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Net Zero Innovation
National Grid Electricity Transmission

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

nationalgrid
Electricity Transmission

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Disclaimer

This report provides a candid assessment of the author's experiences drawing comparisons to the Australian electricity supply industry. Statements and material contained within this report (except where explicitly referenced) are the expressed opinion of the author and do not relate to any person or organisation associated with the author. Any reproduction or referencing of this report should reflect this.

Abbreviations

AEMO	Australian Energy Market Operator
AI	Artificial Intelligence
DMAT	Dynamic Model Acceptance Test
ENA	Energy Networks Association
ESME	Energy System Modelling Environment
ESO	Energy System Operator
ETDP	Engineering Transmission Design Principles
ETO	Energy Transition Outlook
EV	Electric Vehicle
FES	Future Energy Scenario
FSO	Future System Operator
GB	Great Britain
IBR	Inverter-Based Resources
IDD	Infrastructure Development and Delivery
LW	Leading the Way
NET	Navigating Energy Transitions
NG	National Grid
NGED	National Grid Electricity Distribution
NGET	National Grid Electricity Transmission
NGP	National Grid Partners
NGV	National Grid Ventures
NIA	Network Innovation Allowance
NZI	Net Zero Innovation
Ofgem	Office of Gas and Electricity Markets
PPC	Power Plant Controller
RESO	Regional Energy System Operator
RIIO	Revenue = Incentives + Innovation + Outputs
SIF	Strategic Innovation Funding
V2G	Vehicle-to-Grid

Executive Summary

The global energy sector is undergoing a significant and exciting period of change as we transition to a net zero carbon future. UK transmission and distribution service providers have published various future energy system predictions (known as Future Energy Scenarios or FES) to help inform current day network investment decisions, policy changes and carry out innovation accordingly. Whilst these future scenarios equally achieve net zero, they are diverse in technology uptake, consumer behaviour, regulation and government policy, renewable generation mix etc. further emphasising the level of uncertainty ahead of us.

The complex nature of the future energy system and how its various elements interact with each other requires 'Whole System' thinking, which involves collaboration with other network licensees and participants in the wider industry. I am excited to be working as an Innovation Engineer in the Net Zero Innovation Team at National Grid Electricity Transmission (NGET) as my first placement. More specifically, my primary responsibility is to look after the Whole System portfolio of projects which has given me exposure to a diverse array of technologies and services that are strategically designed to benefit our networks whilst also delivering best value to customers.

This report delves into two key themes: the first focusses on the evolving modelling capabilities within the energy sector for both power systems and whole system and the second explores efforts to accelerate customer connections to the network. More specifically, it examines the applications and purposes of EMT modelling across both the UK and Australia and whole system modelling tools such as PLEXOS, which is widely used for capacity expansion and market dispatch modelling. Finally, it summarises efforts, at both transmission and distribution levels, to manage the growing backlog of customer connections to the electricity grid.

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Power Systems Modelling Capabilities

Power system modelling in Great Britain (GB) and Australian utilities share many foundational similarities but also display key differences due to their unique grid structures, regulatory environments and energy transition strategies. The UK uses many of the same power system analysis modelling tools to perform load flow, fault level, dynamic stability and harmonics studies. Some of these well-known commercial products include DIgSILENT, ETAP, IPSA PSS/E and PSCAD.

In Australia, the requirement for generators to submit PSCAD EMT models was formally mandated in July 2018.This requirement was established through updated Power System Model Guidelines by the Australian Energy Market Operator (AEMO) to highlight the need for high-fidelity modelling due to increasing integration of IBR and detailed system strength assessments. Prior to this, PSCAD modelling was typically reserved for exceptional cases where traditional RMS models were insufficient. AEMO also introduced the Dynamic Model Acceptance Test (DMAT) Guideline in February 2021, which specifies rigorous testing procedures for PSCAD models. These procedures involve extensive simulation tests to validate the dynamic performance of generating systems, ensuring their reliable integration into the National Electricity Market (NEM).

During early 2023, the National Grid ESO enforced strict requirements around the EMT studies to be performed for any generation connected plant, which was driven by the August 2019 blackout in the UK. As a result of this change, manufacturers are now required to prepare and submit a PSCAD EMT model for verification purposes by the National Grid ESO. These changes are not significant for inverter-based generation such as solar, storage and wind as equipment suppliers typically already have detailed models of these inverters and the PPC. National Grid ESO has also enforced further guidance for synchronous machines and induction machines (i.e. combustion turbine generators, steam turbine generators, hydro generators and certain types of wind turbines). These requirements include the need to [1]:

- Represent the mechanical rotating mass of the given generator as a single lumped inertia as used in transient stability. Furthermore data such as inertia constants, shaft spring constants, torque share between different masses and damping should be provided.
- Represent the generator excitation system as a user written PSCAD model. If standard block models are used in PSCAD to achieve this, then manufacturers are required to confirm the model is representative of the excitation system in transient simulations (10-20 micro-second time step).
- Represent all protection systems in detail associated with balanced and unbalanced faults.

Australia vs. UK Comparison

Australia appears to be more advanced in terms of EMT modelling capabilities due to two main reasons. Firstly, Australia has higher inverter penetration particularly in South Australia and Queensland which have among the highest shares of rooftop PV and grid-scale renewables in the world. Secondly, weak grid conditions in Australia, particularly due to long transmission lines and low system strength, has meant traditional RMS models are inadequate.

EMT modelling in Australia is now deeply integrated into planning, operational security, and connection approval processes which aligns with the operational needs of AEMO and regulatory requirements. The UK has also adopted EMT modelling as well although the urgency is slightly different. While there are significant levels of wind and solar, its system is still stronger and more meshed than in Australia, especially in England and Wales. EMT studies are used more selectively and often for studying HVDC systems (such as interconnectors to Europe) or assessing the impact of grid-forming inverters as part of future network strategies (e.g. ESO's "stability pathfinder" projects). The ESO and National Grid are increasingly adopting EMT tools for future-proofing the network as synchronous inertia continues to decline.

Whole System Modelling Capabilities

Whole system modelling is becoming increasingly important in combination with traditional power system analysis due to the evolving complexity of the electricity grid. Power system analysis tools have historically focused on the electricity grid alone which was predominantly comprised of stable and predictable infrastructure. The rapid integration of renewable energy sources, electrification of other sectors (like transport and heating), and the decentralization of energy production have significantly increased the interdependencies between various parts of the wider energy system. As a result, it is no longer sufficient to analyse the electricity system in isolation when planning the future network architecture.

Modelling practices need to include the interactions across electricity, gas, heat, transportation, and even water systems to capture the broader picture of energy flows, emissions, economics, and resource use. This holistic approach is essential for identifying synergies, trade-offs, and potential bottlenecks between systems that might not be apparent when analysed separately. For instance, the impact of widespread electric vehicle adoption not only affects electricity demand patterns but also creates new opportunities for grid balancing through vehicle-to-grid technologies.

PLEXOS

PLEXOS is a leading energy system modelling platform used in both the UK and Australia to simulate electricity markets, plan future generation and transmission infrastructure, and evaluate decarbonisation pathways. It uses mixed-integer linear programming to optimise energy system decisions across multiple timeframes i.e. from long-term investment (years to decades) to short-term operational dispatch (down to 5-minute intervals). The tool models how generation assets, storage, interconnectors, and demand respond to prices and constraints in a competitive market environment. Typically, within NG ESO, PLEXOS applications are over the long-term i.e. beyond 2031 to simulate the build out of generation and storage of electricity supply on a transmission level. Distribution connected electricity supply beyond 2031 is calculated separately using bottom-up assumptions. Vectors that are modelled within PLEXOS are summarised in Figure 1.

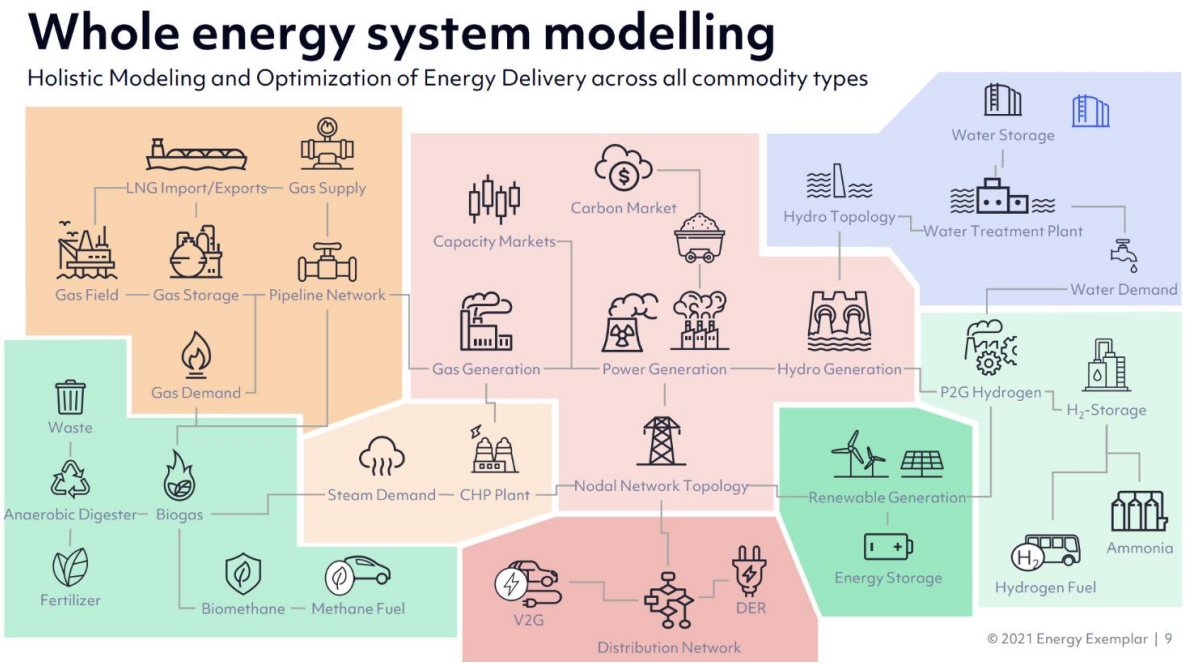

Figure 1 Cross Vector Modelling in PLEXOS [2]

In the UK, PLEXOS is widely used by National Grid ESO, Market Analytic teams (such as within NGET), consultancies, and research institutions to support whole system planning and decarbonisation strategy. For example, National Grid ESO has used PLEXOS in its Future Energy Scenarios (FES) to simulate how various mixes of low-carbon technologies (e.g. offshore wind, nuclear, storage, and interconnectors) can meet long-term emissions targets. These models evaluate

trade-offs between system costs, flexibility, and reliability. The type of outputs produced by PLEXOS includes time-series dispatch plots, marginal pricing trends, and capacity expansion pathways.

For example, the PLEXOS Capacity Expansion Model (CEM) for electricity and hydrogen supply uses transmission connected generation and storage (which meet net zero targets in the long-term) to achieve a least-cost design. It ensures the firm capacity of all generation plants meets peak demand (with an additional 4% to ensure generation capacity mix is suitable for multiple and more extreme weather years). The dispatch (production) model takes in all input data from the baseline year and out to 2050 and optimises system cost with constraints applied in the background. Parameters considered in this model include existing and future assets, techno-economic parameters, demand profiles, various flexible demand archetypes, renewable weather profiles, market-related prices, operational constraints etc. [3]

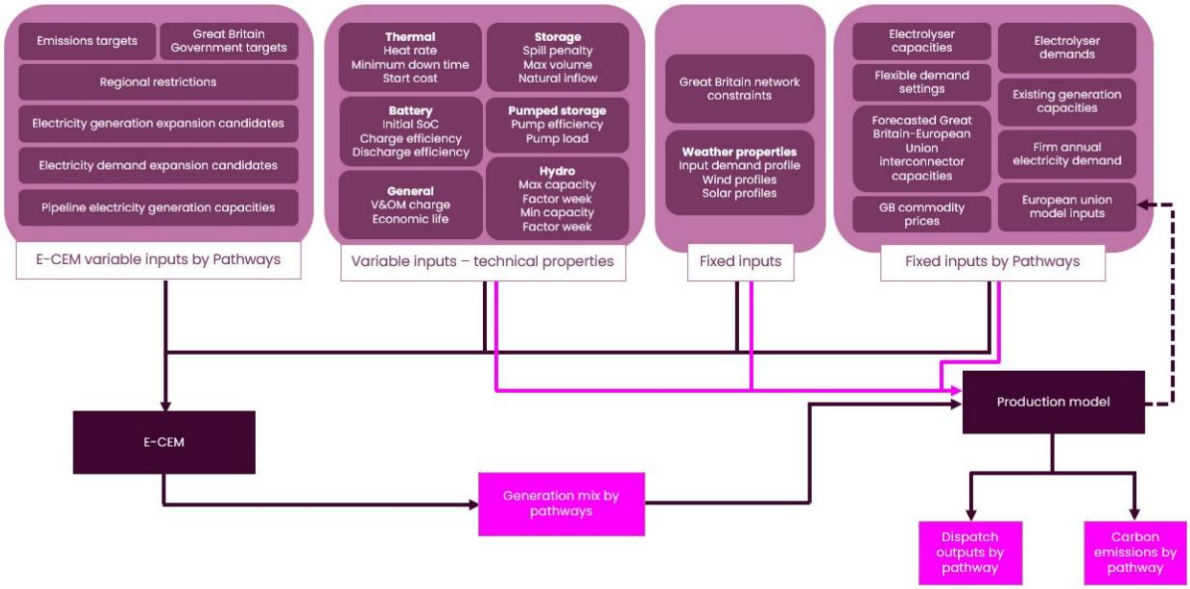

Figure 2 Electricity Supply Process [3]

In Australia, PLEXOS is central to national energy planning and is used by the Australian Energy Market Operator (AEMO) to develop the Integrated System Plan (ISP). In the 2022 ISP, PLEXOS was used to identify the least-cost combination of renewable generation, storage, and transmission needed to support Australia's energy transition. The model informed decisions about major infrastructure projects such as EnergyConnect and the development of Renewable Energy Zones (REZs). The optimisation process captures both technical constraints and policy requirements [4].

While both countries use PLEXOS for strategic planning, its role in Australia seems to be more deeply embedded in regulated investment decision-making, whereas in the UK it is typically used in advisory, scenario-based (such as the FES) or academic contexts. In both cases, the software supports whole system thinking by enabling planners to model the interactions between generation, storage, transmission, and demand under different market and policy conditions. Its outputs are instrumental in evaluating the economic, technical, and operational impacts of future energy system designs.

Other Whole System Modelling Tools

Energy System Modelling Environment (ESME)

The Energy System Modelling Environment is managed by Energy Systems Catapult (ESC). The ESC is an independent, not-for-profit innovation centre set up by the UK government to provide technical, commercial and policy expertise to network operators, industrial sites, energy companies etc. with the goal of achieving Net Zero.

ESME integrates power, heat, transport, and industrial sectors, considering infrastructure requirements such as electricity and gas networks, as well as carbon capture and storage systems. It employs a

least-cost optimization approach to identify decarbonization strategies that meet constraints related to emissions targets, resource availability, technology deployment rates, and system reliability. The model operates on five-year time steps from 2010 to 2050, offering spatial resolution across 12 onshore and 12 offshore UK regions [5].

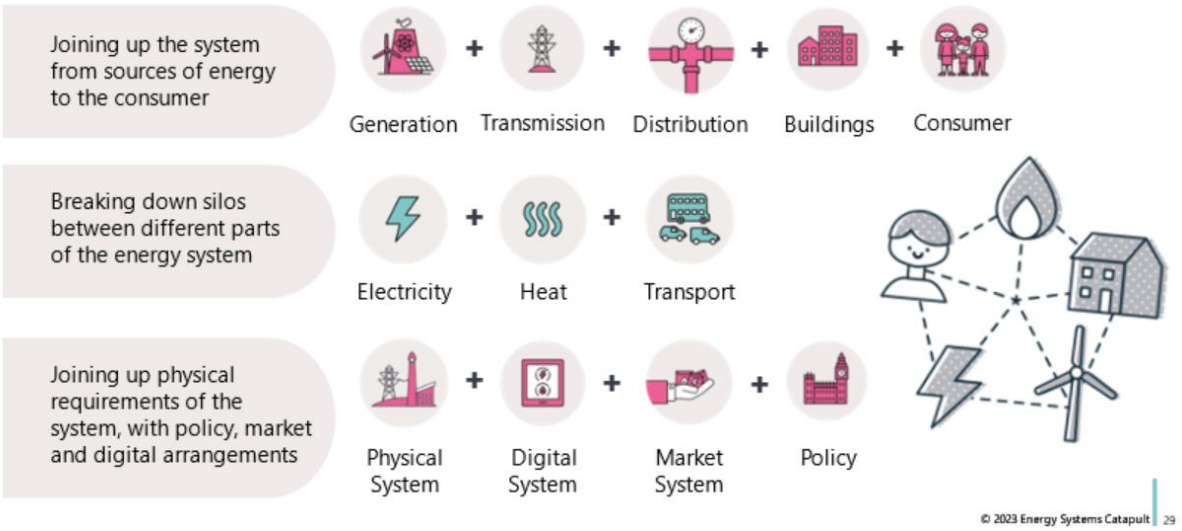

Figure 3 ESC Whole System Thinking [6]

ESME has been used heavily to inform UK energy policy, including the Climate Change Committee's carbon budgets and the Department for Energy Security and Net Zero's long-term planning. It has also supported private sector investment decisions and academic research. The model's capabilities have been enhanced with the development of ESME Flex, which provides detailed hourly dispatch modelling to assess system flexibility and operational dynamics under various scenarios. ESME is typically also leveraged in innovation projects as necessary to assess the feasibility or impacts of a given technology in the Net Zero context.

Energy Transition Outlook (ETO)

The Energy Transition Outlook is DNV's flagship annual report offering a comprehensive independent forecast of the global energy landscape through to 2050. Unlike ESME or PLEXOS, it is not a modelling environment and is simply a forecasting product. It models the shift from fossil fuels to renewables, analysing energy demand, supply, technology adoption, emissions trajectories, and investment trends across ten world regions (including Australia). The ETO is mainly targeted towards policymakers, industry leaders, and investors seeking data-driven insights into the pace and structure of the energy transition.

For example, the report warns that the decline in emissions will be too slow to meet the Paris Agreement's 1.5°C target, with the most likely scenario pointing to a 2.2°C temperature rise by 2100. While renewables are expected to supply half of the world's energy by mid-century, "hard to decarbonise" sectors like heavy industry and aviation are falling behind, and technologies such as hydrogen and carbon capture are developing more slowly than anticipated [7].

These insights help stakeholders across the industry to align strategies with realistic, evidence-based scenarios to manage challenges and opportunities of decarbonisation.

Neptune

Neptune is an in-house tool for National Grid Electricity Transmission (NGET) aimed at exploring and evaluating multiple decarbonisation pathways to achieve the UK's Net Zero target by 2050. This tool enables DC power flow analysis on a zonal model of the network and is designed to assist in strategic planning by considering various scenarios and their implications on the electricity system. By analysing different routes to decarbonisation, Neptune supports NGET in identifying the most effective strategies for reducing carbon emissions across the energy sector [8].

Accelerating Connections

As the UK accelerates its transition to a low-carbon energy future, the number of customers seeking to connect to the electricity transmission network has grown exponentially. Large-scale wind farms, solar farms, battery energy storage, hydrogen production and data centres all depend on timely and reliable grid connections to operate. To keep pace with the scale and urgency of change, *accelerating customer connections* has become one of the Net Zero Innovation Team's strategic objectives as of this year.

The CP2030 Action Plan details the Government's intentions to achieve 95% carbon-free electricity by 2030 as an intermediate step before moving towards a net zero UK economy by 2050 [9]. Over 40% of all new generation capacity holding transmission connection agreements have connection dates of 2030 or later [9]. The contracted capacity also exceeds the ESO's predicted total future generation, as given in the FES. As such, the Government and other stakeholders in the industry agree a connections reform is essential to meet 2030 and 2050 clean energy targets in a timely and cost-effective manner.

The connections process should enable viable projects to connect as per the required timeframes and the required pathways to net zero. In order to unlock more capacity on the network, the RIIO regulatory price control is enabling strategic investment in network infrastructure to ensure network is built ahead of need. Some of these network infrastructure upgrades and programs are outlined in documents such as the Holistic Network Design (HND), Accelerated Transmission Strategic Infrastructure (ASTI) etc.

The transmission connection queue now exceeds 400 GW, more than three times the UK's peak demand, placing immense pressure on the traditional "first-come, first-served" process [10]. This volume requires a fundamental rethink of how readiness is assessed, how capacity is allocated, and how grid reinforcements are planned. Ofgem, the ESO, and other network companies support the need for connections reform as infrastructure investments and upgrades alone will not enable 2030 and 2050 net zero targets. The objective is to see electricity connection offers, at both transmission and distribution, with shorter average connection dates which better meet customers' needs and enable a timely transition to net zero.

There is also an agreement that communication with customers should be improved such that they receive consistent customer service and are well-informed and supported to make effective and realistic decisions regarding their application. As such, accelerating connections through innovation includes improving both network capability and customer experience. To help achieve these ambitions, the ESO and network service providers have set more transparent milestones, clearer timelines and are working together more collaboratively with the following goals:

- To significantly reduce the difference between requested and offered dates at both transmission and distribution level.
    - For net zero aligned projects, transmission connected dates are to be on average no more than 6 months beyond the requested date.
    - A majority of the projects are to receive the requested connection date. Currently only 14% of projects are considered to be on-time.
- The pipeline of anticipated projects and their corresponding connection dates are to align with net zero targets. The relevant teams across Network Planning, Construction and Connections for example are to work with each other closely to enable this.
- Current initiatives as summarised in the ESO 5-point plan (detailed in following section) should unlock 100GW of capacity which in fact is more than the current installed capacity on the transmission network. It is anticipated that connection dates should be improved by 2-10 years [11].
- Similar to above, the ENA's 3-Step plan will enable 39GW of capacity to be unlocked on a distribution level [12].

Accelerating Transmission Connections

The ESO has adopted the following strategies (i.e. the 5-point plan) to address the growing backlog of projects awaiting connection to the Great Britain transmission grid [11].

1. Transmission Entry Capacity (TEC) Amnesty

The transmission entry capacity is essentially the maximum amount of electricity a generator is allowed to export onto the transmission system. The TEC Amnesty allowed developers to voluntarily relinquish or reduce their reserved capacity on the transmission network without incurring penalties. This initiative aimed to clear queue of stalled or speculative projects, thereby freeing up capacity for ready-to-connect developments. The amnesty concluded in April 2023, with over 8.2GW of capacity released, facilitating efficient queue management and helping viable projects in the pipeline to get connected sooner.

2. Construction Planning Assumptions (CPAs)

The ESO updated its modelling assumptions to better reflect the actual connections rates, acknowledging that historically only 30-40% of projects in the queue proceed to completion. This was a result of:

- Overestimating demand/generation
- Network congestion appearing worse than it actually was
- Delays in offering realistic connection dates

To overcome this, the ESO began factoring in the likelihood of each queued project actually connecting which was based on historic delivery rates. Projects were also grouped based on how far along they were i.e. planning approved, finance secured etc. The further along a project was, the higher its weighting in modelling. Also the ESO started collecting more real-time data on project development stages. This allowed them to update their modelling assumptions dynamically – not just rely on static forecasts. New connection studies now include scenarios that adjust for risk which show what happens if only a certain percentage of projects were to actually connect.

3. Storage

Recognizing the dual role of battery energy storage systems (BESS) in both absorbing and supplying electricity, ESO revised its approach to their integration. By treating storage projects differently in system impact assessments, ESO has enabled faster connections for these projects, which in turn enhances grid flexibility and reliability.

4. Contract Terms

To streamline the connection process, ESO introduced new contractual terms incorporating queue management milestones. These milestones require projects to demonstrate progress, such as securing financing and planning permissions, to maintain their position in the queue. This approach ensures that only viable projects occupy capacity, thereby reducing delays for other developments.

5. Interim Offer for BESS

ESO implemented an interim connection offer for battery storage projects, allowing them to connect to the grid sooner under certain conditions. While these projects may face occasional operational restrictions, this measure accelerates the integration of up to 95 GW of energy storage capacity, contributing to system security and the transition to a low-carbon energy mix.

Accelerating Distribution Connections

Whilst the above initiatives are specifically to address transmission connections, DNOs are adopting similar strategies to help accelerate connections which are further detailed below:

1. “First Ready, First Serve”

The ENA identified that many projects in the distribution network connections queue are not progressing toward completion, effectively blocking capacity for viable projects. To address this, the ENA proposed a shift from a “first-come, first-served” approach to a “first ready, first connected” model. This prioritizes projects that are more advanced in their development, such as those with secured planning permissions and financing, thereby freeing up capacity and reducing delays for projects ready to proceed.

A project is considered “ready” when it has demonstrated progress and commitment in construction and operation. Typically, this involves:

- Land Rights Secured: the developer has obtained legal rights to use the site for the project. This could include ownership, leases, or wayleaves for grid infrastructure/access.
- Planning Permission Granted: this means the local authority or government has approved the necessary planning consents. Without this, a project is speculative and less likely to go ahead soon. This may involve an environmental impact assessment.
- Financial Close or Funding Secured: this is evidence that the project has secured investment or finance or has a clear route to doing so. This ensures it’s not just a placeholder in the queue.
- Milestone Met in the Grid Connection Agreement: projects must meet key contractual milestones (e.g., design submissions, consents, readiness to build). Failure to do so can now result in removal from the queue.
- Equipment Procurement of Construction Start: some networks might also consider procurement of key assets (e.g., transformers, turbines) or start of construction as readiness indicators.

This change in approach ensures speculative projects aren’t holding what is actually “free” capacity and prioritise projects which will contribute to Net Zero targets. Developers are now required to submit evidence, in-line with the above examples, or otherwise they risk losing their connection slot or capacity reservation.

2. Enhancing Coordination Between Transmission and Distribution Networks

Recognizing the increasing interdependence between transmission and distribution networks, the ENA emphasized the need for improved coordination. This includes better data sharing, aligning planning processes, and reviewing thresholds for when distribution-connected projects impact the transmission system. Such measures aim to streamline the connection process, reduce duplication of efforts, and ensure that projects are assessed holistically across both network levels.

3. Providing Greater Flexibility for Storage Customers

The ENA acknowledged battery storage projects have unique operational characteristics compared to traditional generation. To facilitate their integration, the ENA proposed offering more flexible contractual arrangements, allowing storage projects to connect to the grid under conditions that reflect their actual usage patterns. This approach aims to optimize network capacity utilization and support the rapid deployment of storage solutions essential for balancing a renewable-heavy grid. This adjustment ensures more realistic planning and helps in allocating resources affectively, thereby improving the accuracy of projected connection dates.

Figure 4 shows the impact each of these strategies are anticipated to have by connection capacity in GW.

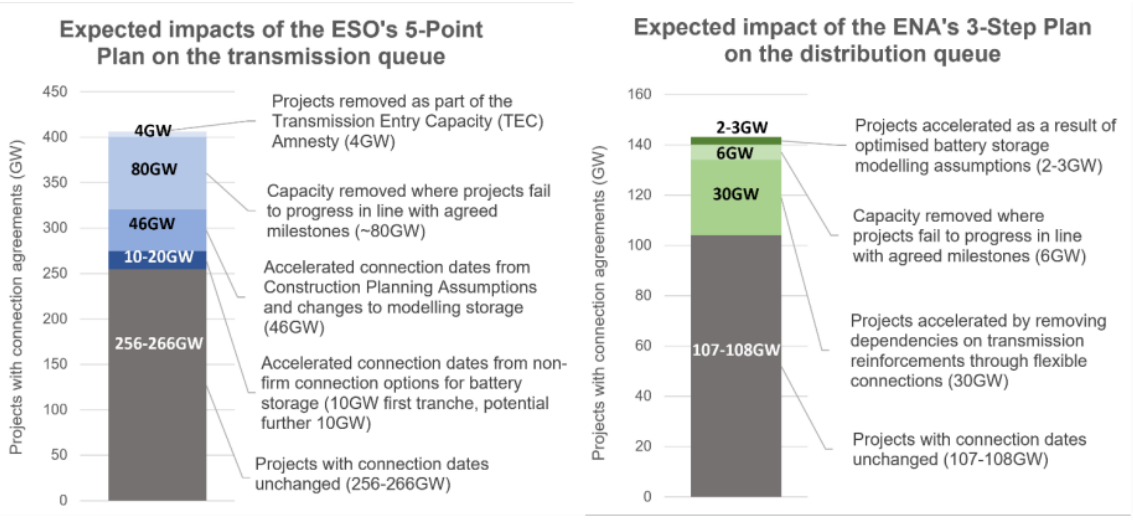

Figure 4 Expected Impacts of ESO's and ENA's Strategies [13]

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