Electricity System Restoration Assurance – 2024 Report

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Acknowledgements

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1 Introduction

In 2021, the authors of this report were engaged by National Grid Electricity System Operator (NGESO) to provide an audit of a model developed by NGESO to assess the time that would be taken to restore electricity supplies on the power system in Great Britain (GB) in the event of a GB-wide power outage, henceforth referred to as the Model. The resulting "Electricity System Restoration Assurance – Model Audit" was submitted to NGESO on February 10, 2022. It contained some key findings and recommendations for the further development and use of the Model. The report was also shared with OFGEM.

In 2023, the authors of this report were asked by NGESO to provide an updated report on the progress made in Model development during 2022. This report was submitted to NGESO on March 29, 2023. It contained seven key recommendations, a comment on the ESO Modelling requirement for DNO boundaries, and four comments on the "2023 Restoration Performance Statement".

Since February 2022, NGESO has taken a number of actions related to the above findings and recommendations.

The objectives of this new report now are:

- To review the progress and the priority setting of the work undertaken, in progress and planned, on restoration modelling as a response to our recommendations plus some model change requests from within NGESO.
- To comment on Model results for NGESO's assessment of 2023 Black Start Restoration Performance.

This report is based on the following documents:

1. The "Electricity System Restoration Assurance – Model Audit" from February 10, 2022.
2. The presentation "Model Audit – Findings and Recommendations" from February 15, 2022, authored by Simon Waters, NGESO.
3. The document "Summary Briefing – 2023 Black Start Restoration Performance" from November 11, 2022, authored by Simon Waters, NGESO.
4. A short report "Restoration Modelling Activities since February 2022" provided by Simon Waters, NGESO.
5. A short report "Restoration Modelling Activities since March 2023" provided by Simon Waters, NGESO.
6. The document "Projections of ESO Glide Slope to 2026 Restoration Standard Compliance" from August 8, 2023, authored by Simon Waters, NGESO
7. The document "Summary Briefing – 2023 Black Start Restoration Performance" from October 26, 2023, authored by Simon Waters, NGESO.
8. The document "Electricity System Restoration Assurance Framework 2023/24", date and author unknown.
9. Some additional information provided by e-mail by Simon Waters as a response to our requests for clarification.

2 Review of Model updates

2.1 Results from previous audits

In order of priority and urgency, our key recommendations from the February 2022 Model Audit were:

1. Clarify the interpretation of ESRS (Electricity System Restoration Standard) targets.
2. Implement a formal process to agree on Model input data.
3. Perform systematic sensitivity analysis with respect to input data.
4. Improve Model documentation.
5. Improve the modelling of demand and distributed generation.
6. Prepare for restoration strategy updates and bold changes to strategy.
7. Revisit the software technology.

One additional work item was added to the work list by ESO as a response to internal requirements:

8. Align the six black-start zones to DNO license areas.

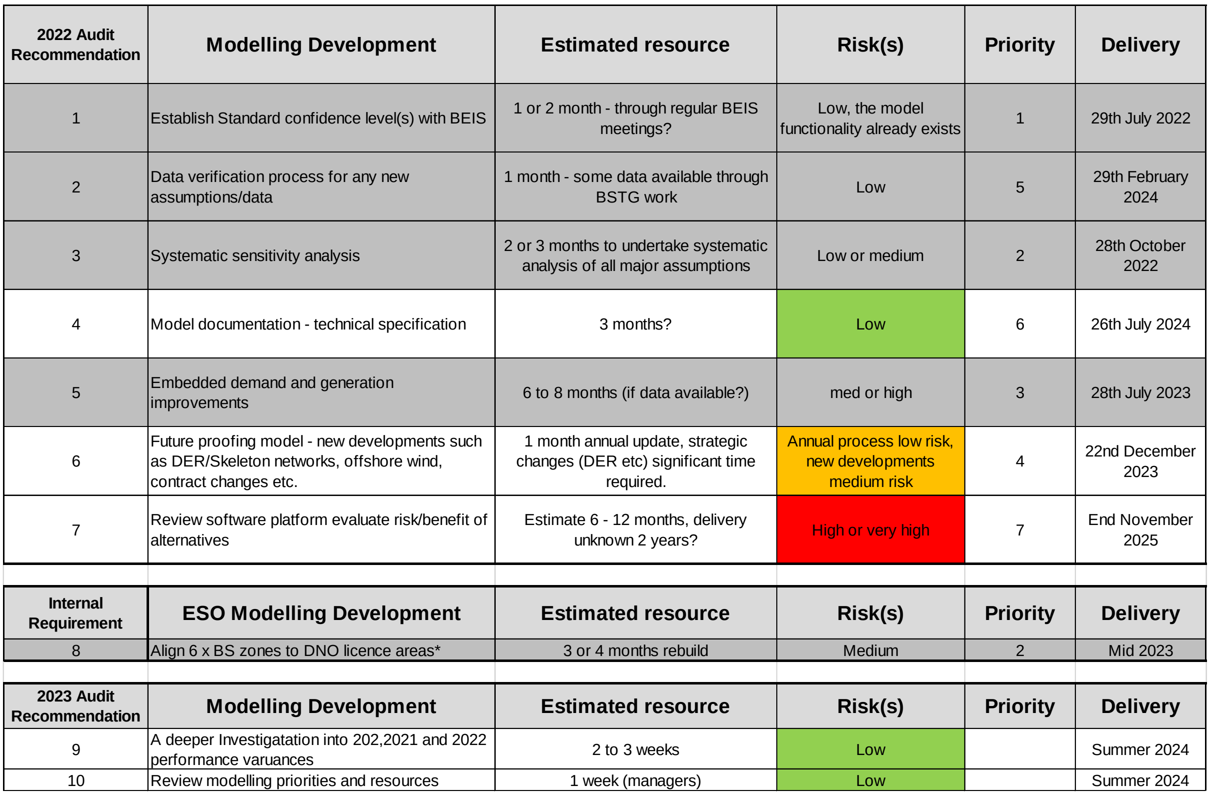
Two further key recommendations resulted from the March 2023 audit:

9. A deeper investigation into 2020, 2021 and 2022 performance variances.
10. A review of modelling priorities and resources.

As a response to the above NGESO has developed a priority order for the individual work items and has started considerable R&D work as shown in Table 1. The table is copied from the document "Restoration Modelling Activities since March 2023".

Items 1, 2, 3, and 5 have already been finalised. Target dates for the remaining work items are set according to the "Delivery" column. We note that item 6, while planned for delivery by December 22nd, 2023, has been completed only in parts, e.g. in respect of potential utilisation of distributed energy resources (DER).

Table 1: Key Work Areas from the February 2022 and March 2023 Audit report



2022 Audit Recommendation	Modelling Development	Estimated resource	Risk(s)	Priority	Delivery
1	Establish Standard confidence level(s) with BEIS	1 or 2 month - through regular BEIS meetings?	Low, the model functionality already exists	1	29th July 2022
2	Data verification process for any new assumptions/data	1 month - some data available through BSTG work	Low	5	29th February 2024
3	Systematic sensitivity analysis	2 or 3 months to undertake systematic analysis of all major assumptions	Low or medium	2	28th October 2022
4	Model documentation - technical specification	3 months?	🟩 Low	6	26th July 2024
5	Embedded demand and generation improvements	6 to 8 months (if data available?)	med or high	3	28th July 2023
6	Future proofing model - new developments such as DER/Skeleton networks, offshore wind, contract changes etc.	1 month annual update, strategic changes (DER etc) significant time required.	🟨 Annual process low risk, new developments medium risk	4	22nd December 2023
7	Review software platform evaluate risk/benefit of alternatives	Estimate 6 - 12 months, delivery unknown 2 years?	🟥 High or very high	7	End November 2025
Internal Requirement	**ESO Modelling Development**	**Estimated resource**	**Risk(s)**	**Priority**	**Delivery**
8	Align 6 x BS zones to DNO licence areas*	3 or 4 months rebuild	Medium	2	Mid 2023
2023 Audit Recommendation	**Modelling Development**	**Estimated resource**	**Risk(s)**	**Priority**	**Delivery**
9	A deeper Investigatation into 202,2021 and 2022 performance varuances	2 to 3 weeks	🟩 Low		Summer 2024
10	Review modelling priorities and resources	1 week (managers)	🟩 Low		Summer 2024

2.2 General remarks on NGESO's action list

As already stated in our 2023 audit report, we understand that the column "Risk(s)" refers to the difficulty of implementation. From a business perspective we again recommend a different approach for risk evaluation focussing on the risk for NGESO and for use of the Model in guiding restoration strategy and procurement of restoration services of NOT solving these work items with the possible consequence that NGESO might not be able to meet UK Government requirements and comply with the restoration standard. From that business perspective high risk work items should have the highest priorities, regardless of how difficult their implementation is.

2.3 Item 1 – Confidence levels

NGESO states that a consensus was reached with the authorities that average values – in terms of assessment of stochastic processes, "expected" values – shall be basis on which they report results on restoration durations. We support this consensus based on the arguments detailed in our 2023 audit report. Item 1 is therefore closed.

However, we still recommend that in future reporting an explanation of the stochastic properties of these average values should be included to avoid misinterpretation by stakeholders. Senior policy makers should be made aware that, if the reported average value meets the set target, the standard might be missed in (if the distribution is symmetrical) half of all scenarios with the potential for a large number of scenarios to result in restoration time significantly longer than 24 hours for 60% of demand in every region or 5 days for all GB demand.

2.4 Item 2 – Data verification process

Due to the rapid development of the electricity supply system as a response to climate change issues and policy to reduce greenhouse gas emissions, regular updating of the database of the Model is of utmost importance. This includes a review of, in particular but not limited to, data of all generation units.

Even though significant progress has been made in data procurement as stated in the document "Electricity System Restoration Assurance Framework 2023/24" ("All parties involved in the restoration process will be expected to provide assurance data and/or test results on a continuous basis") we still want to emphasise that a regular formalised process for keeping the input data of the Model up to date should be established with all relevant stakeholders. This should also include additional data for improved modelling capabilities with respect to distributed restoration resources. Actions should also be backed up by suitable governance and regulatory arrangements to ensure that all relevant parties are clear about the responsibilities and their importance. To enable checking of compliance with such processes, rather than refer to a "continuous basis", it might be better to stipulate provision of updates on an annual basis and to specify the frequency with which key tests should be carried out.

We would also note the following in respect of the Assurance Framework document:

1. An annual review against an Assurance Framework is valuable. However, it seems to us that what has been published under that title reads as a mixture of review against a framework and definition of that framework. In our view, ongoing assurance would be better served by clear definition of a comprehensive, enduring framework in a standalone document agreed by relevant stakeholders with separate annual reviews of performance against that framework.
2. The Assurance Framework document that has been published should have had a named author and a date of publication in order that the validity of the document in an annual process and the timeliness of actions it describes can be easily understood.

2.5 Item 3 – Systematic sensitivity analysis

This recommendation has been thoroughly followed and the results are documented in the report "Projections of ESO Glide Slope to 2026 Restoration Standard Compliance" from August 8, 2023. Some observations are given below in Chapter 4 of this document.

2.6 Item 4 – Model technical specification

We understand that this work item has not yet been started due to lack of resources.

2.7 Item 5 – Embedded demand and generation improvements

We understand that a suitable modelling approach for including embedded generation – commonly referred to in other contexts as distributed generation – from solar and wind power plants has been developed, implemented, and tested. This includes three aspects:

- Demand Update:
  Due to the growing capacity of generation connected to distribution grids, the Total System Demand (TSD) seen from the transmission grid no longer represents the Total Demand (TD) of end users of electricity. In order that the impacts of wind and solar output might be represented separately from end user demand, TD is now used by the Model. A TD value is

created by adding the wind and solar generation in a 30-minute resolution to the TSD. Like the TSD forecast, these wind and solar data stem from historical records that are projected into the future. With the information made available to us we neither can comment on the quality of these forecast data nor on the quality of the data of installed units. However, we understand that these forecasts are made separately for each zone to correctly represent the zonal restoration conditions. From our perspective the general approach taken is reasonable. However, we recommend agreeing on a common set of demand definitions since we have noticed that related terms are not consistently used across the various documents.

- Wind generation:
  Wind generation capacity and availability is distinguished between embedded generation (i.e. connected to distribution networks) and generation connected to the transmission grid, including offshore wind parks. For both it is assumed in the Model that they are fully controllable.

  A two-step approach is followed:
  i) Determine the available wind generation during the restoration process:
     This is done via historical wind speed data which are mapped to a generic turbine model to create power outputs. The statistical data are derived separately for each zone and are transferred to zonal probabilistic functions. To our understanding, by sampling values from these probabilistic distributions, the seasonal characteristics as well as the correlations between zones are lost. It is well known that the correlations between zones are considerably high, and it can be assumed that there is also a strong seasonal change in these distributions. Looking at the growing share of wind generation, we therefore recommend to check whether these assumptions are valid and future-proof.
  ii) Determine the amount of wind generation used during the restoration process:
     For the deployment of available wind generation during a restoration process, a rather cautious approach is chosen. No wind is permitted for islands with less than 1 GW of served load and from 1 GW onwards only 20% of additional sources can be from wind generation. However, in cases where the available generation from wind is smaller than the above limits the entire possible generation at that point in time could be used by the Model. This appears questionable and should be checked against operational policies since an operator would partly lose control in cases where the wind speed reduces further as there would be no upside potential available.

- Embedded solar generation:
  For solar generation it is not distinguished between small roof-top installations and bigger utility connected plants. Both are assumed in the Model to be fully controllable.

  Again, a two-step approach is followed:
  i) Determine the available solar generation during the restoration process:
     Historical time series solar output records are used for each zone which must therefore include correlations between zones. Also, the time of day and day of the year characteristics are kept. For the Model's random black-out moment in the year the historical solar outputs from each zone are derived based on known capacities in each zone.

ii) Determine the amount of solar generation used during the restoration process: Again, a rather cautious approach is chosen, which derates solar output to 50% of the above values since the response of solar sources once re-energised is unknown.

In general, we support the new approach. For the time being it appears a fair compromise between modelling and data acquisition efforts and accuracy. It is therefore a significant improvement compared to the old approach using the TSD.

We welcome the development of a capability within the model to represent the availability of wind and solar power, distinguished by zone and by whether generation is transmission or distribution connected. However, having in mind the expected further strong growth in embedded generation, in our opinion it would be useful to distinguish further between embedded generation resources that are or are not controllable from the TSO control room (with respect to wind) and the DNO control room (with respect to solar). That is the prerequisite to being able to adapt the Model to foreseeable changes in restoration strategies with respect to the employment of embedded generation.

With the information made available to us we can neither comment on the quality of the used forecast data, which add another stochastic variable to the restoration process, nor on the quality of the data of installed units.

For solar generation we recommend to check the Grid Code and Engineering Recommendations in place and related information from vendors of PV inverters to better understand their re-synchronisation and ramp-up characteristics. This is of utmost importance in cases where the installed capacity of solar PV not directly controllable by a system operator may grow beyond the immediate demand after re-energisation, since it can potentially come back uncontrollably and may hinder DNOs' ability to provide the requested block-loads.

It is also important that modelling of the availability of wind and solar adequately reflects seasonal variations and correlations between zones. While this might not be easy to achieve given the way sampling is done in @Risk, the software used for the current Model, it should be done.

The ability to utilise controllable wind and solar power in a restoration scenario should only be used in modelling of years in which a strategy for using such resources can be expected to be fully in place. Moreover, the modelled strategy must be practically deliverable. It is our understanding that it is not in place today and that, notwithstanding progress apparent in the Distributed ReStart project, it will likely take some years to become established. However, regardless of the extent to which controllable distributed resources are used in restoration, all uncontrollable DER should be modelled because of its potentially very large impact on the net load seen from the transmission network[1].

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[1] By 2020, almost 34 GW of generation capacity was connected to the distribution network in Britain. See Gordon, S., McGarry, C., & Bell, K. (2022). The growth of distributed generation and associated challenges: a Great Britain case study. IET Renewable Power Generation, 16(9), 1827-1840. https://doi.org/10.1049/rpg2.12416

2.8 Item 6 – Future proofing for new developments

We want to pinpoint again that, in our understanding, “new developments” may include many more aspects besides the representation of services from smaller distributed energy resources (DER). The Model should be capable of aligning to any foreseeable strategy changes as e.g. the introduction of a skeleton network approach.

2.9 Item 7 – Review of IT platform and dependencies

We understand the difficulties of this work item given the lack of resources. However, we still believe that not migrating the Model to a more easily maintainable software platform constitutes a high medium- and long-term risk from business and licence compliance perspectives. More details are given in Chapter 3 of this document.

2.10 Item 8 – ESO Modelling requirement for DNO boundaries

This task has been successfully finished and the item is closed. We understand that no further work needs to be done if DNO license areas remain unchanged.

2.11 Item 9 – A deeper investigation into 2020, 2021 and 2022 performance variances

See comments in Chapter 3.

2.12 Item 10 – A review of modelling priorities and resources

See comments in Chapter 4.

3 Comments on the 2023/24 Restoration Performance Statement

The “2023/24 Restoration Performance Statement” is a rather high-level summary of the latest developments related to the new ESRS and the results of the “Distributed ReStart” project. The presentation of the latest simulation results is rather short and limited to GB-wide values: no breakdown into regions is given. As such it provides little insight of technical details, modelling aspects, and input data. Therefore, a comprehensive review of the results is hard if not impossible. Instead the following observations are given.

- Figure 3: We are again curious about the large changes in restoration times from 2021 to 2022 and 2022 to 2023. In particular, we wonder about the explanations given, as some of the aspects are not explicitly represented by the Model, e.g. gas supply, delayed contracts, inertia of islands, reactive power provision (the Model doesn’t include a grid representation). Therefore, for us it remains unclear how these aspects have been modelled and the extent to which Model results reflect
    - changes ‘on the ground’;
    - updated information from other parties involved in a restoration process; or
    - changed assumptions.

- We are sorry to state that the Distributed ReStart project, although ambitious, is not the world’s first bottom-up approach to restoration. There have been several other projects and pilots worldwide, in particular the well-elaborated strategy of “KNG-Kärnten Netz GmbH” in Austria[2].

- Unfortunately, for the development of a Restoration Decision Support Tool, only very limited technical details are given. Having in mind the results from the parameter analysis (see Chapter 4) we believe that these tools are of utmost importance to meet the new ESRS targets. If properly designed, these tools will not only support the operators in finding optimised restoration paths but will also reduce the risk of a further island collapse during the restoration process. They are therefore a prerequisite for implementing more aggressive strategies to reduce the duration of the restoration process. However, they are also very complex to develop with similar projects in other countries taking years to come to fruition. We would therefore welcome information on the ESO’s estimated timelines for development of such a tool for GB. This would give confidence about the practical support for future restoration strategies such as might be represented within the Model.

- For the presentation of results, we again strongly recommend the inclusion of a more detailed explanation of the probabilistic nature of the process and the implications of having agreed on average values for target setting and reporting – see our comments in section 2.2 of the 2023 Audit Report.

Based on the 2023/24 Restoration Performance Statement, there seems to currently be a lot of interest in new strategies for restoration. In order to verify any strategy changes, the development of the Model should keep pace with or, better, be ahead of the decision-making and implementation of these changes. That might require the re-implementation of the Model into a more maintainable IT-environment. With the given limited resources, the difficulties in recruiting, and the relatively short time span of 2026 for completion, we are wondering whether it is reasonable to assume that all this work can be done in due time.

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[2] See, for example, RestoreGrid4RES (ffg.at) and PR_Polster.pdf (tugraz.at)

4 Comments on the 2023 report “Projections of ESO Glide Slope to 2026 Restoration Standard Compliance”

In our 2023 audit report we recommended the ESO to undertake a wider set of sensitivity analyses to help identify key pinch-points and also focus the data acquisition process on topics of high impact.

With the August 2023 report our recommendations have been thoroughly followed and we believe that this report is very useful in both respects. In addition, the results can also support strategy discussions in order to meet the 2026 targets on restoration performance.

Our intention when asking for this sensitivity study was predominantly on focusing Model development and data acquisition efforts on those aspects which show a dominant impact on results. We believe that the report fully satisfies this intention. In the document possible strategy changes are also discussed in order to meet the set restoration duration targets. Our feeling is, that for a strategy discussion, the results of the parameter study are still very valuable but might be insufficient because a couple of important options cannot be represented by the current Model or haven’t been studied. Further details are discussed below related to the specific topics.

In Chapter 1 of the report 11 levers for advancing and preserving restoration performance are listed. They are mostly about improving failure probabilities, reducing the time needed to perform specific actions, and adding resources. We want to point to the following additional aspects, which are also under discussion internationally:

i) Changes in restoration strategy:
  - There are policies in place, where starting from a few black-start units, a so-called skeleton grid is built which spans larger areas. This skeleton network is energised rather quickly without any load but enables energisation of a greater number of substations and hence provides cranking power to non-BSUs and allows DNOs to start their resupply processes simultaneously. Note that careful planning and the provision of reactive power support are preconditions.
  - The policy for re-synchronisation of islands and zones offers optimisation potential: early resynchronisation helps to build stronger islands with higher inertia and hence allows for higher block-loads. On the other hand, a tripping event may cause the collapse of bigger islands and hence increases the risk.

ii) Improvements in operator tools and automation:
  - Advanced operator tools for restoration may help to speed up the restoration process and to reduce the risks of a further collapse. These tools my include awareness functions, security checked switching (including the calculation of a frequency response) and decision support tools (in terms of offering a pre-calculated selection of most suitable next actions). Note that parts of these functions must be implemented at the DNOs’ control rooms.
  - Changes in TSO-DNO co-ordination may also contribute: while the TSO remains responsible for the overall system security, the DNO may gain more responsibility in re-energising demand and managing distributed resources. A key element is to change from block-load requests to a negotiated active-power exchange bandwidth between the grid voltage levels. Note that parts of or the entire bandwidth could also be negative in cases where significant generation is available at distribution levels.
  - An improved level of automation of the re-energisation process at DNO control centres has the potential of speeding-up the process while reducing the risk of human error.

In addition to the above general remarks, we want to provide the following comments to the results of the parameter studies:

- Variables explored: we recommend a study of the effect of the size of block-loads. The basic idea is that with growing islands their frequency stability increases. Therefore, the size of block-loads could be increased as the restoration process progresses. This reduces the number of switching actions at the DNOs and hence the duration and the risk[3].
- The study on reduced block-loading intervals shows the high impact of this parameter. Unfortunately, from the information we have received we don't fully understand what is really being done today and whether 15 minutes for each block load is a reasonable approximation of how the process would be implemented in reality. Also, we want to better understand the control of generators at each step, how active power points are determined and how frequency is regulated. (Does a DNO just look at system frequency when deciding to switch? Does the 15 minutes include generator ramping?)
  It might be useful to further investigate this topic since, relative to contracting with additional BSUs, it is a low-cost high-impact measure. Careful TSO-DNO co-ordination is key to leverage this option. However, we would not recommend the TSO to devolve overall system responsibility to DNOs or generators.
- We partly disagree with the statement related to the generation, control function and switching resilience. It is true that an increase of resilience beyond 72 hours (3 days) has no significant benefit for the target of 60% load restoration, provided critical supplies enabling further restoration steps – substation and generator controls, communications and so on – can be guaranteed to be reconnected in the earliest stages. However, it still might have a high impact on the restoration of 100% of the load. This aspect needs further investigation.
- Results on Telecoms performance/resilience: we assume that the presented results strongly depend on the non-linear function between imperfect communication and instruction delays. Since we have no information about this function we cannot comment on the study results.
- Quality of Restoration Strategy and Operational Decisions: since we do not understand the type of assumed errors and their consequences, we feel unable to comment on the study results.
- Delivered automated DER Service: in our view, a contracted firm power output from a DER for the entire time span of the restoration process is a high hurdle, in particular if weather forecast data might be deteriorated under black-out condition. We therefore recommend to investigate the option that a guaranteed but time dependent output, e.g. in 1 hour time steps, might facilitate higher utilisation of DER resources in the future. We also recommend that these offerings should be contracted and aggregated by the DNOs if they are connected to the DNOs' grids.

Notwithstanding our above comments we fully support the conclusions given in Chapter 8 "Results Summary" of the document.

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[3] Typically, the breakers in sub-transmission and distribution networks remain closed when a system collapse develops. Hence, the DNOs first have to open all breakers before they can start to re-energise their networks step-by-step and provide block loads. The risk is that some breakers remain closed by human error. If there is a clear strategy in place about the size *and* the location of block loads, then the blocks can be built in advance and not all breakers need to be opened.

5 Conclusions and recommendations

With the limitations of the resources made available to it, the approach taken to compile the “2023 Restoration Performance Statement” appears fair and reasonable. We again recommend a closer look at the reasons for the changes in results of years 2021 to 2022 when the average time to restore GB-wide demand decreased, and 2022 to 2023 when the restoration time increased. We believe it is important to understand their drivers (whether they reflect real-world changes or modelling and data upgrades).

Regarding the long-term perspective, we recommend a review of setting of priorities among the Model maintenance, documentation, and development work items and, accordingly, an adjustment of the resources made available. Priorities should be set in line with the impact for modelling of restoration, not simply in terms of ease of carrying out the action.

We recommend a careful check of the assumptions made for the representation of embedded generation, in particular related to the non-controllable resources such as small solar. Embedded generation now represents around 40 GW of capacity. This portfolio is very likely to grow. It is essential that it is modelled well.

The volume of wind generation capacity, both transmission connected and embedded, is so large – and growing – that its use in restoration represents a significant opportunity. However, it must be modelled accurately, taking proper account of how availability of power varies seasonally and is correlated between zones.

We recommend a careful check of the assumptions made for the time and the size of block loads as it can be assumed that they have the highest impact on the restoration duration.

We recommend to separate the annual reporting into two documents, namely a description of the framework (which is more stable over the years) and a separate document on the simulation results and compliance with the framework.

With the ongoing discussion on strategy changes it should be made clear which simulation results reflect the restoration strategies currently adopted and in place. In addition, “what if” studies – clearly identified in reporting of Model results – are recommended to better understand the impact of improved policies or strategy changes. The assumptions used in how new strategies are implemented must also be explained clearly.

Appendix: Terms and definitions

BSU	Black-Start Unit
DER	Distributed Energy Resources
DNO	Distribution Network Operator
ESO	Electricity System Operator
ESRS	Electricity System Restoration Standard
NGESO	National Grid Electricity System Operator Limited
OFGEM	Office of Gas and Electricity Markets; Great Britain’s independent energy regulator
TD	Total Demand
TSD	Total System Demand
TSO	Transmission System Operator