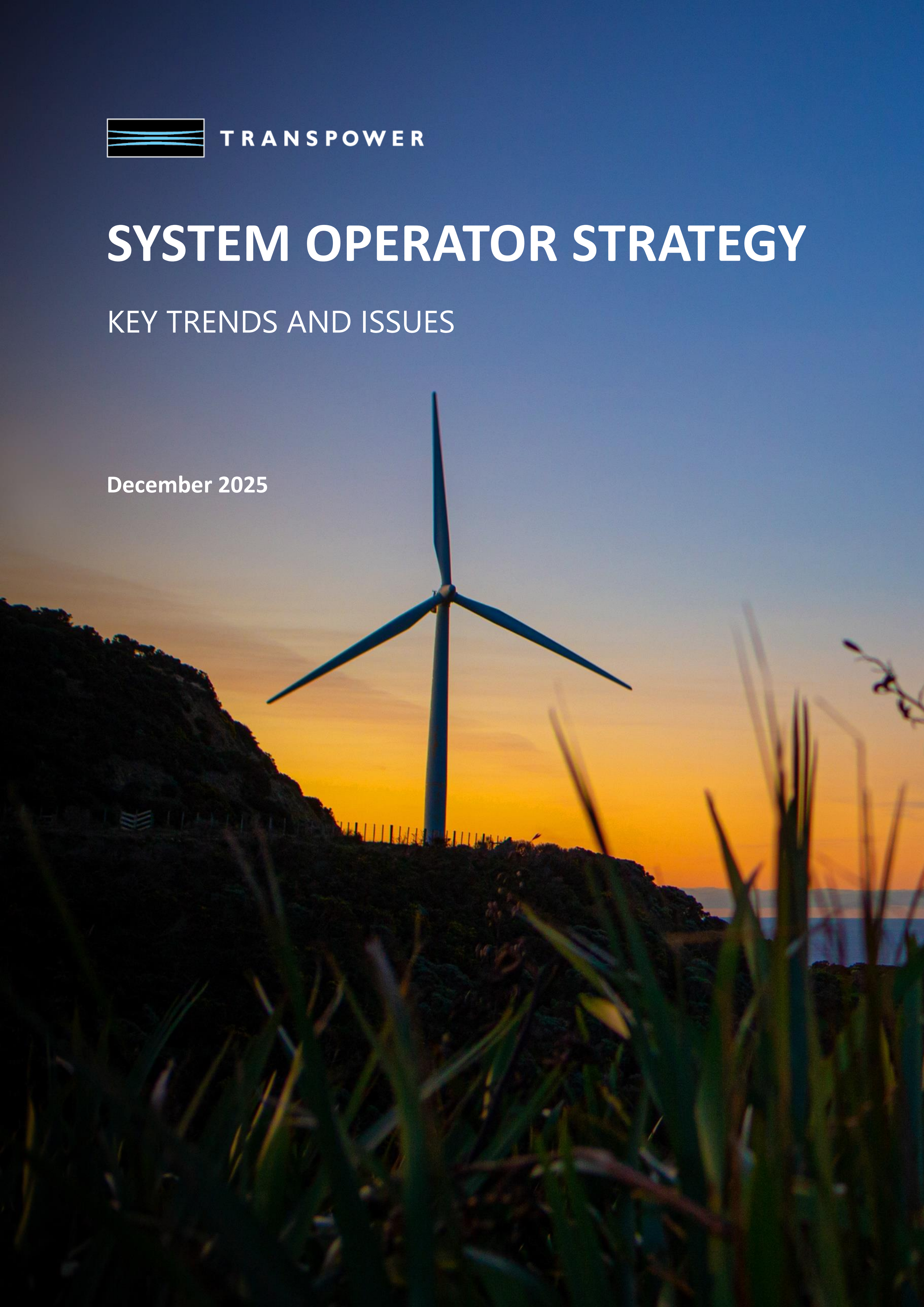
TRANSPOWER

SYSTEM OPERATOR STRATEGY

KEY TRENDS AND ISSUES

December 2025



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1 BACKGROUND

The System Operator plays a pivotal role in New Zealand's power system. We are responsible for maintaining real-time security of supply, operating the wholesale electricity market, and ensuring the system remains stable today and in an increasingly complex and dynamic future. Our role also extends to supporting the government and Electricity Authority (the Authority) in designing market and policy requirements that ensure we transition towards a renewable, affordable, and secure energy future.

1.1 Why a new strategy now?

The System Operator must work across a number of time horizons – from managing real time operations to preparing for the issues of tomorrow. The electricity industry is undergoing fundamental changes which impact every aspect of system operations and therefore our ability to deliver reliable and affordable electricity for consumers. As technology advances and consumer participation in the industry increases, the System Operator plays a significant role in the co-ordination of these shifts and the mitigation of risks involved.

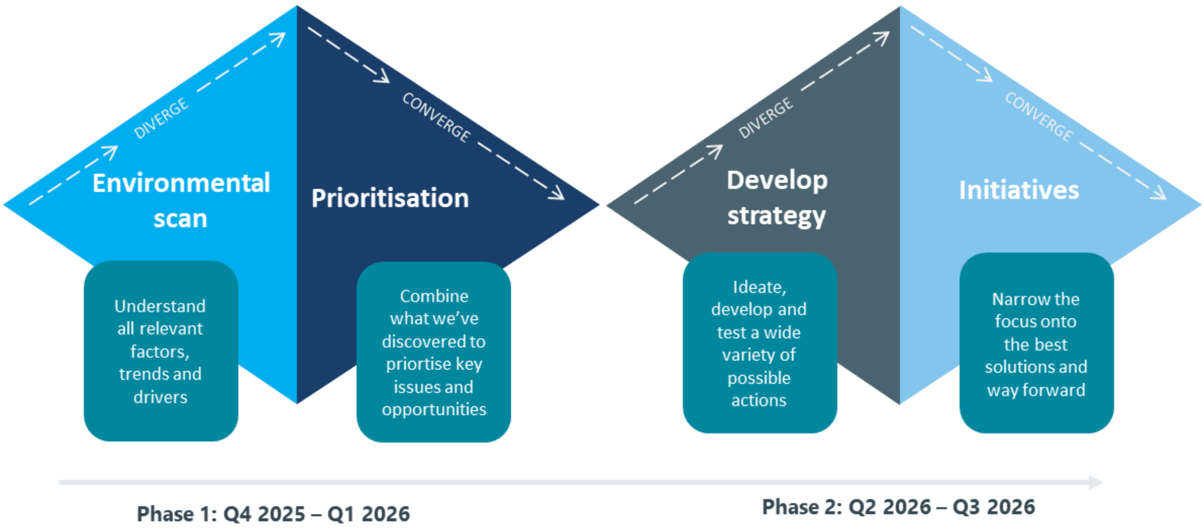
For the past five years, the System Operator has produced an annual Strategic Plan, most recently in June 2024, to satisfy our contractual obligations to the Authority. This approach has not always reflected the perspectives and needs of participants across the energy sector. The Authority are supportive of us adopting a refreshed and broader method, one that will clarify the System Operator's capacity and capability requirements and assist the Authority to scope and develop their work programme. We are eager to glean insights from external stakeholders whose views we have not explicitly considered until now.

The benefits will be reciprocal. Consulting on our strategy will strengthen and deepen our understanding while also enabling the industry to better appreciate the complexities we jointly experience in maintaining a stable, secure electricity supply.

1.2 Our approach

The System Operator Strategy (our Strategy) will take a ten-year forward view, guiding investment planning for the next funding period (the 2028-31 System Operator funding period) and beyond. It will set a clear direction for how the System Operator service evolves and will be supported by annual reviews of key focus areas. Industry consultation is a new and important element of this, ensuring that diverse perspectives from across the sector contribute to shaping our priorities.

We are beginning the development of the strategy with two rounds of industry engagement. In the first phase, we are inviting feedback on a broad review of trends and influences in our sector (this paper). These have been informed by our day-to-day operation of the system, international engagement with other system operators, system events domestically and internationally as well as the System Operator's risk management approach. In the second phase we will outline the key risks and opportunities that the System Operator must address as strategic priorities. This second phase will also seek industry input on how we have interpreted the options for the System Operator in addressing the various trends, their materiality, and the pace of change that is required. This second phase will also include key areas of proposed investment and development of System Operator capability and capacity. We expect this second round of industry engagement to occur in early-mid 2026.



1.3 Working together with other industry processes

The System Operator Strategy will combine technical, market, and policy information to complement a range of existing and planned work programs. It will consider both the scope of the System Operator's role and functions today, as well as contemplating the future needs of the power system, market and industry. This requires a coordinated and joined up approach to bring together a range of technical, market and policy information. As the analysis for our Strategy contemplates the broader needs of the power system and stakeholders' own plans and strategies, we anticipate that our Strategy will feed into the Authority's work plan development and prioritisation process. There may also be other issues that require further review from other parties, and this will be identified during the consultation.

It is also important that the SO Strategy both considers and helps shape the industry's plans, as well as Transpower's Te Kanapu future grid blueprint. These reflect a common strategic context – a rapidly evolving electricity sector. Te Kanapu focuses on how the transmission grid needs to evolve to support an electrified future, looking ahead to 2050. In contrast, the SO Strategy is focused on keeping the power system functioning over the next 10 years and in real time. Transmission is an important part of that operational perspective, but only one of many factors the strategy must consider. Likewise, Te Kanapu will look to the System Operator Strategy to assess how transmission planning and operations may need to evolve to support a more complex, dynamic system. While distinct, the two workstreams are highly complementary.

1.4 We want to hear from you

We want to hear your views on the trends shaping the industry to ensure that we have formed the most complete and accurate view of the next decade's outlook and what it means for system operations. We invite you to scrutinise our analysis and consider questions such as:

1. Do you agree with the trends and drivers we have identified for the energy sector over the next ten years?
2. Which ones do you think will have the biggest impact? Are there any that will be less or more impactful than we've identified? Less or more likely to occur?
3. What other trends or drivers may come into play for the energy sector over the next ten years that are relevant for power system operations?

4. What advanced technologies (e.g., AI, automation, digital twins) and real-time data capabilities will be critical for maintaining power system reliability as the system becomes more complex?
5. Where do you see the operation of the power system being in ten years, and its role in the broader electricity sector? What will be the same and what will be different?
6. What skills and capabilities will the System Operator need to expand or develop, and how can the sector best support workforce transition and wellbeing during this change?
7. Are there areas where the System Operator could usefully provide more of a leadership role?
8. What is one thing that you would like the System Operator strategy to address?

1.5 How to provide feedback

We have outlined 8 questions above and are seeking your input on these. This will inform the second phase where we define and prioritise risks, opportunities, and then the initiatives needed to respond. You are also welcome to raise other issues you believe might be relevant.

We recognise that there are currently elements of the market settings that are being developed and areas where market participants may like further action. Our work on current issues will continue. The Strategy provides an opportunity to lift up from the current approach to system operations and consider the possible – how settings and systems could and should evolve to adapt to, and benefit from, the significant electricity transformation that is occurring here and around the world.

We have included a Word document, for the convenience of submitters, which incorporates all the questions contained in this paper. You can use this for your submission if you would like to.

Please send submissions to system.operator@transpower.co.nz. We will acknowledge receipt of all submissions. Submissions will be published on our website on our System Operator Strategy page. You can also contact us at system.operator@transpower.co.nz to arrange a group discussion or phone call to provide verbal feedback.

If your submission contains confidential material, please ensure this is clearly identified and provide a version of your submission that can be published.

Please note that all information provided to Transpower is subject to potential disclosure under the Official Information Act 1982. Clause 7.20(4) of the Code also requires that the System Operator provide a copy of each submission received to the Authority.

If you have any questions about this consultation, please send them to system.operator@transpower.co.nz. Your questions and our responses to them will be published on our website for reference by other submitters and stakeholders.

Consultation closes at 5pm, Friday 27 February 2026.

Further phases of this work will progress in early 2026 with the Strategy being finalised in mid-2026.

2 ENVIRONMENT SCAN SUMMARY: WHAT WILL THE INDUSTRY LOOK LIKE IN 10 YEARS?

This table summarises our initial consideration of the key trends and drivers that will impact New Zealand's power system in the next 10 years. The following chapters elaborate on our thinking and highlights particular points of interest.

Area	Issues and drivers of change	Implications for NZ's energy sector	Implications for the operation of the electricity system
Political and regulatory environment	• **Geopolitical instability –** Global geopolitical shifts impacting energy trade and security, in parallel with a global drive to electrify • **NZ electricity reform –** Government reform of the electricity sector with an emphasis on security of energy supply and building stronger energy market functions and institutions to support electrification. • **Security of supply –** Government investment in energy security of supply. • **Pace of regulatory and technological change –** rate of technological change outpacing regulatory reforms, creating investment uncertainty.	Competition to electrify globally and supply chain challenges impacting costs and pace of delivery. Greater focus on affordability and security of supply, in addition to decarbonisation of the economy. Increasing need for market setting changes pushing regulators and policy makers to move at pace.	Greater engagement with policy makers to align market settings with operational needs. Need to increase the pace of regulatory change to ensure confidence in investment decisions and new resources can connect and operate as quickly as desired. The System Operator and market participants must also be able to effectively adapt to setting changes Need for more sophisticated forecasting and planning, reflecting potential supply-side uncertainty. Actions from the *Review of Electricity Market Performance* including enhanced monitoring and security of supply assessments, a new regulatory framework to incentivise firm generation and flexibility capacity, and improving security of supply standards will place increased resource and funding pressure to deliver.

Area	Issues and drivers of change	Implications for NZ's energy sector	Implications for the operation of the electricity system
Economic and market changes	• **Electrification investment –** projected increase in investment levels in electrification and renewable energy development. • **Meeting increased electricity demand growth –** expectation of increased load growth (e.g. data centres) • **Economic impacts of higher energy prices** and the need to manage price volatility in the electricity market. • **Firm and flexible supply to meet capacity peaks –** declining gas supply, sovereign risk impacting gas investment and the lack of flexible resources in the energy system. • **Electricity market innovation –** evolution of energy markets as demand-side technology adoption increases.	Greater volatility in spot prices will challenge traditional investment models. Declining gas supply impacts both investors and consumers, with affordability a key concern. The wider economy and broader investment trends have a strong impact on the electricity sector (e.g., global interest rates, state of the global and local economy). Economics of renewables are compelling, increasing value of dispatchable capacity as the proportion of intermittent generation on the system continues to grow. Energy markets will need to adapt and change in response to the adoption of new technologies such as battery energy storage systems (BESS) and distributed system operation (DSO) models. More transmission and generation assets will need to be built to meet growing demand for electricity and renewable generation.	Increasing electrification and DER impacts forecasting which affects generation and transmission/distribution investment planning, system operations and market services. Increased use of data and risk assessment to cover a greater range of demand variability in market and system behaviour. More effort to support new generation and load connections and commissioning. Greater need for power system monitoring and analysis and changing market rules and systems to manage risks presented by new technology. More modelling and forecasting complexity in distributed energy resource scheduling. More work on the power system will be needed to enable growth in demand and generation. To complete this work will requires more outages in a more complex market.
Environmental	• **Climate change** – increasing frequency and severity of climate change events impacting on energy infrastructure presenting physical risk and community and consumer resilience impacts. • **Weather dependence** – less predictability in forecasting adequacy in a weather dependent power system.	Increasing unpredictability of load and generation forecasting, which can lead to less predictable prices and power system risks. Electricity grids are facing pressure to ensure infrastructure is resilient. As weather events become more severe, their impacts on the power system are increasing, creating greater risk of asset damage and prolonged loss of supply which needs to be managed.	Need to better understand climate dependent risks that may require new and improved skills for managing system events and vulnerabilities. We must expect the number of events to increase Greater need for detailed solar and wind forecasts (including sensitivities) and ability to plan around uncertainty. Potentially greater need for more reserve capacity to cover sudden unexpected loss of generation.

Area	Issues and drivers of change	Implications for NZ's energy sector	Implications for the operation of the electricity system
Societal and consumer evolution	• **Changing demographics** – workforce and workforce expectations • **Increasing reliance on electricity** – electricity is expected to be the major fuel of choice in the future, requiring a high degree of public trust. • **Local resilience** – increasing interest in personal, community and regional resilience • **Increased vulnerability to cyber risks** – and the risk of failure in one area could affect the whole system. • **Energy affordability –** cost of energy is impacting living conditions and large consumers ability to continue operating (amongst other economic factors), threatening jobs	Societal change will impact the industry, particularly through workforce changes. The workforce is aging with skill transfer becoming increasingly important. Talent pipeline and domestic resources pools need development. Active consumer participation in the market is increasing, motivated by resilience. Rooftop solar, electric vehicles, battery storage systems, and more flexible retail pricing plans all influence consumer behaviour and increase complexity in operating electricity networks. Greater vulnerability to cyber risks and changing needs for risk mitigation. Public concern with increasing electricity prices may temper future ability to transition.	Investment in and retention of key power system talent in New Zealand requires broader immigration and tertiary sector engagement. Greater need for knowledge capture and information sharing to mitigate key person risks and highly skilled, tenured workforce cohorts transitioning to retirement. Articulating value of our services to customers requires clear communication of value propositions to embrace new technological opportunities. Need for conscious engagement with communities to develop new talent. Consumer participation in the market is enabled by a strong digital infrastructure which permits data sharing and interoperability across industry service providers.

Area	Issues and drivers of change	Implications for NZ's energy sector	Implications for the operation of the electricity system
Technological change	• **Inverters and BESS** – costs of inverter-based generation and storage are reducing rapidly. • **Decentralisation and distributed energy resources** of new technology (e.g. rooftop solar, prosumers). • **Data and digitalisation** - massive increase in quantity of data available to the sector and the infrastructure supporting a more digital operating environment. • **Artificial intelligence** – advances in information technology on the economy and workplaces, particularly artificial intelligence (AI). • **Control rooms** - changing generation make-up and increasing variability in load is changing the way in which control room's function.	New system risks from reducing inertia, system strength and stability issues requiring clear prioritization and investment pathways to be developed within Transpower and across other organisations. Increased uptake of smart grid technologies and advanced metering, and automation to support a more complex and decentralised network. Increasing data availability and expectations of greater optimisation benefits which need to be reflected in investment plans and delivery. AI and machine learning applications are becoming mainstream operational tools and will transform energy sector modelling and data analysis, and handle greater complexity and variability.	Need for operations to evolve rapidly to reduce/remove barriers on new technologies with a particular focus on AI adoption. Changing customer and stakeholder expectations requires management of operational risks with better data. Enhanced data access and use requires data and asset information from different parties. Supporting innovation across the market by developing and supporting new modes of participation. Use of commons standards and communication protocols for data. Pace of delivery needs to increase to support change, building in flexible delivery capability. Faster and accurate forecasting and scenario modelling, helping manage more complex power systems.

3 POLITICAL AND REGULATORY ENVIRONMENT (LOCAL AND INTERNATIONAL)

Global geopolitical shifts, climate pressures, and resource constraints are impacting on the energy transition for countries around the world. Heightened geopolitical uncertainty has resulted in a shift from rules to power, from economics to security and from efficiency to resiliency. New Zealand has limited influence on these macro trends, but we can adapt. As with other countries, we face challenges in decarbonising transport and certain industrial sectors, ensuring energy security, and attracting investment amid fuel supply uncertainty and upward pressure on energy prices.

The recent *Review of Electricity Market Performance*[1] covered a broad range of issues facing the New Zealand power sector, which the Government is now actively working to implement as part of a series of policy actions. The current government has adopted a market-led approach, using carbon pricing and energy reforms to support renewable growth and infrastructure development.

However, as covered in the government's review, energy adequacy and capacity adequacy issues from supply-demand imbalances, reduction of thermal generation capacity, and declining gas availability remain significant risks to the energy system. Ongoing investment in new technologies, long duration firm and flexible generation, and the infrastructure that supports our electricity system is essential to support a resilient, low-carbon economy and maintain economic competitiveness on the global stage.

With our strong renewable base, we are well-positioned to drive economic growth while electrifying our economy. As New Zealand is a technology taker on the global stage, addressing our challenges within the industry must be supported by regulatory and policy change. However, owing to the complexity of the subject matter, regulatory and policy inertia can become a significant constraint in realising the opportunities this change brings.

3.1 Global geopolitical shifts impacting the energy transition

The global landscape has become more volatile and unpredictable as changing power balances create geopolitical uncertainty. The policy impact has been mixed with some countries such as the USA and China removing incentives and subsidies for particular clean energy technologies, while Europe has balanced short term needs for addressing energy affordability, economic stability and security of energy supply. Despite this, China is the world's leading electro-state, using energy for both their domestic transition and exporting the capacity to the world with manufacturing of solar, electric vehicles and battery technology.

The world is electrifying and, increasingly, renewable energy is favoured as a key fuel of choice by governments and investors. This presents additional pressures on existing global supply chains in a world with competing demand to electrify, leading to increased time and cost pressures. For example, this has led to delays in securing critical equipment such as power transformers.[2] In 2024, the worldwide capacity for renewable electricity generation surged by an estimated 25% to around 700 GW.[3] The global investment for this transition is significant and requires a significant expansion in material, equipment and specialist workforce. If New Zealand lags in securing these inputs, electrification could slow. In our role as System Operator, our ability to monitor and assess the impact of these external forces on the New Zealand power system appears to be growing. Specifically, as we consider our annual Security of Supply Assessment analysis and the longer term development pipeline for generation, any delays that impact the ability to build generation and transition must be understood in detail.

[1] Beehive releases, 1 October 2025
[2] International Energy Agency, Building the Future Transmission Grid
[3] International Energy Agency, Global Energy Review 2025

Key geopolitical challenges and response

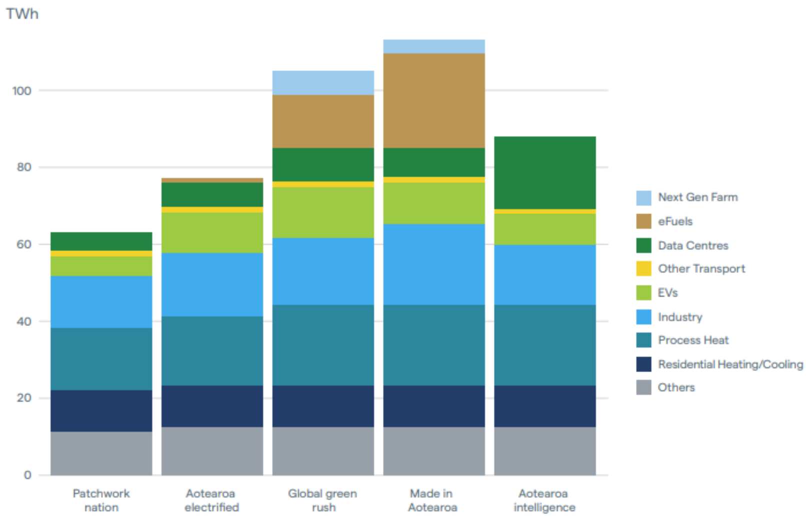
Source: World Economic Forum

At a supply level, increasing electricity production domestically through renewable energy reduces our reliance on imported fuels such as diesel and petrol. For businesses, New Zealand's ability to complete in the global economy relies on a foundation of reliable, affordable and sustainable energy. Much of New Zealand's export revenue comes from countries which have climate-related disclosures or carbon border adjustment mechanisms. For example, over 80% of exports are going to countries with mandatory carbon disclosure obligations and 40% are going to countries with carbon border adjustment mechanisms.[4] This drives energy choices in carbon-intensive export industries. New Zealand is well positioned to deliver international markets relatively low-cost, low-carbon electricity into the future.[5]

To that end however, there is the potential for international policy choices to drive demand for a range of future fuels which could significantly change the direction of our energy demand profile. Of particular current interest are alternative sustainable fuels for aviation and marine applications. It is unclear whether these fuels will be produced domestically or imported. Regardless, understanding how global geopolitical forces are moving will become increasingly important for the New Zealand power system.

4 Chapman Tripp/The Aotearoa Circle (2024) *Protecting New Zealand's Competitive Advantage*
5 Boston Consulting Group, Energy to Grow: Securing New Zealand's Future

New Zealand Electricity demand breakdown by driver, 2050



Source: Te Kanapu[6]

3.2 Domestic government reform of the energy sector

In 2024, the Government released a policy statement for electricity, and most recently in 2025 announced next steps following its review of the electricity market. These announcements signal a market-led approach to both energy and carbon. The Government has decided that carbon pricing is the primary tool to drive decarbonisation decisions in electricity and its energy policy package underscored the importance of two key areas - investing in energy security and building stronger markets.

Key pillars of the approach to energy include exploring whether to progress with a Liquefied Natural Gas facility and accelerating renewable generation investment with a policy to double renewable energy by 2050. While many of the actions are yet to be delivered, these signal policy responses to energy security and affordability challenges.

New Zealand's current ability to meet energy demand is being challenged as we transition to a more renewable energy system. Growth in peak demand has outstripped investment in new flexible resources, leaving current gas and coal-fuelled generation as the only available solution for firming renewable generation. Natural gas supply is reducing faster and sooner than previously expected – with natural gas (2P) reserves down 27% between 2024 and 2025.[7] Energy imports contributed over half of New Zealand's total energy consumption – and we are increasingly reliant on coal, liquified petroleum gas and liquid fuels to meet our domestic energy needs. As noted above, the Government is investigating the viability of importing liquified natural gas to provide firm capacity during dry periods.

Absent any unifying, bipartisan energy strategy for Aotearoa, there will likely be changes in policy direction that will require the sector to adapt and pivot. Consultation processes and engagement with market participants by the System Operator and other implementing agencies will need to be thorough and timely.

Dry year conditions also create challenges, as observed during winter 2024 and again at the start of 2025. The retirement of thermal generation and increased uncertainty over gas availability is threatening the system's ability to respond, which can in turn drive up wholesale prices. Without action,

[6] Te Kanapu "*A future grid blueprint for Aotearoa*" *Te Kanapu Consultation 2 - Potential Scenarios.pdf*

[7] Ministry of Business Innovation and Employment, Gas supply reducing faster and sooner than previously forecast | Ministry of Business, Innovation & Employment

the electricity system remains vulnerable to dry years and households and businesses exposed to potential higher electricity prices and reliability risks.

Following the Government's review of the electricity market, a series of actions including enhancing security of supply assessments, a new regulatory framework to incentivise firm generation and flexibility capacity and improving security of supply standards are being investigated. The Government has also signalled the need for enhanced market monitoring of security of supply by the System Operator. We will continue to work with MBIE and the Authority on these policy developments and will look to provide a clearer assessment of their impact on the market and system operations once the details of the policy decisions are known.

3.3 Pace of regulatory change

Energy regulators all over the world are also having to adapt to a more dynamic and complex operating environment. This can be challenging for organisations who are often resource constrained and not exposed directly to the changes being felt by the market participants that they regulate. Similarly, those impacted by regulatory change can also find the pace of that change difficult to incorporate into their operations. We work closely with the Authority to support effective prioritisation of their work program based on analysis of power system risks. Our current focus is on Phase 3 of the Future Security and Resilience roadmap to ensure that emerging risks in managing frequency are prioritised given the potential lead time associated with Code changes, system updates and industry engagement.

Future Security and Resilience Roadmap

2022 · 2025 · 2027

Changing generation portfolio

Accommodating future changes within technical requirements
- Parts 8, 6, 7, 13, 14 of the Code will be updated to incorporate the capability and performance of new technologies and changes in the power system.
- Harmonics standards and other engineering standards, modelling and testing standards will take into account the introduction of new technologies.
- The Policy Statement and any other policies, procedures, guidelines and tools will be updated accordingly.

Operating with low system strength
- System strength performance criteria will be defined and established.
- The regulatory framework will be updated to include technical requirements for system strength.
- Develop suitable market products and tools.

Balancing renewable generation
- The market system, operational procedures and tools will allow the scheduling and dispatching of renewable generation.
- Intermittent generation offers and the System Operator's demand forecast will be efficient and accurate.
- New or revised ancillary services will effectively manage active power imbalances.

Managing reducing system inertia
- A frequency reserve strategy will be created.
- The updated Procurement Plan and testing methodologies will support assessment and procurement of new reserve types.
- Operational procedures and tools will be ready to dispatch new reserve types.

Rise of Distributed Energy Resources (DER)

Coordination of increased connections
- All System Operator and distributor processes will be updated to accommodate increased connections.
- The Grid Owner, Electricity Distribution Businesses and the System Operator will have the resources and capability to commission DER.
- Updated market tools, real-time operational tools and study tools will reflect the behaviour and capability of DER.

Enabling DER services for efficient power system operations
- The Code will define the technology agnostic role of DER. The market system will accept offers from DER owners, and operational tools and procedures will assess and dispatch DER.
- Electricity markets, the Grid Owner, Electricity Distribution Businesses and the System Operator will send efficient signals to DER.
- Grid exit point aggregation and participation of third-party flexibility traders will be enabled.

Visibility and observability of DER
- The impact of high levels of DER will be understood and managed.
- The regulatory framework will accommodate a high degree of DER uptake.
- Operational requirements will be established between the System Operator and distributors.

Source: Electricity Authority, Transpower[8]

We will need to continue to work closely with the sector to drive regulatory change based on the changing power system dynamics. The System Operator service will also need to have a way to implement and fund the system and tool changes that may be required to support these changes in a timely and efficient manner. As with all critical infrastructure, significant changes to our market systems, SCADA or power system tooling need to be done in a considered manner with considerable change management across the sector. An example of a recent successful change can be seen with the implementation of Real Time Pricing but going forward changes of this magnitude may well be required more frequently.

[8] Electricity Authority, Future Security and Resilience Roadmap

4 ECONOMIC AND MARKET CHANGES

The energy sector is experiencing significant economic and market shifts, driven by global and local trends. Investment in new renewable capacity is growing markedly in New Zealand, however businesses and consumers still rely on diminishing supplies of natural gas. Population impacts, skills shortages, and energy fuel availability and costs are affecting confidence in the energy sector. A period of high inflation, supply chain disruptions and high interest rates have increased delays and costs of financing new energy projects. Globally the cost of renewables continues to fall, and investment in solar capacity and battery energy storage is ramping up in New Zealand. The value of firm and flexible capacity is increasing as investment in intermittent renewables increases. Markets are also evolving, with increased adoption of flexible contracts for industrial users, digital platforms, and sophisticated trading mechanisms to manage risk and optimise energy resources.

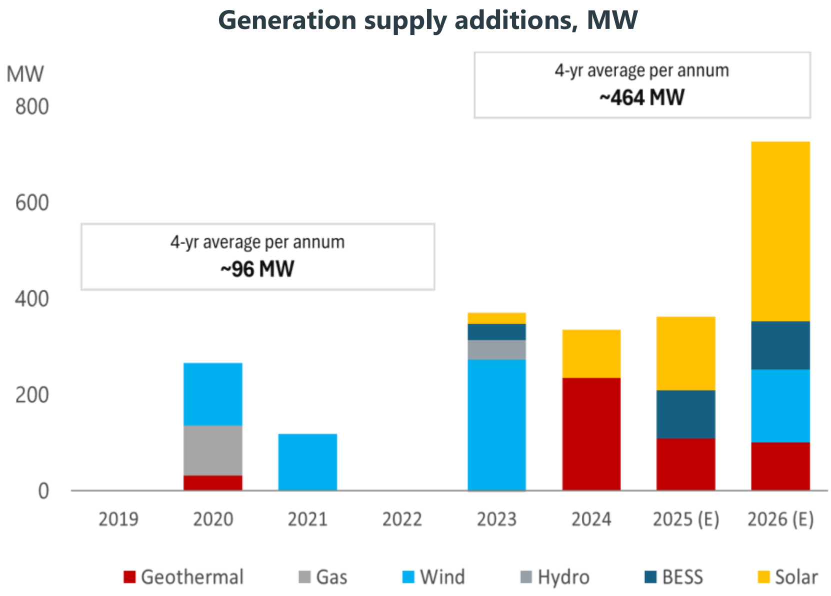
4.1 Electrification investment

Transpower expects electricity demand to increase 68% by 2050, largely met from investment in renewable energy.[9] In the last 2-3 years, the amount of investment in renewable energy has substantially increased in New Zealand.[10] We are observing sustained volumes of new generation and load enquiries leading to new customer connections – both grid connected and distributed – as a result of increasingly aligned forecasts of increasing demand. Most of the renewable generation now connecting to Transpower's assets is utility scale solar, wind, geothermal and battery energy storage systems (BESS).[11] We are seeing investment in distributed energy resources, such as solar and batteries and expect this to play an increasingly important role in the energy system. Approximately two-thirds of all investment in renewable electricity generation in New Zealand since 2018 has connected to Transpower’s high voltage electricity network. The Government is also considering removing capital constraints on mixed ownership model companies to build new generation, supporting New Zealand’s energy supply.

On the load side, electricity demand remains steady. We continue to observe signs of growth and expect mature and proven technologies in transport and process heat to continue to drive electricity demand growth in the long term. For example, falling battery costs are reducing the cost of electric vehicles compared to internal combustion engine vehicles and process heat conversions by industrial energy users in the food processing sector are switching away from coal and natural gas. Data centres loom as a potential new electricity-intensive sector which could increase electricity demand. When integrating new technologies on the grid, their characteristics can have a negative impact on power quality and system operation if not managed.

To facilitate this electrification investment, a significant amount of work must take place on power system assets. Transpower is expecting to more than double its investment in the transmission grid from 2024 to 2030. To facilitate this work requires power system assets to be removed from service, and every time this happens it introduces more risk and cost to the power system that the System Operator needs to manage through its planning activities. Currently this is a significant driver of work for the control rooms and engineers. As the electrification investment increases, the amount of planning needed to manage the risks and costs outages introduce will rise unless mitigated. As this investment in growth is taking place it should also be noted the grid is aging. As the majority of the grid was built in the 1950’s - 1970’s, it now requires more maintenance to keep it in service, or more life cycle replacement work further increasing outages.

[9] Whakamana i Te Mauri Hiko - Empowering our Energy Future | Transpower
[10] Transpower analysis.
[11] Transpower: What's the latest with grid connections? | Transpower



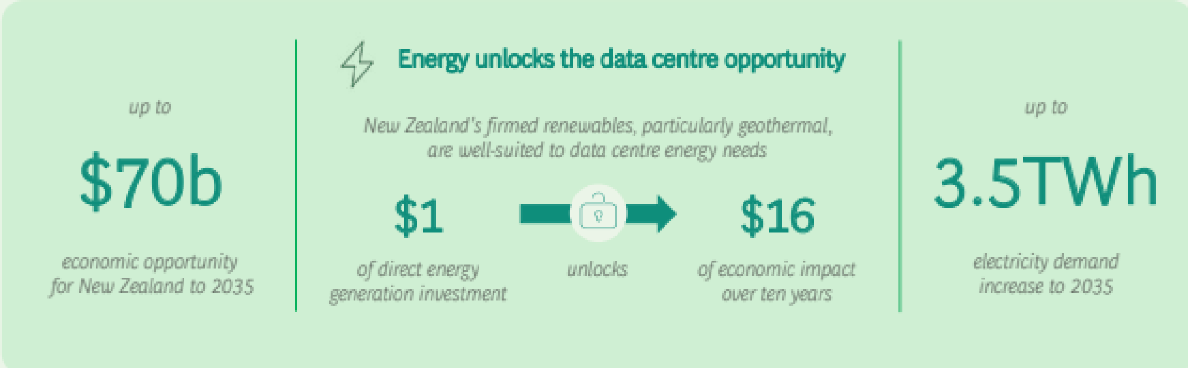
Source: Transpower analysis

4.2 Impacts from expected increases in electricity demand

While New Zealand's load growth has been relatively small in recent years, some jurisdictions are grappling with rapid load growth and particularly data centre load growth. With uptake of artificial intelligence expected to continue to increase, an increasing amount of data centres will be required to provide the processing power for these models. Both the number and size of data centres are expected to increase. Conventional data centres typically have power consumption of around 25 MW, while newer, hyperscale AI data centres may reach hundreds of MW. Notably, around 10-30% of power consumption from data centres stems from auxiliary services such as air conditioning. Therefore, an increasing load from data centres could impact not only the magnitude of power demand but also drive changes to the demand profile across both days and seasons.

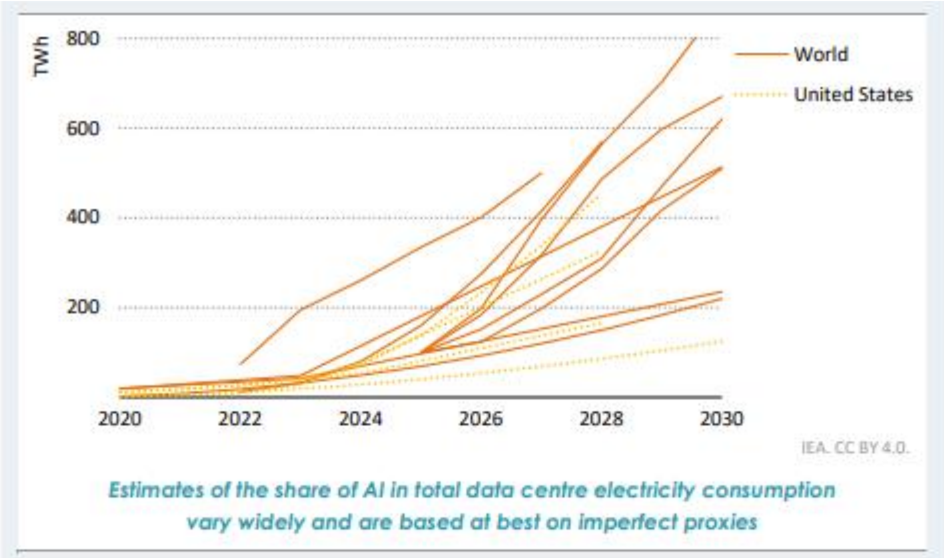
Data centres are often highly concentrated within particular regions of a country, which, given their potentially substantial energy consumption, has implications for both the grid owner and system operator. The challenges that data centres or any other large single point loads create for system operations is captured in the figure below. Data centre load growth is progressing at pace and has the potential to bring significant benefits to hosting jurisdictions but there has been huge uncertainty about both the size and pace of that growth. Such uncertainty creates significant challenges for load forecasts and assessments of reliability margins to manage security of supply.

Data centre challenges and opportunities



Source: Boston Consulting Group[12]

International Energy Agency data centre electricity demand forecasts, 2020-2030



Source: IEA[13]

4.3 Economic impact of higher energy prices

Increased pressures on households and businesses from rising costs, including energy, continue to be a key concern. A recent survey of businesses found energy prices, inflation and cost of living pressures were the factors having the biggest impact on business confidence in New Zealand.[14] This, combined with other economic factors, has resulted in a decline of industrial electricity demand due to closures of plant and curtailed operations. This has been particularly evident in some key sectors, such as the wood pulp and paper sector. New Zealand's industrial sector relies on both fossil fuels and renewable energy sources. In the future, greater electrification should see some fossil fuel demand replaced by electricity. Further, NZ households and businesses are increasingly focused on ensuring affordability and security of our electricity system and natural gas supply.

As the makeup of the generation fleet changes, and there are longer and more frequent periods of high intermittent generation penetration, and increasing amounts of distributed resources, we need to

[12] Boston Consulting Group, Energy to Grow: Securing New Zealand's Future
[13] IEA analysis
[14] Mood of the Boardroom: Executives call for long-term energy plan as power prices climb - NZ Herald

be more flexible with scheduling and dispatching generation to meet all the needs of the power system to ensure that prices reflect real-time system conditions. How the System Operator may need to adapt to maintain price accuracy and least-cost dispatch while integrating more ancillary services will require greater consideration. For example, pricing of reserves may need to factor in a greater range of services which will need to be driven by higher investment in enabling technology on the system, more sophisticated operations and market system and procurement of new services from non-traditional sources. Similarly, consideration will need to be given to how price uncertainty and volatility impacts forward price signals and generator commitment decisions. If changes are required to reserve requirements, then a question that needs to be addressed is how costs of managing these services are passed on, and who pays.

4.4 Investment in firm flexible supply to meet capacity peaks

The energy sector needs to ensure there is enough fuel storage and generation available to meet electricity demand, particularly during dry years when low rainfall impacts hydro generation. Recent declines in the estimated remaining life of domestic natural gas resources for production have further highlighted the urgent need for diversified fuel sources to help manage New Zealand's security of supply risks. To provide secure energy supply, sufficient investment in firm and flexible resources such as existing thermal plant, batteries, DR and peaking generation is needed.

Peak electricity demand growth continues to raise concerns for potential capacity issues during peak demand periods, particularly during winter periods of colder temperatures and low wind and solar generation. This is also a concern regionally when major transmission circuits are on planned outage for maintenance and upgrades and slow start thermal generation is insufficiently incentivised to run for short durations. While energy adequacy remains a key challenge[15] due to dry year and variable renewable energy, the peak capacity risks are ever present until sufficient investment in flexible resources occurs. These risks are being influenced by:

- increased investment in new renewable generation such as wind and solar (causing increased supply variability and growing uncertainty due to dependence on prevailing weather and increased inverter-based generation which is less capable of supporting system frequency and voltage);
- increased flexible distributed energy resources (DER) within the distribution network such as electric vehicles, rooftop solar panels, batteries and smart home devices (contributing to demand variability and uncertainty but also the opportunity to respond flexibly to market signals);
- increased battery energy storage systems (ability to shift energy to smooth out variability and uncertainty for relatively short durations and also to provide ancillary services); and
- increased uncertainty in the unit commitment decisions and usage of less-flexible thermal generation due to growth in renewable generation, more volatile market prices (causing step changes in supply capacity offered into the market), and greater forecast uncertainty.[16]

The shift from dispatchable to intermittent generation also causes risks of over-supply during low load periods, which are having significant operational impacts in New Zealand and other jurisdictions in steady state. Transpower's market clearing engine, the scheduling, pricing and dispatch (SPD), can produce arbitrary or inoperable outcomes when too much energy is offered at near-zero cost. Like other markets, we will need to consider changes to market rules and systems that ensure the market keeps delivering operable outcomes in these circumstances. Specifically, we anticipate the need to reconsider how the merit order is constructed for dispatch purposes as well as a fundamental review of how SPD subsequently meets any new market pricing and optimisation outcomes. The first issue, how

[15] System Operator 'Supporting resource adequacy in a highly renewable, islanded power system'
[16] Evolving market resource co-ordination in Aotearoa New Zealand

prices are to be determined, is a matter for the Electricity Authority. The System Operator will then need to be able to adapt the SPD engine to meet any new obligations, working with industry.

4.5 Electricity market innovation and tools

Demand response is emerging increasingly in the New Zealand context with large industrial consumers. The New Zealand Aluminium Smelters (NZAS) signed a 20-year electricity arrangement – which included new electricity arrangements for demand response (DR). NZAS may be requested to reduce electricity consumption in tranches over certain periods of the contract and demonstrate the increase of a broader trend of arrangements for fuel flexibility across major industrials.

Smart demand management is increasing down to household level through development of smart metering and control technology, innovation in tariffs and flexibility services as an energy product. We expect adoption of Consumer Energy Resources (CER) and other distributed energy resources (DER) will increase through investment in personal and community reliability, and adoption of new technologies such as vehicle-to-anything (V2X) and coordinated control mechanisms (virtual power plants, 'VPP'). This will demand increasing sophistication in Aotearoa's energy markets to orchestrate these resources and may drive the need for distribution system operation type competencies to complement. We discuss the outcomes that may be required at the distribution level in the Technology section below.

Regulations and policy settings will need to keep pace with technological change. Ensuring clear and up-to-date technical standards and common quality requirements for how these new innovations and technologies should behave on the power system allows greater certainty for investment and uptake. There are also transitionary impacts on industry participants that will need to be managed. Monitoring settings and organisational policies and procedures will need to align with regulatory changes as they occur. The increased regulatory scrutiny and increased enforcement powers signalled as part of the Government reforms will likely bring increased compliance activity for our monitoring functions and new obligations on all market participants.

5 ENVIRONMENTAL

Our changing climate is impacting power system operations across long- and short-term horizons. In New Zealand, our already highly weather-dependent system is becoming more so, with wind and solar generation supplanting 'firm' generation sources that rely on stored fuels. Operating the system and market depends on having robust ability to predict the weather and manage asset availability to ensure reliable supply. We need to have confidence both in predictions of stored water in hydro lakes and the potential snow melt in surrounding mountains, as well as short-term forecasts of wind speed, direction and cloud cover.

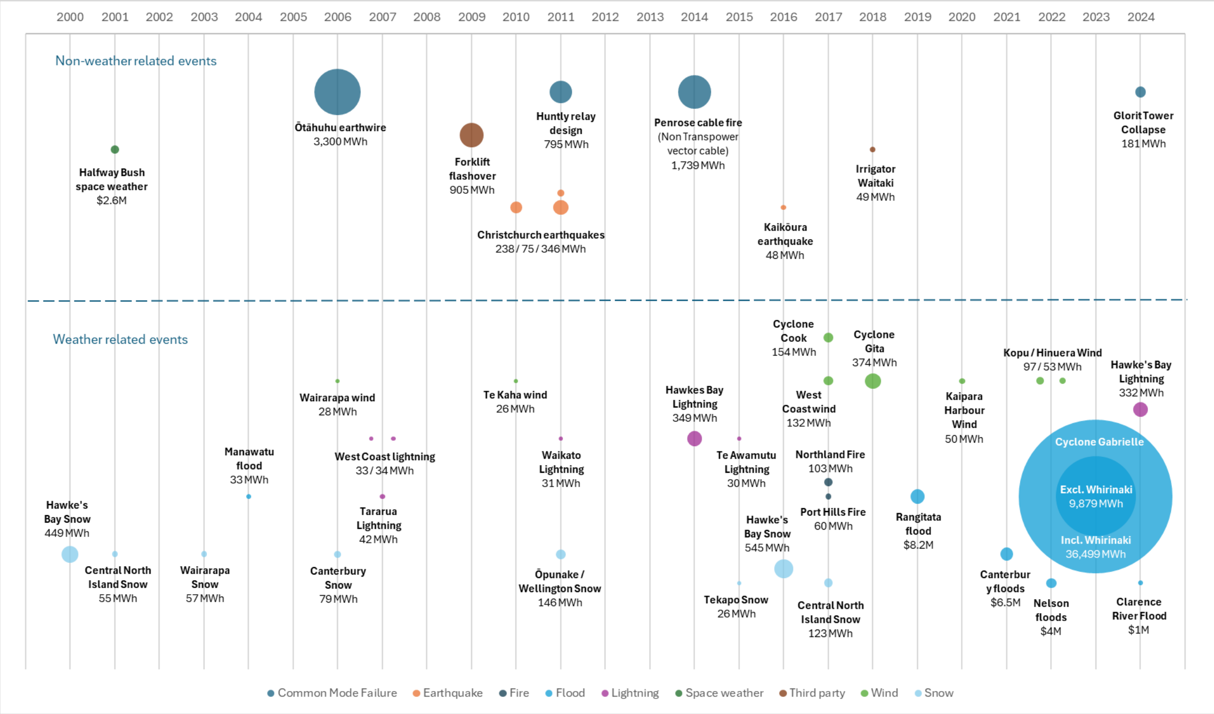
On the demand side, weather is a significant driver of seasonal and diurnal load variation, so the ability to forecast the weather accurately is vital for power system planning. In the extreme, severe weather events are having greater impacts on power system assets, requiring greater preparation for managing emergencies and replacing damaged equipment. We also need to have dynamic assumptions for planning outages against that look ahead weeks and months. These changes require the System Operator to be able to provide robust guidance on how reliable renewable generation is, noting that as renewable generation grows its diversity ultimately increases its reliability. The scale of that reliability and the consistency of how it plays out will need to be carefully monitored and modelled in future.

5.1 Climate change and severe weather is impacting the energy sector

Weather events are increasing in frequency and severity globally, and in New Zealand. Power system assets are being impacted by higher winds and variable rainfall, leading to a reduction in physical resilience. Communities are responding, with greater attention being paid to regional self-sufficiency. This is influencing individuals' decisions to invest in consumer energy resources and prompting interest in whether decisions to invest in particular locations are more than simply economic.

Operationally, extreme weather can lead to grid emergencies, with the potential for unexpected asset impacts and involuntary demand reduction. Our control room operators need to be well prepared to manage high-impact low-probability events, while continuing to do their 'day jobs' for unimpacted areas of the network. As a business we need to have sufficient capacity – people and systems – to manage multiple events at one time.

Transpower analysis of transmission events



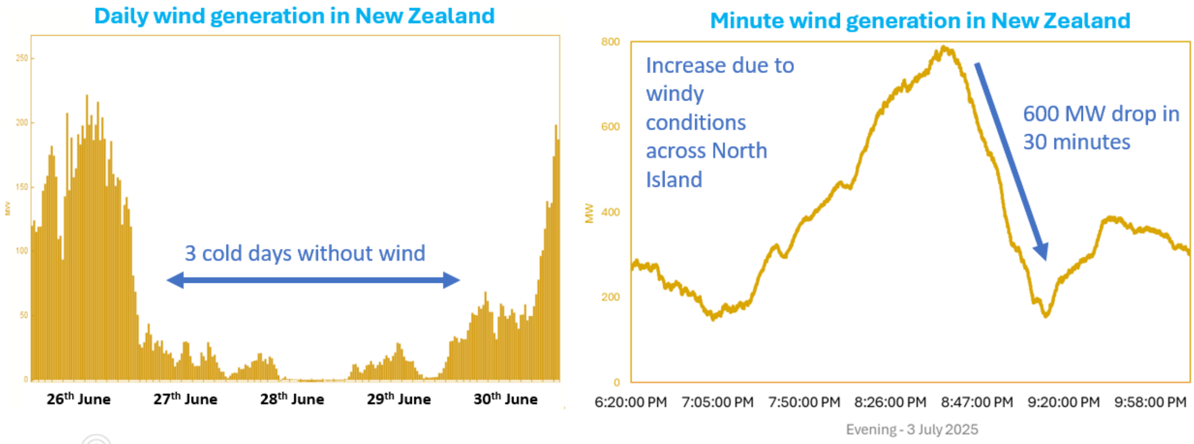
Source: Transpower

5.2 Electricity generation is becoming more dependent on the weather

As the proportion of intermittent generation on the power system increases, our ability to operate the system becomes less certain. We are more sensitive to changes and forecasting short-term wind and solar availability. At the same time, changing longer-term weather patterns impact our ability to predict hydro lake inflows, making it harder to ensure sufficient energy storage (and creating greater uncertainty in market trading, which presents as a risk premium on consumers' energy payments).

Balancing the supply of energy with demand each second of the day requires a combination of sufficient responsive reserve (flexible firming) capacity and regular system redispatch—regularly instructing changes in generation output to meet changes in load. As the amount of non-dispatchable intermittent generation increases, the amount of reserve capacity also needs to increase (on average) to ensure consistent supply. The need for reserve capacity also increases with increasing variability in demand forecasts, also driven by weather variability. As noted above we expect to need a review of how the energy-reserves co-optimisation occurs in the New Zealand power system in the near future.

Examples of wind generation patterns



Source: Transpower

6 SOCIETAL AND CONSUMER EVOLUTION

As a sector we depend on our social licence to operate — what we do and how we perform must align to what society expects of us. Consumer expectations for affordability and reliability are changing, and the electricity industry is under constant pressure to reduce its costs and demonstrate its value. Alternatives to traditional central generation supply are rapidly becoming more affordable and consumer energy resources (CER) will build to a level that challenges our ability to operate, firstly in the distribution networks and ultimately impacting on transmission system operations. This changing mix also introduces concerns about cybersecurity risk which also plays into consumer expectations about reliability and maintaining a secure system.

At the same time New Zealand's demographics are shifting and the sector workforce is aging. We enjoy the benefits of New Zealand being a desirable location for skilled workers from overseas, but we are competing in a global market for talent. Our unique and valuable skilled workers may find more opportunities elsewhere, particularly in Australia. As demand for electricity services increases we need to ensure we are creating opportunities for talented people of all backgrounds to contribute to the sector.

6.1 Changing New Zealand demographics and workforce

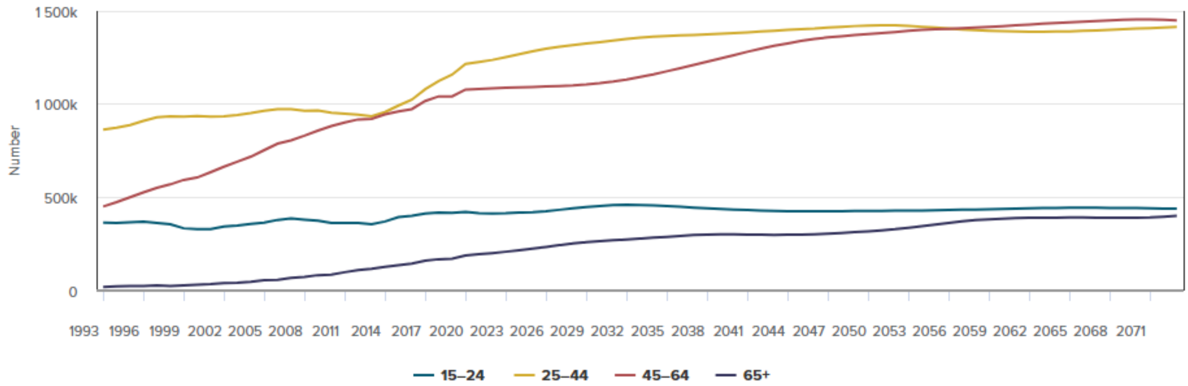
The workforce in New Zealand is projected to "grow and grey"[17] over the coming years. We expect that availability of skilled workers will continue to be an ongoing concern for the electricity industry. At the same time, New Zealand's demographics are changing. As a sector we need to recognise the potential of people who have not 'grown up' within the industry and create opportunities for people from current gender and cultural minorities to join and feel welcome working with us.

There has been significant growth in the Māori economy and the Māori population. Between 2018 and 2023 the Māori population increased by 14 percent from 775,800 to 887,500.[18] The Māori population is growing significantly faster than the non-Māori population and is younger on average compared to the general population. The total number of Māori employed has increased and more Māori are now employed in high-skilled jobs compared to those in low-skilled jobs. In 2023, the Māori asset base was valued at $126 billion (an 83% increase from $69 billion in 2018).[19] While the traditional sectors of agriculture, forestry, and fishing are still significant, the Māori asset base appears to be diversifying. The Māori economy has almost doubled its contribution to Aotearoa's GDP ($32 billion in 2023, up from $17 billion in 2018). One of the three largest sectors was professional, scientific, and technical services at $5.1 billion. Māori have previously been involved in energy production with interests in geothermal and hydro resources. Now with the Māori economy showing rapid and significant growth and a diversifying asset base there are opportunities for Māori to partner in the energy sector and contribute to New Zealand's economic future.

Migration is a significant driver of workforce changes. New Zealand is attractive to highly educated workers from overseas.[20] This will help us to attract and retain the skilled workers in demand in the industry. Conversely, Australia is a magnet for skilled talent, offering 30% higher wages on average, and it is particularly accessible for New Zealand residents. Our ability to train and retain talent in New Zealand's electricity sector is strongly influenced by the comparative opportunity across the Tasman. Like most businesses in the sector, and particularly given our central role, it will be important for the System Operator to have the ability to develop a pipeline of suitably qualified talent and invest in the retention of that talent.

[17] Labour force projected to grow and grey | Stats NZ
[18] MBIE (2023) Te Ōhanga Māori 2023 Te Ohanga Maori 2023 report
[19] BDO (2025) Pūrongo Pakihi Māori BDO Māori Business Sector Report 2025 - BDO
[20] Talent Attractiveness 2023 | OECD

Trends in the labour force: number of people by age group



Source: Statistics NZ

6.2 Increasing reliance on electricity

Consumers are shifting away from fossil fuel energy sources such as natural gas for heating and liquid fuels for transport. This is noteworthy particularly in the residential sector where electricity consumption is now the largest single electricity using sector.

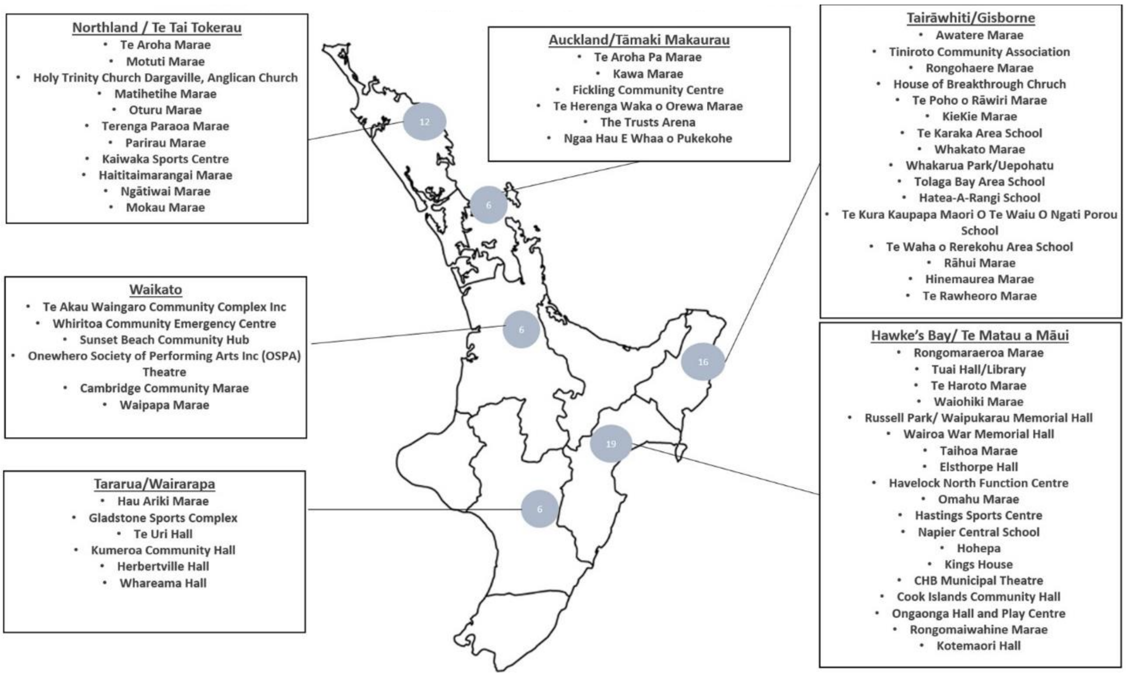
Consumers are increasingly reliant on electricity for heating, with the 2023 census showing heat pumps were used in 66.8% of homes, up from 47.3% in 2018.[21] The increasing affordability of electric vehicles means they are also becoming more reliant on electricity for transport. Declining natural gas availability is likely to shift energy consumption from gas to electricity as people change appliances. We expect increasing reliance on electricity to lead to less consumer tolerance for electricity supply interruptions and increased pressure on the industry to deliver low electricity prices to consumers. Ultimately this will result in a busier industry with generation growth requiring more effort to enable connections and market registrations. There will also be step changes in operational processes as the increasing demand is met by intermittent generation (solar and wind) and increasingly distributed energy resources (DER). These impacts are discussed further in later sections.

6.3 Greater emphasis on community resilience

There is increasing interest in and focus on resilience, locally and globally. Locally, we are seeing increased interest in community resilience as it relates to the power system. A survey result from the Consumer Advocacy Council found that, for small businesses and residential consumers, resilience ranked as their second biggest electricity-related concern after affordability.[22] Relative to our international peers, a large proportion of our infrastructure is exposed to a broad range of natural hazards, exacerbated by Aotearoa's geography and increasingly our exposure to the growing frequency and magnitude of weather events. One driver for this has been the severe weather event experienced in the North Island in 2023. The Ministry of Business, Innovation & Employment (MBIE) set up a Community Renewable Energy Fund (CREF)[23] to fund solar PV and battery systems to be installed to community buildings, on the basis that community buildings are important to civil defence during emergencies. A recent Electricity Authority green paper[24] highlighted a trend towards considering decentralised energy planning, such as peer-to-peer schemes and community virtual power plans.

[21] 2023 Census population, dwelling, and housing highlights | Stats NZ
[22] Consumer Advocacy Council consumer sentiment survey 2024
[23] Community Renewable Energy Fund | Ministry of Business, Innovation & Employment
[24] Working together to meet the needs of New Zealanders | Our consultations | Our projects | Electricity Authority

Location of Community Renewable Energy Fund sites across the North Island



Source: Electricity Authority Green Paper[25]

We expect to see a continued focus on community resilience over the long term. The ability for communities and regions to self-supply has implications for how transmission outages are managed and how the electricity market reflects the value of regional investment in electricity supply. These impact (positively and negatively) our ability to plan outages and schedule generation in a way that reflects community needs, for example, where there is little spot price impact it may be prudent to schedule generation to maximise reserve capacity in vulnerable areas.

Additionally, consumers have more ways to get involved in the electricity market than ever before, with the increasing availability of affordable rooftop solar, electric vehicles, smart meters and time-varying retail pricing plans. We expect to see a continued growth in the uptake of these options over time, as technology affordability, awareness and trust grows amongst consumers. Strong uptake of consumer energy resources, particularly generation and storage devices, will have a significant impact on how the power system is operated and the decisions which drive transmission investment. This is discussed further in the section on Technological Change below.

6.4 Increasing vulnerability to cyber risks

The electricity sector in New Zealand consists of multiple businesses with different roles and levels of capability. There are twenty-nine distribution companies, with operations ranging from large urban networks to smaller rural systems. Their size and technical sophistication vary; some have extensive networks with automation, while others operate on a smaller scale with basic setups. Electricity generation is dominated by five main firms, but smaller generators also contribute. Distributed and embedded generation, such as rooftop solar and industrial cogeneration, adds further complexity.

This diversity helps decentralise supply, but it potentially increases risk. Some smaller operators may not have robust cybersecurity measures, while larger organisations face complex threats due to their scale and connectivity. The interconnected nature of the sector means that a failure in one area may affect the wider system.

[25] Working together to meet the needs of New Zealanders | Our consultations | Our projects | Electricity Authority

Transpower uses the Inter-Control Centre Communications Protocol (ICCP) for secure, real-time data exchange with industry partners. Telemetry links with external parties, such as generator and distributor control centres, are being migrated to this standard. The ICCP system transmits critical functions, including dispatch instructions, over secure channels. Transpower also operates the TransGO telecommunications network, which connects substations and control centres for protection and SCADA communications. This private, fibre-optic network allows Transpower to monitor and control the grid, as well as operate the wholesale electricity market systems, without relying on public internet networks.

While New Zealand has not experienced major cyber-induced outages, international incidents are increasing and cybersecurity risk in the electricity sector is no longer confined to firewalls and passwords. Our analysis shows there are three critical emerging areas of threat.

- **Supply Chain:** Sophisticated cyber adversaries increasingly bypass direct attacks by targeting third-party vendors, suppliers, and service providers with privileged access. Considering this sector, this can include manufacturers of operational equipment, software vendors supporting SCADA and corporate systems, and contractors with remote access for maintenance. A compromise at any point in this chain—whether through malicious code in a software update or stolen credentials—can serve as a gateway into critical infrastructure.
- **Geopolitics and State Actors:** Geopolitical tensions are reshaping the threat landscape for critical infrastructure, with state-sponsored cyber actors increasingly targeting electricity networks as part of broader strategic campaigns. Groups such as Volt Typhoon and Salt Typhoon, linked to the People's Republic of China, exemplify this shift—operating stealthily within energy and telecommunications systems to establish footholds for potential future disruption. Their tactics, which blend into normal network activity, make detection particularly challenging.
- **Personnel and Human Engineering Risk:** Personnel risk remains one of the most persistent and complex challenges in cybersecurity. Inadvertent errors and insider threats can undermine even the most robust technical controls. The rise of AI-assisted impersonation— through hyper-personalised phishing, voice deepfakes, and synthetic personas—has elevated the threat landscape. These techniques blur the line between legitimate and malicious communication, making user awareness and rapid reporting essential.

Going forward there is a clear need for a coordinated, sector-wide approach to cybersecurity and reliability within New Zealand's electricity sector. As the threat environment continues to escalate government and industry must work in partnership.

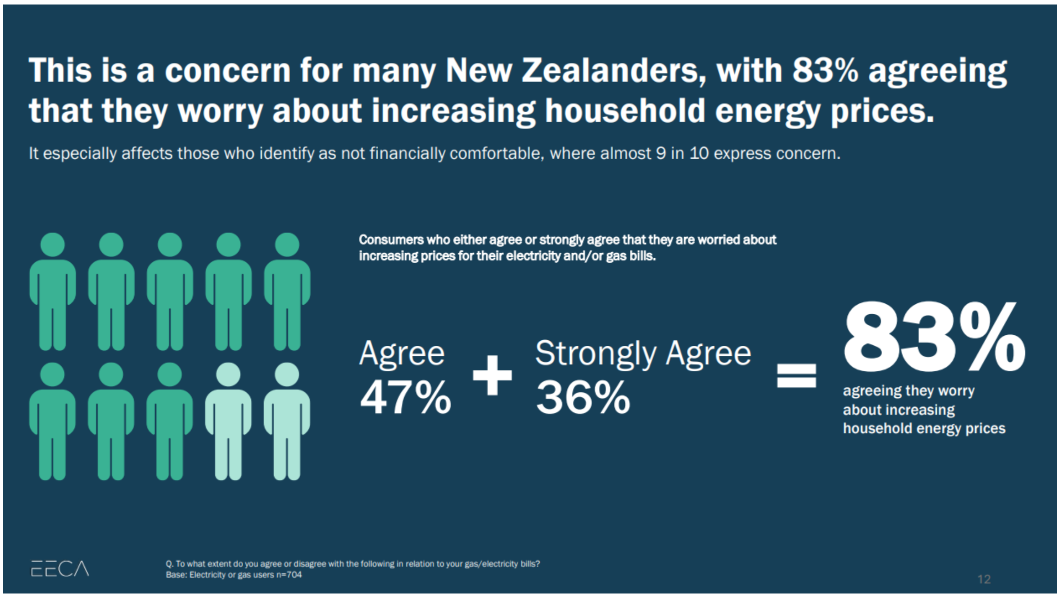
6.5 Affordability is a major concern for consumers

Energy affordability is a core pillar of the energy trilemma. Electrification is only likely to occur if electricity is affordable and competitive against other forms of energy. This is also increasingly challenges by the increased costs from delivering a more resilient electricity system as noted above. A study by the Energy Efficiency and Conservation Authority (EECA) found that 83% of New Zealanders worry about increasing household energy prices.[26] Amongst those who did not consider themselves financially comfortable, this proportion was even higher, at closer to 9 in 10. Avoiding increases in energy bills was ranked as residential consumers' number one concern.

On the positive side, electrification itself will provide a pathway to lower overall energy costs for consumers of the future. We expect that affordability will continue to be a high priority for consumers over the long term.

[26] Energy Efficiency and Conservation Authority, Consumer Energy Monitor Q1 FY25

New Zealanders worry about increasing household energy prices



Source: EECA – Community Energy Monitor, Q1 2025

As System Operator we need to ensure that our market is delivering the most efficient pricing outcomes for New Zealand's consumers and that we support a vibrant and competitive market. That requires to ensure that we continue to prioritise and support development of efficient products and services, invest prudently in our people and systems and work with the Electricity Authority in their monitoring and enforcement role.

7 TECHNOLOGICAL CHANGE

It is clear from the various trends and issues that have been discussed that the energy sector in New Zealand is facing some fundamental shifts. This is particularly the case when it comes to the impact of technology. Technological changes impact both what the sector must deliver but also how it will deliver. There are a huge range of potential benefits from new technologies. They hold the promise of supporting better optimisation of existing assets, more robust simulation and training environments and significant efficiency benefits. But with that promise comes significant complexity. The power system has always been complicated but technology is driving much greater complexity in power system operations which must be addressed on top of the increasing volume of work due to greater numbers of market participants and grid investment.

7.1 Trends in system inertia in Aotearoa

Worldwide, the proportion of generation from intermittent sources and inverter-based resources (IBRs) connected to power systems is increasing rapidly, and New Zealand is no different. This trend leads to challenges for our power system, but we are also starting to see market and technological developments overseas that are taking advantage of the capabilities of these technologies to mitigate the risks to the power system. The decreasing proportion of synchronous generation lowers system inertia,[27] particularly at times of high wind and solar generation. With lower inertia the system is more vulnerable, as the speed at which frequency varies after an event increases and will impact on the types and quantity of reserves we need to procure to avoid either AUFLS events or potentially cascade failure. Our modelling indicates that we are already crossing estimated minimum inertia thresholds for some periods.[28] The New Zealand power system will likely need new or enhanced ancillary services to manage our frequency risks.

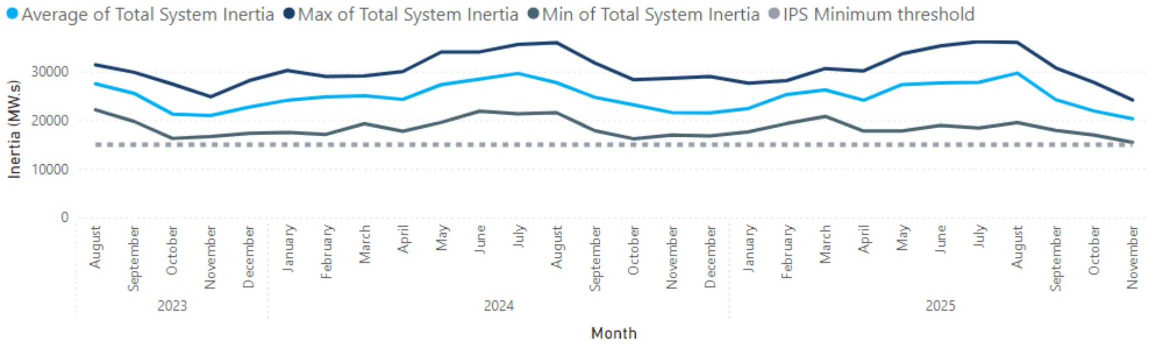
IBRs are also less well suited to low system strength conditions. We have already seen events overseas[29] where IBRs have struggled to maintain synchronism leading to interactions between control systems and causing oscillations on the power system. IBRs contribute to lowering system strength generally, and in other jurisdictions operational interventions and investments in reactive support equipment have been required to mitigate this challenge. These changes have significant impact on day-to-day power system operations and exacerbate system events. Managing voltage to avoid cascade failure, one of the principal objectives of any system operator, is becoming more difficult, and more work is required in the planning phase of new connections to ensure new equipment added to the power system interacts positively with the rest of the network. Existing control mechanisms such as switching circuits out during low load periods is being shown to have unexpected consequences and impacts to system strength, which has follow-on impacts for stability. Periods of low net-load (load supplied by central generation through the transmission network) will become more common as the uptake of distributed solar photovoltaics increases, so system operations will become more involved. As each power system is unique, while international experience can inform the technical risks we are likely to face, the mitigations we put in place must address the particular needs of New Zealand's power system.

[27] The Electricity Authority publishes system security and resilience indicators here: Future security and resilience indicators | Electricity Authority

[28] https://www.ea.govt.nz/documents/8567/FSR_Minimum_system_inertia_study_report.pdf

[29] Particularly events in Odesa, Texas and on the Iberian Peninsula.

Trends in system inertia in Aotearoa



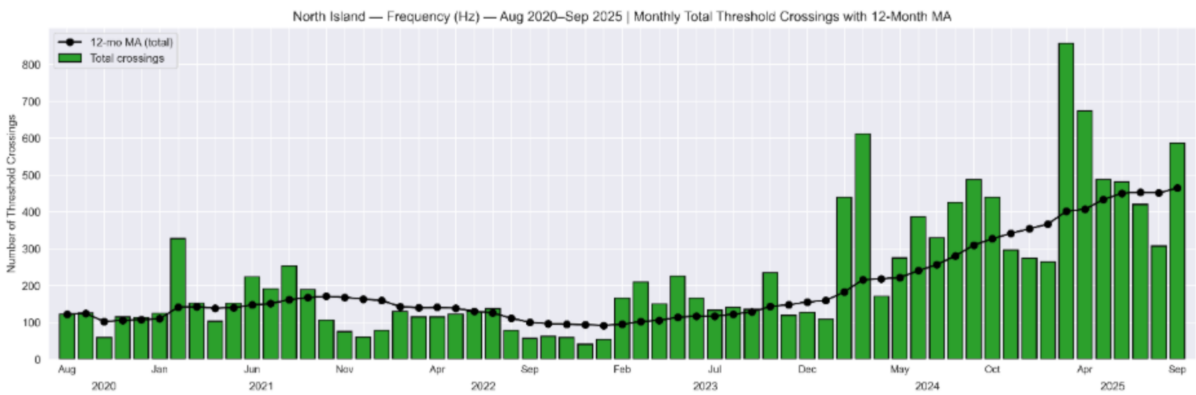
Source: Transpower

Inertia and System Strength

What is system inertia? System inertia refers to the energy stored in the rotating shaft of generators, motors and other industrial plant as they rotate at a speed that is synchronised to the power system's electrical frequency. Inertia helps the system operator manage the frequency of electricity across the power system. Inertia is particularly important for slowing the rate at which frequency changes due to a disturbance on the power system that affects the electricity demand / supply balance. A low inertia system has an increased rate of change of frequency (RoCoF), which means a faster response from connected machines and systems is required to recover the lost MW following a frequency event.

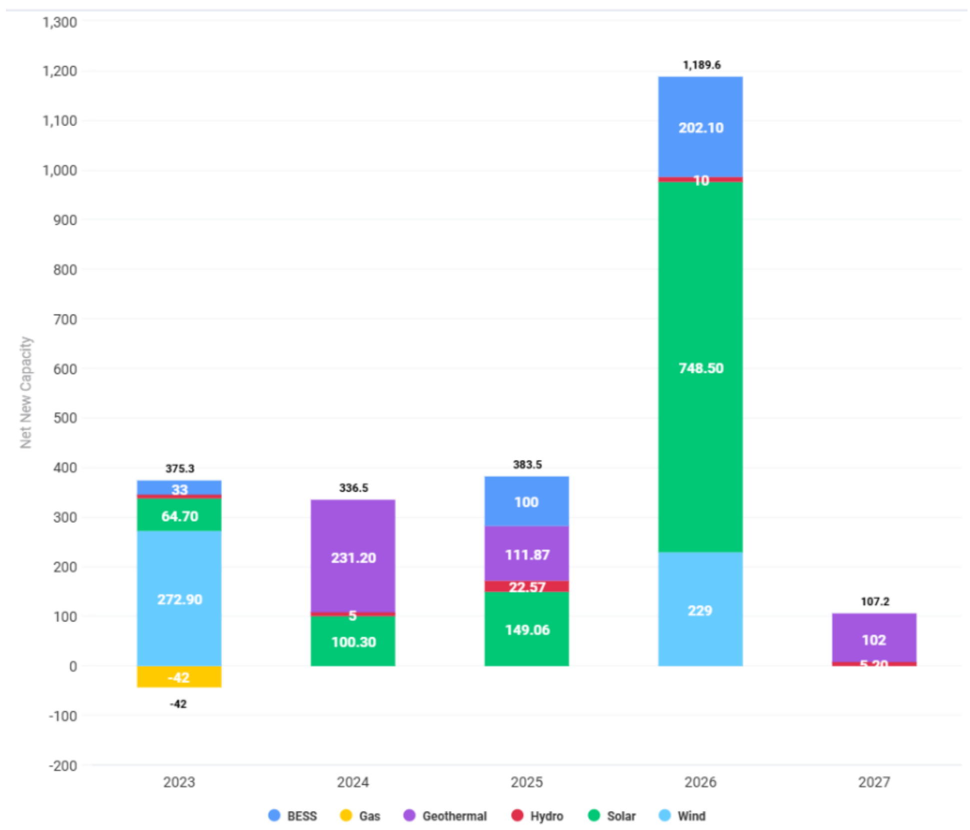
What is system strength? System strength is a measure of the power system's ability to maintain a stable voltage waveform and recover following a fault or disturbance on the system. Low system strength connections make voltage harder to control as the system is voltage is more susceptible to being moved around due to changes in reactive power output or absorption. Inverter based resources (particularly grid-following) may have challenges remaining synchronized to the grid following large disturbances in low system strength conditions.

Frequency threshold crossings in the North Island



Source: Transpower

Total new generation commissioning (MW) by first sync date



Source: Transpower

Managing these risks is contingent on being able to monitor system health effectively. Transpower already maintains a network of power quality monitoring devices on the transmission grid and requires asset owners to also provide information to augment that data. However, to monitor the new risks requires vastly higher resolution data than we currently source. New computation and communication infrastructure is required to transport the required data for analysis and real-time monitoring. Importantly, system controllers and coordinators, as end users of the data, must be able to access and act on intelligent insights. This is discussed further below.

Internationally, these new phenomena have resulted in significant power system events, such as in Odessa, Texas and on the Iberian peninsula, described in the table below.

Event and Jurisdiction	Observation
2017 ERCOT SSO Event, Texas	Oscillations between 22-26 Hz identified on three separate occasions when unrelated contingencies caused several wind farms to become radially connected with a line with series capacitors for compensation. Oscillations lasted until either the wind farms tripped, or the series capacitors were bypassed.
2019 Great Britain disruption, United Kingdom	An offshore wind farm was experiencing poorly damped 9 Hz oscillations. A lightning strike caused a nearby transmission line to trip, which lowered system strength, prompting the wind farm to inject reactive power. This caused the oscillations to become undamped and the turbines de-loaded. The ramp down of the wind farm combined with other generation loss caused widespread interruptions.
2020 West Murray Zone SSOs, Australian NEM	Beginning in August 2020, oscillations between 15-20 Hz in the West Murray Zone were observed on various occasions. Analysis eventually identified that some solar farms had an underdamped 17 Hz mode when system strength and irradiance were low.
2025 Spain, Portugal power outage	Increase in net load (either through distributed generator trippings, variation in solar and wind resource, or additional load) led to a series of trippings, cascading into an over-voltage and under-frequency event which collapsed the Iberian Peninsula power system. This blackout was the most serious incident to occur on the European power system in over 20 years.

The Iberian peninsula event was "the most severe power system event in Europe in over 20 years, and the first ever of its kind".[30] Reports on this event identify several factors but include oscillations on the system, actions to strengthen the system which led to challenges in managing voltage and the inability of IBRs to remain connected to the system.

Voltage and frequency in the Spanish power system

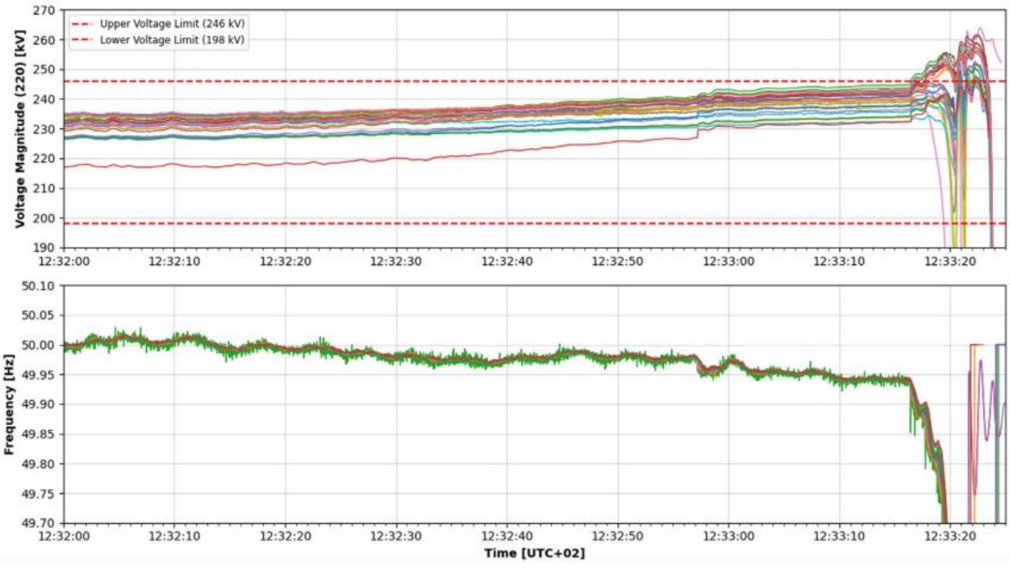


Figure 3-4: Evolution of the electrical quantities in the Spanish power system during the event

Source: Grid Incident in Spain and Portugal on 28 April 2025, ICS Investigation Expert Panel

[30] ENTSO-E (2025) 28 April 2025 Iberian Blackout Factual Report. https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/

Whilst the new technologies introduce change and challenges for managing power system risks, they also introduce opportunities. BESS technologies enable much faster response to frequency changes, and inverter technologies are increasingly able to assist both frequency and voltage management and potentially mitigate control system interactions. So called 'grid-forming' inverters are being integrated into ancillary service markets and connection requirements. To take advantage of these technologies will require cross industry work to review and design market rules, market products, mitigation measures. Common to this work is the need to model and analyse our system and to invest in different tools.

7.2 Decentralisation and distributed energy resources

Technological developments in power electronics and generating technology, particular solar photovoltaic panels, have enabled a proliferation of smaller-scale participation. Internationally this has driven extraordinary change in the operating load profile of power systems—in Australia, states now routinely export more power than they consume on sunny days, and AEMO has had to establish new procedures for managing minimum load conditions.[31] Distributors, traditionally employing long-lived assets for delivering electricity from the grid to consumers, now contend with power being exported from their networks. Where this causes congestion on distribution networks, the sector is considering employment of Distribution System Operators to ensure maximum collective benefit is realised from these new assets.

The term Distribution System Operator can mean different things to different people. Our view is that implementing DSO capability means running the distribution level like the transmission system, that is, having the physical capabilities in the network to manage two-way flows of energy, understanding actual asset conditions to efficiently use available network capacity and proactively orchestrating required changes to the system in a dynamic way to maintain grid reliability. In this sense we are interested in the physical capabilities of distribution businesses to support required operational changes on their networks so that when demand response, for example, is required it can be delivered. We recognise that some distribution businesses are also interested in managing the financial flows associated with different products and services and creating distribution-level markets. We will leave these conversations to be progressed with the Electricity Authority. This Strategy will instead seek to consider the level of interoperability required between the wholesale power system and the distribution level in terms of our systems as well as the data and protocols required to support that physical interoperability to drive overall system benefits and support better consumer outcomes.

Decentralisation also fundamentally changes the way the transmission system is operated. The benefit is security of supply increases, as the net load on the system (the amount of demand needing to be met by central generation) decreases on average. Whereas demand has historically been reasonably forecastable, even to a highly granular location level, as solar PV penetration increases the net load being supplied by the grid is likely to become more variable. As local energy generation fluctuates, to maintain supply, any deficiencies must be made up from other generation around the country, which requires transmission and distribution infrastructure to transport. These resources can help facilitate planned outages in a secure way, but only if we have sufficient data and tools to help make informed planning decisions. This will require different tooling and methodology than what is employed today.

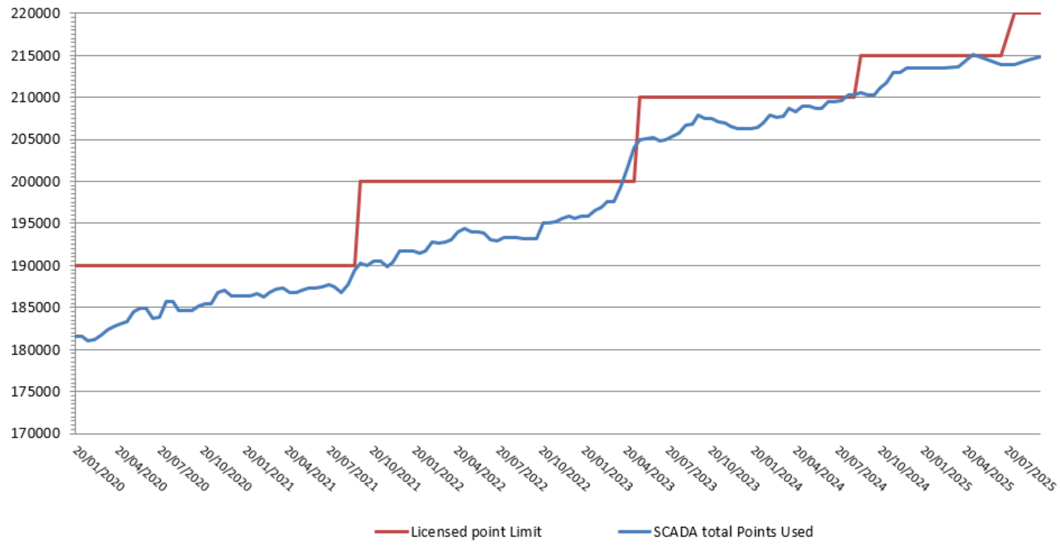
This mode of operating clearly drives a new system need: data. To be able to make reasonable forecasts of the state of the system and the degree of uncertainty in those forecasts, much more data and analysis is required. Advanced technologies for processing that data and deriving meaningful conclusions will be required. New policies and practices around equipment standards, interoperability, data stewardship and security will be needed to ensure all industry actors, from suppliers to consumers, have the right information when they need it.

[31] https://www.aemo.com.au/learn/energy-explained/fact-sheets/minimum-system-load

7.3 Data and digitalisation

Our increasingly digital society has created an explosion of data and information, and it is no different on the power system. We can take measurements at higher resolution and frequency and are developing novel techniques to process the enormous volumes of data being collected, using artificial intelligence technologies such as machine learning and neural networks. The ability to quickly draw intelligence from data is likely to improve forecasting and real-time decision-making, reducing system risks and driving economic efficiency. Overall, robust and accessible data infrastructure is a critical enabler for DER and ultimately consumer reliability and affordability.

SCADA total points used over time



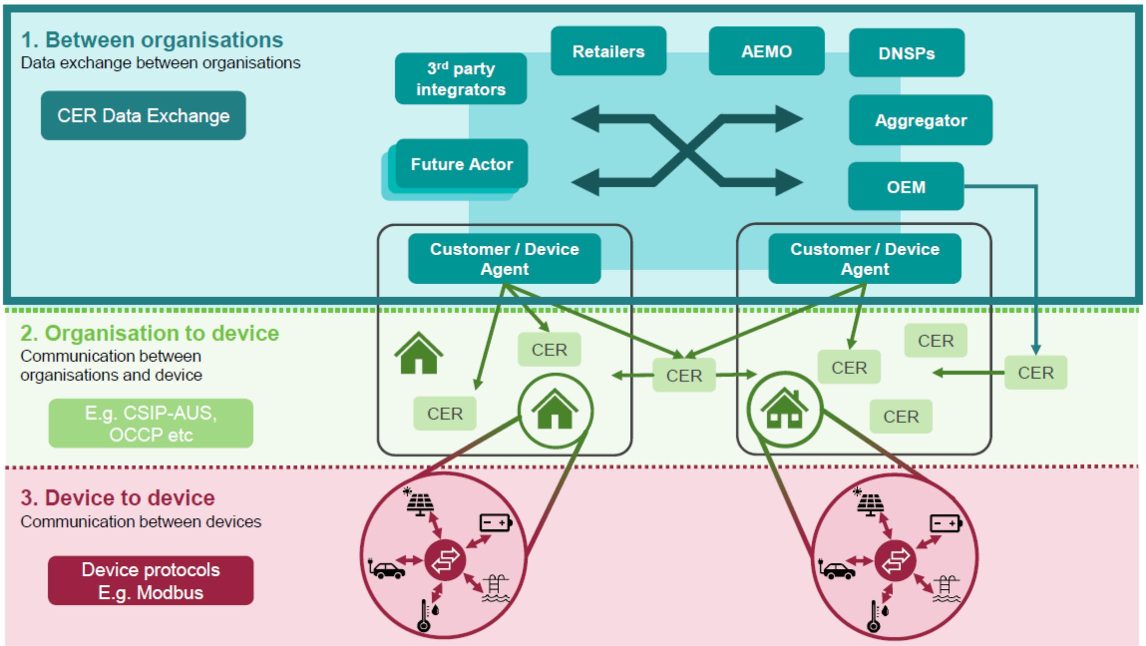
Source: Transpower

The proliferation of devices connected to the power system, whether they are kilowatt-scale photovoltaics at residential consumers' properties or grid-connected BESS, require standards to ensure safety, security and common quality. This extends to ensuring new assets are built with the capability to respond to control signals as system needs arise.

Data collection and sharing is vital to achieve visibility and coordination of DER, regardless of which entity is responsible for that control. Historically, network operators and retailers have installed monitoring and data management infrastructure, including smart meters and intelligent relays, to the extent which is necessary to serve their own needs. However, there is increasing value in these entities being able to exchange data with each other for the overall good of power system operations. Ultimately consumers will benefit from increased reliability and cost effectiveness when data interoperability and optimisation is improved. In Australia, this has led to a collaboration of industry bodies to develop a CER Data Exchange,[32] focussing on ensuring the necessary parties have visibility of the operation of consumer energy resources.

[32] Australian Energy Market Operator, AEMO | CER Data Exchange Industry Co-Design

An example of data and information integration in Australia



Source: AEMO[33]

Similarly in the UK, the Energy Digitalisation Taskforce recommended development of a "digital spine" for the sector—an energy system data sharing infrastructure.[34] Data sharing was identified as a fundamental component of the decarbonisation of the UK's energy system, and necessary to manage its increasing complexity.

As well as new opportunities, the rapid expansion in digital technology creates risks that utilities and asset owners must manage to ensure security of supply. This impacts both new assets connecting to the power system, and also the tools that operators use to manage networks. New DER devices, being largely commercial-off-the-shelf and internet-connected, may not come with robust cybersecurity protections by default, which in aggregate creates a significant risk of exploitation (see earlier section on increasing cybersecurity risks). In some cases, these technologies are also vulnerable to malign influence from state actors. Similarly, a more complex network requires sophisticated software solutions and network integration, many of which are vendor-supplied; as vendors meet their requirements to maintain operable and secure software, this is driving increased maintenance costs. Increasing digitalisation and mitigation of inherent risks will require greater interconnectedness among industry participants to collectively manage and enforce good data hygiene and cyber security.

7.4 Artificial Intelligence and advances in computing

Advances in artificial intelligence (AI) are expected to provide opportunities in the energy sector for a range of forecasting and data analysis applications. We expect to see increasing use of tools such as machine learning, digital twins of the power system, deep learning, and neural networks, both within system operations and other functions within the sector. Each of these tools has its own particular strengths and weaknesses, and we expect that time and effort will need to be spent on finding the right tools, or combination of tools, and right implementation methodologies, for each application. With the right investments in applying these tools, we expect to be able to process more data, faster and more accurately.

[33] AEMO | CER Data Exchange Industry Co-Design
[34] Digital spine feasibility study: exploring a data sharing infrastructure for the energy system - GOV.UK

Weather forecasting is one area where AI is already showing exceptional promise, with Google's GraphCast being shown to outperform traditional weather models in 90% of cases.[35] This has significant positive implications for demand, wind and solar forecasting and overall power system management. There are similarities between this application and power system state estimation, which is the foundation of real-time monitoring and contingency analysis (essentially shifting a computationally expensive power-flow modelling exercise to a data-driven statistical model).

Managing more variable resources will require large numbers of scenarios to be tested in power system models in control room timeframes (minutes to days ahead of real-time), and in outage planning timeframes (weeks and months ahead of real-time). Running these scenarios will require large numbers of dynamic inputs and produce large amounts of data. Advances in AI and computing will provide large efficiency gains that will help us manage the power system with more variable resources and more planned outages.

There are a range of other examples of work going on around the world leveraging AI for electricity system operations and connections. We have included a selection below and will consider these and others within the New Zealand context:

- EPRI's Open Power AI Consortium, launched in March 2025[36], to develop domain-specific large language models (LLMs) and generative AI tools tailored for the electric power sector. The goal is to create an ecosystem for safe, reliable, and regulatory-compliant AI applications, including: ChatGPT-like models for utilities trained on decades of EPRI's proprietary energy and engineering data. Use cases: operator decision support, outage management, forecasting, asset optimization, and customer engagement. These models are being developed using hundreds of NVIDIA H100 GPUs and will be available via NVIDIA NIM microservices for early access. The consortium includes major utilities (e.g., NYPA, Duke Energy, Southern Company), grid operators (MISO, PJM), and tech firms (Microsoft, AWS, NVIDIA, Oracle). EPRI emphasises sandbox environments for testing and validating AI before deployment, plus open-source libraries and curated datasets for industry-wide adoption.
- California ISO (CAISO) in partnership with Open Access Technology International (OATI)[37] is piloting OATI Genie™, a generative and agentic AI platform designed to transform outage management and broader grid operations. This initiative represents one of the first real-world applications of generative AI in a North American ISO environment. The initiative is aimed at streamlining outage coordination and review processes, enhancing situational awareness by synthesising complex operational data, and has potential for expansion to DERMS, microgrid control, energy trading, and transmission scheduling.
- PJM, the largest grid operator in North America, has launched a multiyear collaboration with Google and Tapestry[38] to deploy AI-powered tools aimed at streamlining its complex planning process for connecting new generation resources to the grid. This initiative addresses one of the most pressing challenges in the U.S. electricity sector: clearing the massive interconnection backlog while maintaining reliability and affordability. The aim is a significant reduction in processing times for new service requests (potentially cutting multi-year delays to weeks or months) and improved decision-making speed and accuracy, enabling faster integration of clean energy resources. the initiative supports PJM's transition to a cluster-based interconnection process and complements its broader automation efforts.

Further new technologies may also become feasible over the coming decade. Quantum computing is an example of one such technology which, while not yet ready to be applied at scale, has the potential to enable a step-change in computing capabilities, enabling probabilistic modelling and improved

[35] Learning skillful medium-range global weather forecasting | Science
[36] Building ChatGPT for the Power Industry: EPRI Leads the Way
[37] OATI Launches Generative AI Platform Pilot for Power Grid Operations with CAISO | American Public Power Association
[38] PJM, Google & Tapestry Join Forces To Apply AI To Enhance Regional Planning, Generation Interconnection | PJM Inside Lines

decision making. We think it is fundamentally important that we have the ability to stay across these developments and invest in solutions to support New Zealand at the appropriate time.

7.5 Impacts in control rooms

Operating the power system, whether from the System Operator's national coordination centres or within industry participant's control rooms, is a function of visibility, forecasting and control. The changing generation make-up and increasing variability in load is changing the way in which control rooms function – the data they need, how they make decisions, and the tools and systems used to monitor new system attributes and respond to events. System operators worldwide are grappling with how to ensure their controllers' cognitive loading remains manageable and that they are adequately equipped to continue operating growing power systems which are significantly more dynamic, unpredictable and complex than in the past. Digital technologies including artificial intelligence offer great potential to augment decision-making processes, provide the ability to handle the increasing complexity of the power system and improve the cost-effectiveness of electricity supply. We foresee significant benefit in our ongoing active involvement in the development of advanced digital technologies for control-room and system operations applications more broadly.

Control Room of the Future

The National Coordination Centres (NCCs) are at the heart of what we do as System Operator. The Control Room of the Future (CRoF) initiative aims to provide a strategic plan for Transpower's control rooms, across both system operations function (NCCs) and the grid owner function (National Grid Operating Centres, NGOCs), to ensure they can continue to deliver these vital services for New Zealand given the country's rapidly changing system attributes and associated operational impacts. By taking a view across both functions within Transpower, it aims to deliver efficiencies and avoid duplication of effort, to benefit consumers while maintaining impartiality.

We have aligned this initiative with the Electric Power Research Institute's (EPRI) CRoF framework, enabling comparison and leveraging of other international operators' assessments completed for the Global Power System Transformation Consortium (G-PST) and targeted research for evolving control room operations. This includes key operators in Australia, the United Kingdom, the United States, Ireland[39], Peru[40], Indonesia[41], and Colombia[42]. Through CRoF we have identified eight strategic shifts which will guide our plans to leverage data and technology advancements such as AI to evolve our control room operations, shown in the graphic on the next page.

CRoF will stand alongside the System Operator Strategy, providing valuable insight into the needs of our control rooms and a strong vision for how to get there. We are interested to hear stakeholder's views on this as part of the System Operator Strategy and will engage further in 2026 on key implementation initiatives like CRoF.

[39] G-PST-Vision-for-the-Control-Room-of-the-Future-V0.5-Final.pdf
[40] Control Center of the Future Road Map for Peru's System Operator, COES SINAC - Global Power System Transformation Consortium (G-PST)
[41] Control Center of the Future Assessment for Sulawesi Power System in Indonesia - Global Power System Transformation Consortium (G-PST)
[42] Control Center of the Future Assessment for XM Colombia - Global Power System Transformation Consortium (G-PST)

Control Room of the Future

EIGHT STRATEGIC SHIFTS

Standardised and unified operational data

Ensuring access to trusted, high-quality data that enables real-time operational intelligence and decision support for power system and market operations.

Streamlined and sensibly automated operational processes

Leveraging digital workflows and automation where sensible

Knowledge management capability

Operational knowledge is captured, maintained and accessible, enabling consistent, informed decision-making and continuous improvement of control room functions and capability.

Operational intelligence and decision support

Enabling operators to manage an increasingly complex power system through leveraging advanced analytics to deliver real-time and planning intelligence, decision support, and trusted recommendations.

Unified operator experience and advanced tools

Evolving our operational tools to meet the demands of a complex, changing market and power system—focusing on intuitive, unified, and resilient solutions, and ease of updates.

Operator learning evolution

Modernize training to ensure operators stay competent in managing complex power systems—both with automation and when it fails—through accessible, simulation-based learning.

Operational communications and event response

Leveraging technology to ensure our operational communications, logging and reporting is timely, appropriate and efficient.

Adaptable facilities and hardware

Maintaining secure, resilient facilities that ensure effective operations through intelligent systems, adaptability, and collaborative approaches.

DOCUMENT GLOSSARY

Term / Abbreviation	Description
AI	Artificial Intelligence
BESS	Battery Energy Storage System(s)
CER	Consumer Energy Resources, a subset of DER
Code	The Electricity Industry Participation Code 2010 and its amendments
DER	Distributed Energy Resources
DERMS	Demand Response Management System
DR	Demand Response
DSO	Distribution System Operator – an entity that manages congestion and reliability within a distribution network
EA	Electricity Authority aka the Authority
ECTF	Electricity Competition Task Force
EDB	Electricity Distribution Business
IR	Instantaneous Reserve
NCC	National Coordination Centre
NZX	New Zealand's Exchange (NZ's national stock exchange)
SO	System Operator – usually in reference to Transpower as New Zealand's System Operator
TSO	Transmission System Operator, as distinct from a DSO