO to "stand-down" flexibility services near-to-real-time, or avoid the need to add extra flexibility, when it knows that recent wind output has been high. Skilful and reliable forecasts of wind power output would enhance this further.

An example from the simulations is shown in the figure below, showing how much extra flexibility is needed to meet the requirement on 999 out of 1000 occasions, and how this varies as the installed wind capacity changes, and as the average output over the last 24 hours changes.

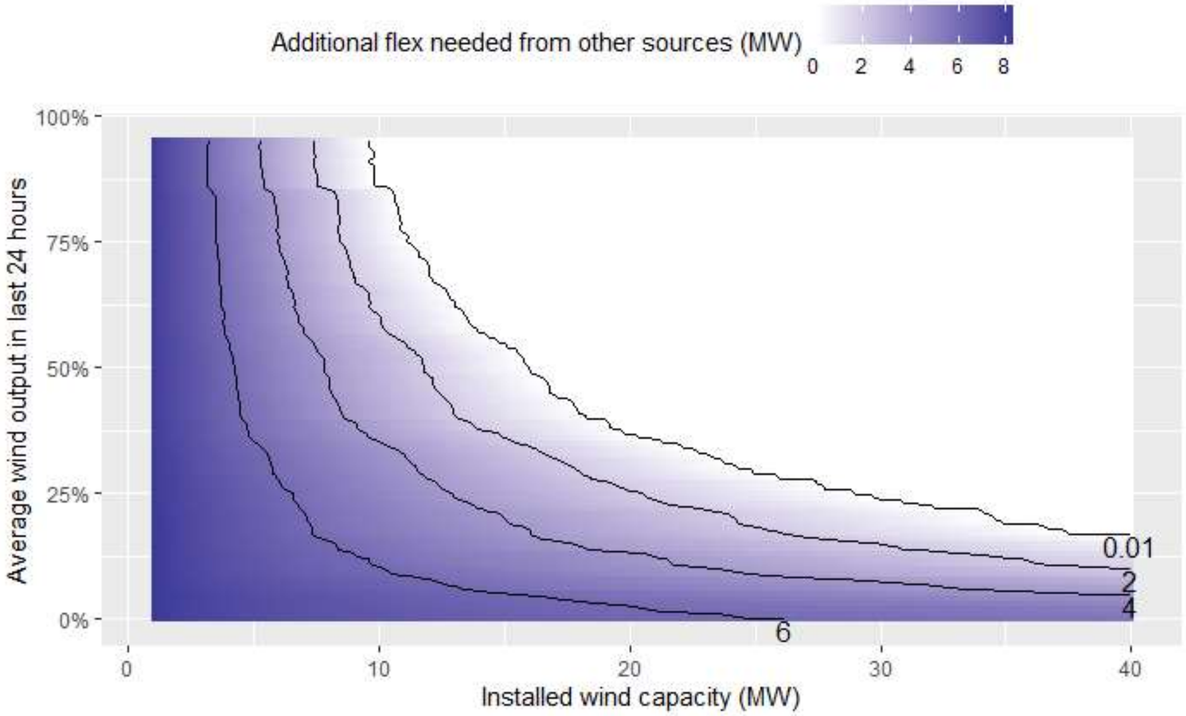

Figure 9: Contour plot showing how the additional flexibility needed to secure the network in 999/ 1000 cases varies as both the assumed installed wind capacity and the 24-hour rolling average output are varied, for Gidlow Primary use case in 2034/35 under the Leading the Way scenario.

This means in principle that variable generation could provide flexibility for demand (e.g., generation turn-up services), particularly at shorter lead-times where they might be able to rely on weather forecasts and persistence of weather. This might prompt some questions about how such generators are considered when the DNO is establishing its flexibility requirements. For example, a DNO might be able to include the output of the wind farm in the short-term operational forecasts which drive its procurement and dispatch decisions, although this might end up introducing different treatment for different types of generators.

4.3 The impacts of short-term uncertainty

4.3.1 Provider reliability

If providers of flexibility services are not always available, or do not always deliver the instructed level of flexibility, then this introduces an additional area of risk for DNOs to manage. This might happen for any number of reasons, including the failure of equipment, or the flexibility service provider choosing to prioritise the delivery of a different service (e.g., transmission level ancillary services) rather than the contracted distribution network flexibility. It might even be a result of network failures from lower voltage levels, if the DNO is using aggregated flexibility.

The prospect of complete unavailability or partial delivery of a service means there is a risk that network assets will become overloaded, or that network security standards are violated, or that a DNO must take other operational actions to stop this from happening (including making other flexibility services available).

Partial delivery may occur with large providers but could also represent a situation where there are a very large number of small providers and some proportion – but not all – of them are completely unavailable. Unavailability (i.e., a service providing none of its scheduled output during some periods) may be more likely if a DNO is relying on just one very large provider where there might be common causes that lead to all of its flexible capacity failing at the same time, or if there are many aggregated providers but all of them fail to provide the service at the same time for some external reason (e.g., they are delivering a transmission ancillary service).

The simulation results show that partial delivery and complete unavailability lead to network assets becoming overloaded (or, becoming non-compliant with security requirements) at similar rates, assuming that flexibility setpoints are given to ensure that network assets are just below their thermal ratings. These results are illustrated in the figure below, which shows how frequently the constrained network assets are overloaded as the probabilities are varied.

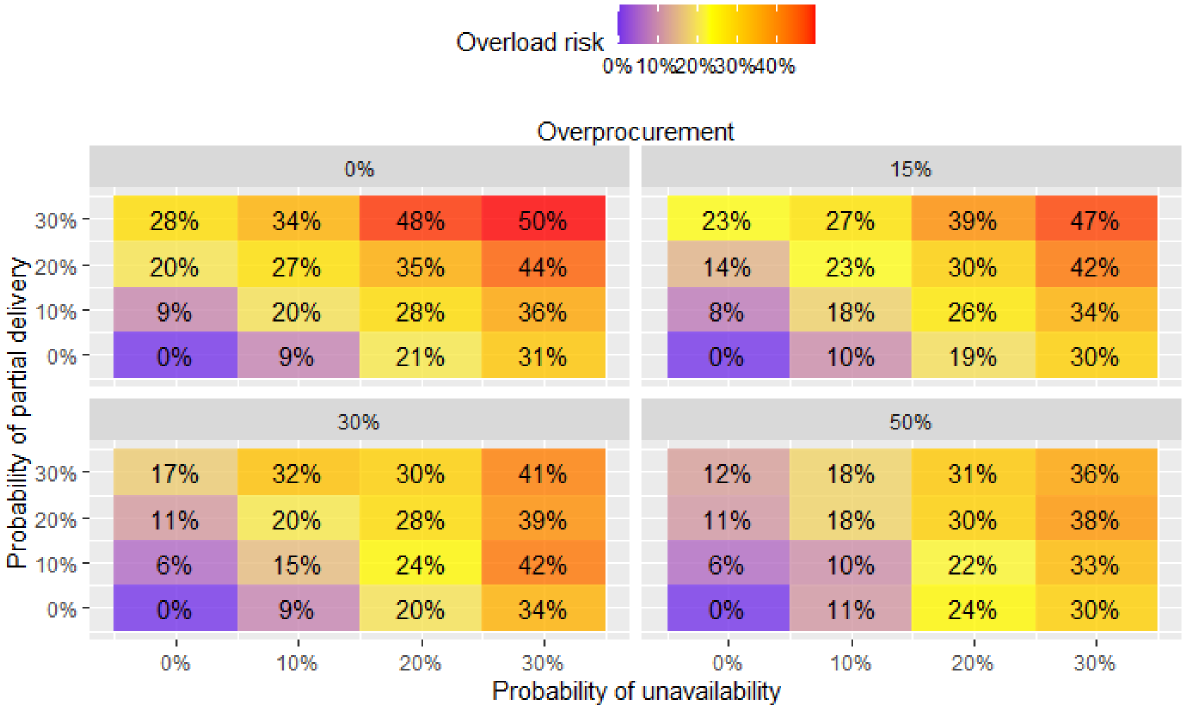

Figure 10: The frequency (probability) of the Gidlow transformers being overloaded under N-1 conditions, varying as the probability of partial delivery and of unavailability are increased alongside different levels of over-procurement, including combinations of both unavailability and partial delivery

However, the magnitude of the resulting overloads could be very different with partial delivery vs unavailability. If a large amount of flexibility has been instructed, and the provider fails to deliver it at all 1 time out of 10, then the results show that this will have a much bigger impact than a provider delivering a partial response 70% of the time. These both have an average output of 90% under the probabilistic models assumed in the simulations, but the impact on the network is very different.

To manage this risk, DNOs can look to incentivise high levels of service reliability through the design of the payment structure[11]. However, they may also need to over-procure and take additional flexibility to protect the network against the risk of unavailability or partial delivery. This can be helpful, but it depends on the nature of the service, and how the reserve is sourced: getting extra flexibility from one provider isn't helpful if that provider fails to deliver at all, but it might provide more protection against partial delivery. In particular, the over-procurement needed to eliminate the risk associated with provider unreliability may be inefficient, or possibly even impossible, to procure.

4.3.2 Forecast errors

Forecast errors will have a similar impact on the network as provider unreliability, requiring a DNO to source extra flexibility closer to real-time or risk non-compliance with network security requirements or the violation of thermal and voltage ratings.

When forecasts have positive errors, and they underestimate demand, then the flexibility need will be underestimated, and issues might arise on the network. When forecasts have negative errors, and they overestimate demand, the flexibility need will have been overestimated, and more flexibility may be delivered than is required. If forecasts are unbiased, and flexibility setpoints are determined to keep assets just below thermal ratings or within voltage limits then (in principle), both of these outcomes should happen with an approximately equal probability. In practice, the finite sample size used in the simulations and a "buffer" (e.g., considering 99.5% of the asset rating) used in the AC optimal power flow when determining the flexibility setpoints (the dispatch volumes for hypothetical flexibility providers) means the overloads frequencies calculated in the simulations are not exactly equal to 50%, particularly for small errors with low correlations where they are lower than 50%.

The impact of the overloads can be very different, though, even if they occur at similar rates. An increasing probability of larger forecast errors leads to an increased risk of overloads that are greater magnitude, even if the risk of an overload is always approximately 50%. Like with reliability, DNOs will need to over-procure reserve flexibility to manage this risk. There are direct parallels with the way NGESO manages the national electricity system, where it ensures reserve generating capacity is available to cover both forecast errors and the risk that generators don't deliver their scheduled output. Over procuring will be more effective if the possible spread of forecasts is smaller (or, to put it another way, less over procurement of flexibility will be required if the evaluation metrics of the point forecasts, like Mean Absolute Error, are better).

In simple cases (e.g., where the constrained network asset only supplies one primary substation), then it is only the spread of the distribution of forecast errors at that primary that affects the risk of overloads. In these simple cases, assets become overloaded approximately 50% of the time. This is because the forecasts have been assumed to be unbiased, which means overestimates and underestimates are equally likely. When the forecast has overestimated, then the loading will be below its rating, but when the forecast has underestimated, then the flexibility will be insufficient, and the asset will be overloaded. Over-procurement can help to manage this and is more effective when the spread of possible forecast errors is smaller.

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[11] TNEI considered payment structures and risk of non-delivery in detail for a different type of flexibility service as part of the Resilience as a Service project. The report is available online at: https://ssen-innovation.co.uk/wp-content/uploads/2021/10/RaaS-WP5-DNO-Business-Case-Review.pdf

However, in more complex cases, where constrained network assets are affected by forecasts at multiple locations (e.g., a constrained BSP transformer which supplies many primary substations), then the correlation between the forecast errors matters too. Correlation of forecast errors leads to the uncertainty distribution of the power flow in the constrained asset becoming more dispersed. This means both very high power flows and very low power flows become more likely as the correlation is strengthened. Since DNOs are risk-averse, they will need to manage the risk of higher flows that this correlation introduces.

An example set of results is shown in Figure 11, where forecast errors have been applied at every separate primary substation below the Kendal BSP transformers, which are constrained under an N-1 condition. Each panel shows a different value for normalised Mean Absolute Deviation (norMAD), which is a measure of how dispersed the possible forecast errors are. Each colour then represents a different level of forecast error correlation. As the spread of the forecast errors (norMAD) increases, the risk of higher transformer utilisations also increases. However, this risk also increases as the correlation between the errors at all the primaries is strengthened.

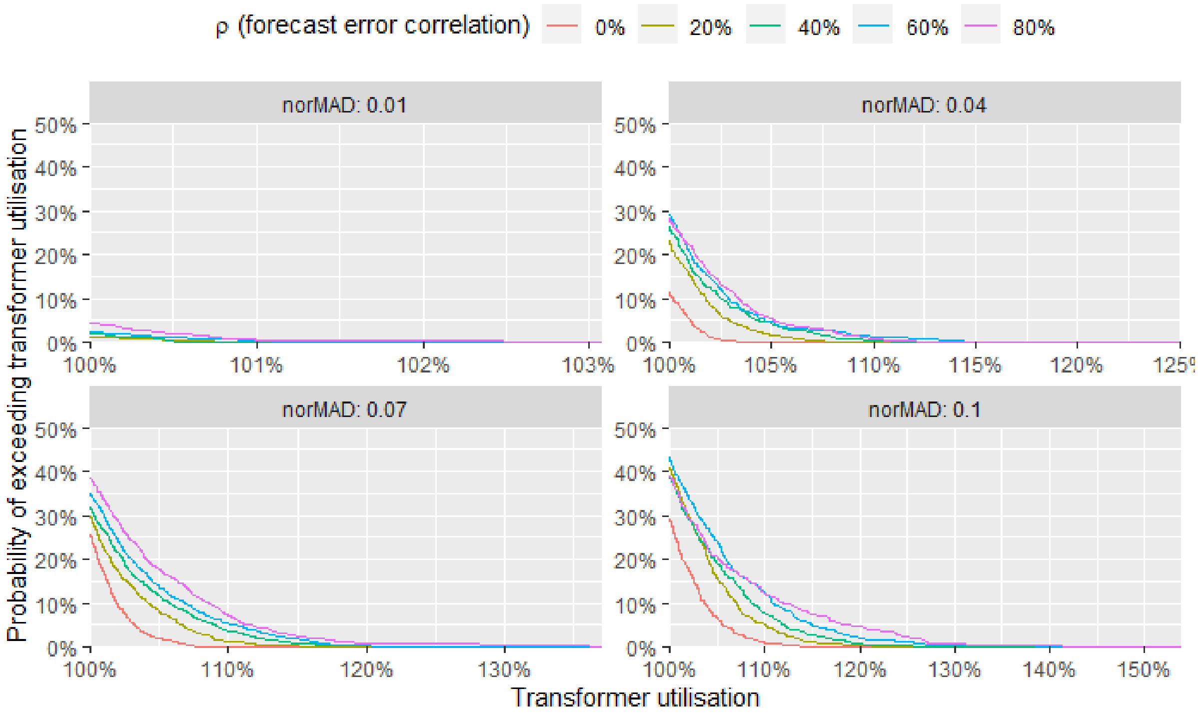

Figure 11: Probability of exceeding different levels of transform utilisation for Kendal BSP under an N-1 contingency, for different values of relative forecast cast error ($norMAD$) and forecast error correlation (ρ)

5 Conclusions and discussions

5.1 Learning objectives

The simulations have satisfied the learning objectives introduced in Section 1.1.

Table 3: Summary of learning generated for each objective

Topic	Objective	Learning
Operational verification	Simulating flexibility services under varying network conditions to verify their operation and benefits.	The use of flexibility services to manage thermal and voltage limits has been demonstrated throughout this work, for multiple use cases and several network models, under a wide range of operating conditions which represent generation and demand patterns out to 2035.
Price behaviour and market/ system interaction	High level insights about how price-forming behaviour in flexibility markets might impact DNO services and, ultimately, on the network, in situations with high liquidity and good availability of services.	The sensitivity analysis in Section 4.1 has demonstrated that some flexibility providers are more valuable than others, depending on where they are located, and that their services might usefully interact in a non-linear way. This section also demonstrated the potential benefit of flexibility from reactive power. Finally, this section considers the impact of simultaneously analysing many contingencies at multiple voltage levels, demonstrating that flexibility services are more valuable if they can relieve multiple constraints at once.
DNO Decision-making	Generating insight about the impact that varying flexibility services requirements might have for decision-making processes.	The results in Section 4.2 have highlighted how year-on-year variation in weather and customer behaviour introduces variation, uncertainty, and risk, in the magnitude of flexibility requirements. This has implications for many aspects of DNO decision-making, like the definition of price ceilings, risk sharing between DNOs and service providers, and the contribution of renewables. Consideration of this variation and uncertainty should be adopted into BAU flexibility decision-making processes.
Provider reliability	Exploring the impact on a network under potential conditions of lack of service provider availability or partial delivery, with such conditions likely to be difficult to control within physical trials.	The results in Section 4.3.1 show that the risks due to periods of partial delivery of a service are, in some ways, like those associated with periods of complete unavailability: both phenomena will introduce risk that network assets become overloaded. However, the risk of higher overloads will be greater with complete unavailability than with partial delivery. This means the latter may be more suitable to management through over procurement of the flexibility service.
Forecast accuracy	Exploring the impact of the inaccuracy in operational forecasts, alongside the tolerance of the flexibility response solutions to different types of forecast errors.	The results in Section 4.3.2 show that, if flexibility services are sized based on point forecasts, then forecast errors will introduce risk of overloads for the network. If these forecasts are unbiased then, in the simplest cases, the network will become overloaded approximately 50% of the time. However, if the spread of possible forecast errors is greater, then the risk of higher levels of overload will also be greater. This means greater forecast errors will be more difficult to manage with over procurement. In more complex cases, the *correlation* between forecast errors at multiple locations will also matter.

5.2 Discussion

5.2.1 Flexibility, uncertainty, and risk

Using flexibility services will change the nature of, and possibly heighten, the uncertainties affecting distribution networks. This will change the risks to which distribution network operators (and, as a result, their customers) are exposed including, for example, risks associated with errors in short-term operational forecasts, which may be large and correlated, and risks associated with providers failing to deliver the volume of flexibility the DNO expected, potentially due to providers delivering other services to other market participants. Some of these sources of uncertainty, like the randomness of customer behaviour and of patterns of weather, already affect network planning, but the impact of these uncertainties could be more pronounced when they affect the amounts of flexibility services which DNOs need to procure. Therefore, DNOs will need to become comfortable and capable in quantifying and managing uncertainty and risk, to ensure the effective and secure operation of their networks when using flexibility services.

Ultimately, customers want high reliability from the distribution network, and therefore DNOs will need to be risk averse. To manage the uncertainties and risks highlighted in this report, it is likely that DNOs will need to regularly make flexibility available that is only used very rarely, essentially as an insurance policy. This is true in the long-term, where DNOs might need to, for example, oversize their Sustain service to protect against risks arising from a colder winter. It is also true in the short-term where DNOs will need extra flexibility to protect against the risk of correlated forecast errors, and partial service delivery by providers.

This extra reserve will come with increased total costs of flexibility availability and potentially utilisation (depending on the payment structure). But it does not provide any extra benefit in terms of the deferment or reinforcement. Therefore, the need for high reliability in the face of this uncertainty means that budgets for flexibility (arising from the benefit of deferring reinforcement) need to be spread across a greater capacity and/or utilisation of the flexibility service, which may erode some of the benefits of using the service.

There are opportunities for DNOs to manage these risks, and potentially reduce the volume (and associated cost) of over-procured reserve flexibility, including:

- A robust end decision-making process that aims to keep total expected costs as low as possible.
- Skilful and reliable probabilistic forecasts could support this by helping decision-makers to understand the conditions that lead to the network being more at risk.
- Payment structures which incentivise high reliability from service providers[11], without discouraging them from taking part in flexibility service markets.

However, one challenge is that not all the sources of uncertainty and risk can be easily quantified.

5.2.2 Benefits of decentralised flexibility

Many of the simulations suggest that there is benefit associated with flexibility service provision being highly decentralised[12]. For example, the results discussed in Section 4.1 showed that it can be beneficial to take flexibility from those locations which are most electrically distant from network constraints as this can have a beneficial effect for network losses. This section also showed that, when there are many contingencies and constraints across multiple voltage levels of the network, it is beneficial to use flexibility sources which resolve many constraints at once, and flexibility services

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[12] The simulations were somewhat limited in scope in that they only considered constraints on some voltage levels (EHV/ HV substation, EHV circuits, and 132kV/ EHV substation), but it is possible that these findings would also apply for lower voltage levels.

delivered at the primary substation can potentially resolve all of these (in an EHV and 132 kV network model), making it very cost effective. The results about short-term uncertainty might also support this, although this requires some speculation about the nature of forecast errors and provider reliability.

At the limit, this might mean that it is most efficient to take flexibility from the low voltage network, directly from domestic and small-and-medium-enterprise customers, particularly if these voltage levels have significant requirements for flexibility. It is possible that these flexibility services for LV networks could aggregate up to provide a significant amount of flexibility for the higher voltage levels, particularly after accounting for the cascading impact of technical losses[13]. More analysis would be required to examine the extent to which aggregated LV services can resolve higher voltage level problems, because this will depend on the topology and capacity of each voltage level and could vary significantly between different networks.

Using a single flexibility service to satisfy constraints on multiple voltage levels is particularly important as it means that a single flexibility service can claim some of the benefit associated with deferring several reinforcements. This could be very important for making the business case for flexibility services as strong as possible. In essence, if a single flexibility service can contribute to the deferment of reinforcement for four circuit voltages and three substation levels, this will have a much higher price ceiling than a service that only defers reinforcement for one of these, although many sources of flexibility will need to be aggregated for this to be effective. This might also mean that flexibility services are harder to justify in areas where only one voltage level is congested.

Another benefit of highly distributed flexibility is that it is likely to reduce the ability of providers to take advantage of locational market power.

5.2.3 Complexity of flexibility decision-making

The simulated flexibility decisions made within this project are very complex and the methodologies and outcomes do not always lend themselves to an easy explanation. This is particularly important in a regulated industry, where stakeholders are reluctant to rely on “black-box” decision tools and processes that cannot be easily explained. The multi-disciplinary nature of flexibility decision-making is also relevant here: the simulations have required expertise on network planning and regulation, power systems engineering, mathematical optimisation, micro-economics, machine learning, probabilistic simulation, and statistical modelling. Complexity in any one of these disciplines can make it very hard for stakeholders and experts from the other disciplines to meaningfully engage.

However, the results of the simulations have also shown that this complexity could be important to acknowledge within decision-making, with examples including:

- The non-linear interactions between multiple flexibility providers within a power network.
- The need to consider many security contingencies and topologies within a single analysis.
- The presence of forecast errors and the correlation between them across a network, which heightens the risk to network operation.

These results demonstrate why it may be beneficial for flexibility decisions to be made in a way that recognises these sources of complexity, as well as others that not been considered in this report. However, there are costs and barriers associated with this, including the computational expense of adopting more sophisticated algorithms and larger networks, but also the burden of having to explain all this complexity to stakeholders, customers, and potential flexibility service providers.

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[13] In their February 2021 losses strategy, ENWL estimated that technical losses on their network are 6% of total energy supplied, with 3.1% of these coming from the LV network and HV / LV substations (see https://www.enwl.co.uk/globalassets/about-us/regulatory-information/documents/losses/losses-documents/losses-strategy---mar-21.pdf)

In general, the end-to-end process by which DNOs will need to make decisions about flexibility services are complicated, due to the many different timescales and decision points, and the way that costs and benefits change at different points[14]. Current approaches for many flexibility services tend to only consider the costs and benefits of many flexibility services in comparison to network reinforcement. However, this is only relevant when making flexibility-decisions on investment planning timescales. Other counterfactual options might need to be considered like allowing some temporary overheating of assets and / or disconnecting customers. In addition, a DNO will have the opportunity to source flexibility services at multiple different time horizons, and at each time horizon they will have varying levels of information at their disposal, as well as different levels of flexibility cost and availability.

It goes without saying that this is a very complicated set of interrelated decisions. These decisions could be streamlined and simplified by various heuristic rules of thumb, policies, and standards. These may need to be continually revised as DNOs increase their use of flexibility services. Some examples include how the failure of flexibility services to provide their response should be considered alongside network contingencies in planning standards, rules of thumb like cyclic ratings, and the generic f-factors that are used to consider variable renewable generation within the P2 planning standard.

5.2.4 Role of complex analysis tools

The real implementation of flexibility services will depend on the interaction of many analytical tools and sources of data. This is comparable to the wide variety of proprietary software tools, open-source programming packages, and data sources have been used to complete the simulated trials. Experience from the process of setting up and running these simulations could provide some lessons for real implementation.

Interoperability between different analysis and operational tools could be critical as it will reduce the reliance on any single algorithm or piece of software to deliver all of the functionality need for flexibility services. For example, the simulated trials have used IPSA for running load flows and an AC Optimal Power Flow algorithm for determining flexibility needs and dispatches, with lots of interaction between these two tools.

The use of standardised data models, such as CIM, can help facilitate the exchange of data between different software systems. Experience from this project has highlighted that the CIM methodology shows a lot of promise but may not account for some of the necessary nuances of various PSA tools. For example, composition of components may vary slightly and lead to inconsistencies which require manual intervention.

In addition, different tools used in different parts of the analysis of flexibility may make very slightly different technical assumptions, or simplifications, which may make it hard to integrate them all into the same workflow. Examples encountered in this work include assumptions about transformer tap steps, the treatment of electrical motors, and assumptions about cable susceptance. While it is inevitable that different software tools may need to make different assumptions, it will be important in implementation that these are documented, so that users may understand any consequential impacts.

Scalability to consider larger networks or more security contingencies is another challenge that has affected the models used in these simulations and will affect similar algorithms in the future. This is particularly important given the previous discussion about the possible benefits of flexibility from the lower voltage level: if it is not possible to practically model this, it may not be possible to implement flexibility that can make the most of these benefits.

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[14] For EHV and 132 kV networks, this complexity is probably comparable to the operation of the transmission network, albeit with a less liquid market for the necessary services, and less historic experience and data about how the flexibility market operates. HV and LV networks add increased complexity due to their scale.

Finally, most of the tools that have been used in these simulated trials have been deliberately developed or set-up to be easily used in an offline simulation mode, by making available re-usable and relatively simple APIs for running them, e.g., through Python scripts. However, in practice, the implementation of tools and algorithms for enabling flexibility service operation might be more focused on getting these running operationally, and it may not be very easy to use them in an offline simulation mode.

5.3 Recommendations

Based on the findings of the simulations, and the discussion in the previous subsection, the following actions are recommended as potentially helpful to support the ongoing efficient implementation of flexibility services on distribution networks.

- Continue to remove the barriers to the provision of flexibility from customers within LV networks, which might include power system modelling challenges (e.g., inclusion of these voltage levels within network analysis), as well IT, commercial, and social challenges.
- Consider the random variation in demand and weather – as done in Section 4.2 - when analysing flexibility requirements within BAU processes.
- Consider how different payment structures affect risk sharing between DNOs and providers. This might include simulations of total payments and costs for providers under different payment structures with the goal of identifying payment structures which ensure high levels of service provider participation in flexibility markets but at lowest possible cost.
- Evaluate the performance and quantify the errors of short-term forecast systems by producing forecasts based on historic data. This can help DNOs to understand what sort of levels of flexibility over procurement might be needed to manage forecast errors.
- Gather and share data on provider reliability to improve quantification of this. Since distribution flexibility services are still quite novel, data on reliability could be quite sparse and, therefore, DNOs may need to work together to maximise the value available from this data.
- Further development of decision-making algorithms to reflect some of the features discussed in this report including integration of information about risks, ensuring scalability for larger models (with more voltage levels and many contingencies), consideration of other operational tools (like network reconfiguration and different types of asset ratings), and the incorporation of more complicated market rules and payment structures.
- Making sure that operational tools are available for offline simulation to help support continuous improvement of policies and practices related to distribution flexibility.