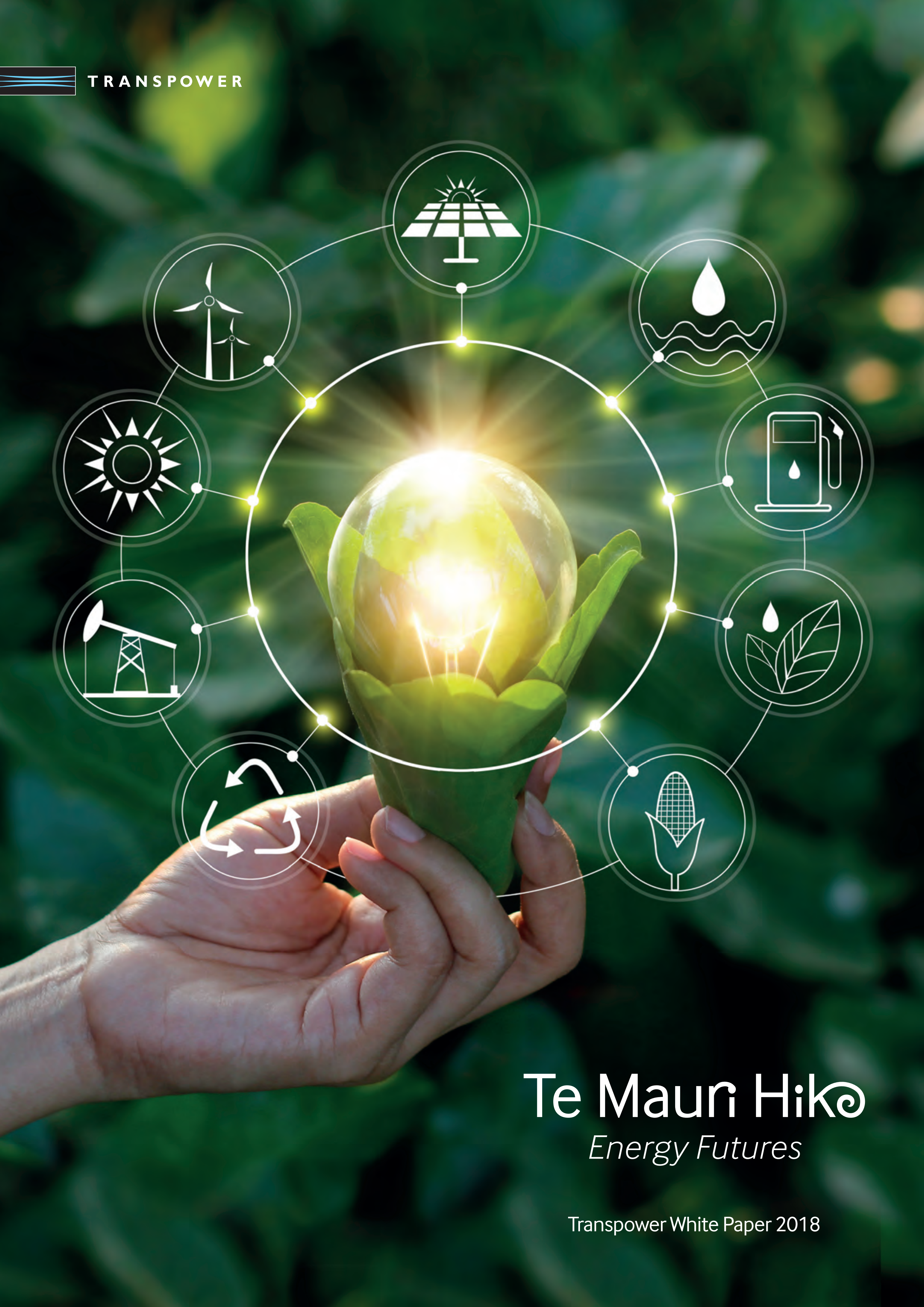
TRANSPOWER



Te Mauri Hiko

Energy Futures

Transpower White Paper 2018

Contents

All graphs use rounding, so may vary slightly from expected sums.

Te Mauri Hiko

Energy Futures

Transpower has commissioned the Te Mauri Hiko – Energy Futures project to closely examine a range of electricity supply, demand and future technology scenarios – and to begin exploring what will be required for New Zealand to maximise the potential of the energy opportunity we are facing.

Foreword

Tena koe

Our world is changing faster than at any other time in the history of humanity.

We rely on access to energy to power our way of life, but traditional forms of energy are compromising our climate – and the world we will leave to future generations. To realise a more sustainable energy future, New Zealand will need to embrace the energy technologies that are rapidly emerging.

The opportunity for a more sustainable future also brings with it implications for energy security and the development of energy policy, as well as the planning required to manage a secure power system.

From a policy and planning perspective, our country has a small window through which to ensure we get the settings right – enabling those new technologies that can deliver a secure, sustainable and affordable energy system for all Kiwis.

I am encouraged that through the Government's Electricity Pricing Review, the Productivity Commission's work into a low emissions economy, and the establishment of the Climate Commission, our country is beginning to engage in conversation about the important issues surrounding our energy future.

Transpower's commitment to providing independent, high-quality analysis to this conversation is what is behind the white paper, *Te Mauri Hiko – Energy Futures*.

The purpose of this paper is to examine the role of emerging distributed technologies (including electric vehicles, batteries and solar), and how an increased number of grid-connected renewable power stations across New Zealand may affect the power system. This paper also canvasses a range of global climate change scenarios as critical context into which energy decisions must be considered.

The decarbonisation of New Zealand's economy will depend on its renewable electricity base and will require widespread electrification of new parts of our economy, such as our transport and stationary energy systems.

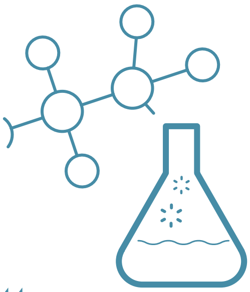
Transpower will continue to contribute to helping New Zealand realise the advantages of the increasing energy options available to it. *Te Mauri Hiko – Energy Futures* is a part of that commitment and I'd appreciate your feedback on it.

Nga mihi nui,

Alison Andrew Chief Executive

Executive Summary

New Zealand's electricity system is unique. There is no other country in the world that generates its electricity from the same mix of generation sources, with the same low levels of energy storage and without a grid connection to another country's energy resources.



"New Zealand must invest resources in innovation and adopt new technologies, as related to energy development – we do not have the luxury of time to follow the lead of others."

It's against this backdrop that New Zealand will shortly find itself in the midst of a global energy transformation. Significant new technologies are emerging, enabling households, businesses and the industry to rethink traditional notions of energy.

These technologies promise the ability to store energy in ways impossible in the past. They offer the possibility of a cleaner, more sustainable global energy system. Combined with political commitment expressed in policy, the emerging wave of energy technologies will transform New Zealand's energy sector.

The extent to which this transformation is successful in enabling a cleaner, more sustainable economy, with security of energy supply and lower prices to consumers, will depend on our ability to plan for and coordinate around a vision of the future.

Transpower has commissioned the Te Mauri Hiko – Energy Futures project to closely examine a range of electricity supply, demand and future technology scenarios – and to begin exploring what will be required for New Zealand to maximise the potential of the energy opportunity we are facing.

This report builds upon Transpower's *Transmission Tomorrow* research. When Transpower started looking into the future of New Zealand's national grid three years ago, we identified a future in which a resilient national grid would still be required to power communities across New Zealand, as well as its economy.

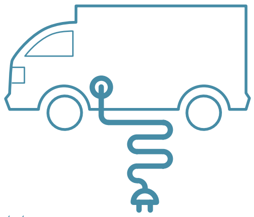
Transmission Tomorrow also identified technology on the horizon that would help deliver efficiencies throughout the electricity industry, with the possibility of reducing overall electricity demand from 2030.

While a resilient national grid remains at the heart of New Zealand's energy future, Te Mauri Hiko also highlights that a lot has changed in the last three years. Climate change has become a central issue for governments globally, technology continues to advance rapidly, and electricity is increasingly positioned as an energy source for whole economies, rather than just homes and some business processes.

Te Mauri Hiko provides an important and material update to the thinking of three years ago and highlights why constant review and inquiry is so critical during periods of change.

It's important in any discussion around the future – particularly during a period of exponential change – that no one party claims to have all of the answers. The goal of this exercise is not to predict the future. The New Zealand electricity sector is complex and challenging, and while there is considerable opportunity in the country's energy future, there is also a great deal of uncertainty.

There is a great deal of detailed analysis in this report and, as with any forward-looking piece of research, a number of assumptions. The key conclusions that underpin the essence of this report are that:



"The efficiency of converting electricity to transport energy is ~80 per cent while the efficiency of petrol is ~30 per cent and diesel is ~20 per cent. In industrial process heat, electricity's efficiency rate is ~95 per cent compared to ~80 per cent for coal, natural gas and oil."

Electrification will significantly decarbonise the New Zealand economy

New Zealand's international advantage lies in its ability to generate clean, renewable electricity. As New Zealand and the world increasingly focus on the pressing challenge of limiting greenhouse gas emissions, New Zealand will generate electricity from renewables and electrify other parts of its economy that are currently using fossil fuels – particularly stationary industrial energy and New Zealand's light and heavy transport fleets.

Electricity demand in New Zealand will double by 2050

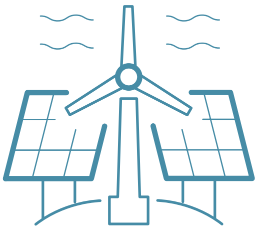
As the New Zealand economy electrifies in pursuit of the most cost-efficient and sustainable energy sources, electricity demand is likely to more than double from ~40 terawatt hours (TWh) per annum today to ~90 TWh by 2050. Electricity demand as a percentage of total delivered energy demand is estimated to increase from 25 per cent in 2016 to 61 per cent by 2050. Meeting this projected demand will require significant and frequent investment in New Zealand's electricity generation portfolio over the coming 30 years.

The transport future is electric

Electric vehicles (EVs) are expected to reach 40 per cent market share by 2030 and 85 per cent by 2050. EVs will be cheaper to run, cheaper to buy, cheaper to maintain, and will have a longer lifespan than internal combustion engine vehicles. Heavy land transport is also expected to electrify, but there is more uncertainty behind this assumption.

Demand will be met by renewable generation and new technologies

New Zealand's electricity sector will meet demand through the use of new technologies and require a wide mix of renewable energy technologies, consisting of grid-connected generation (primarily wind and hydro), plus a range of distributed technologies (primarily solar and batteries).



"under all scenarios new generation is assumed to be mostly composed of solar, wind, geothermal and some hydro."

A renewable future is the most affordable

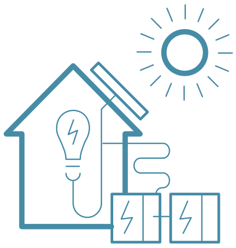
A renewable future based on New Zealand's abundance of renewable energy resources is likely to offer the lowest-cost energy future for consumers. New technologies, particularly solar photovoltaics (PV), batteries and smart appliances, will all decrease in price and place more control in the hands of consumers.

Winter and peak demand is still the biggest challenge to solve

None of this will be easy. While this report focuses on a base case scenario and reviews a number of other possible scenarios, the challenge in the future is similar to that which the energy sector currently faces. How, with low energy storage options, does the system reliably meet demand peaks, particularly in dry years and cold winters? New Zealand's current winter and peak-demand challenge is exacerbated under this report's scenarios, with substantially growing demand being met from increasingly intermittent energy sources.

Distribution is critical

While multiple new technologies will play their part in New Zealand's energy future, all parts of the system will need to be fully functioning to realise their potential. New generation will be both grid-connected and connected into local distribution networks. The national grid and local electricity networks will need to ensure sustained investment in their assets is sufficient to connect and reliably distribute new forms of energy. For the national grid, it is expected multiple new grid connections will be required from increasingly intermittent energy sources. Local networks will similarly need to consider how their assets will handle increasing peak loads, greater solar PV, and battery penetration and the charging of EVs.



"From our power stations to our transmission network to our local distribution networks to our homes, now is the time to prepare for the transformation we know is coming."

Risk is real

Electrifying New Zealand's economy also represents a concentration of risk. With more and more of the national economy dependent on electricity, as opposed to a wider range of energy sources (coal, gas, oil), the resilience and reliability of the electricity system becomes all the more critical to the country.

Policy and regulatory settings must explicitly acknowledge the investment demand pressures that New Zealand's energy future represents and encourage direct investment across all sectors of the industry.

Sustained investment in a secure, flexible and resilient energy future must occur in a planned and systematic way if these risks are to be adequately mitigated.

Electrifying New Zealand's economy is arguably the biggest single economic and environmental opportunity facing the country. It also represents significant risk.

Given the unique characteristics of New Zealand's electricity sector, the country does not have the luxury of sitting back and watching what the rest of the world is doing. New Zealand needs to plan meticulously and work together across the industry and government, and be prepared to invest in realising a very different energy future for New Zealand.

Introduction to the Te Mauri Hiko project

Project Background

Until recently, electricity demand could be projected based on population, economic activity and intensity of use. Changes in demand were gradual and there was a high degree of confidence in Transpower's assessment of future industry requirements.

Climate change and climate policies, global economic and political uncertainty, accelerating adoption of new technologies, evolving government policy, and the unique energy circumstances of New Zealand now require understanding of a much wider range of possible industry futures.

Given the scale of technology change and increasing environmental concerns, there is more uncertainty regarding the future Transpower will experience – and for which it will need to plan.

The period from 2025 to 2035 is of the most interest to Transpower. The period between now and 2025 is relatively well understood by the New Zealand energy industry, but will be a time in which steps are taken to secure a sustainable energy future. Transpower expects this period to be relatively predictable without significant unexpected changes.

Transpower must now set its sights beyond 2035, as it makes investments in assets that are expected to be in service for several decades. These investments need to be made early enough for them to serve their purpose, when there is simultaneously a level of uncertainty about New Zealand's energy future not previously experienced in the domestic electricity market.

This is the challenge Te Mauri Hiko seeks to address and to advance. The project team has developed a base case and a set of alternative scenarios to provide a robust basis for Transpower's decision-making.

Project phases

This project was completed over five phases by a combined team, starting in late-October 2017. A diverse group of individuals and organisations, from inside and outside of Transpower, have contributed to and critiqued this work, including policymakers, business leaders, energy consultants, scientists, future scenario planners and academics.

In Phase 1, the project team developed an understanding of the major drivers of New Zealand's energy futures.

Phase 2 focused on developing an 'outside-in' perspective on energy in New Zealand. The team researched the forces influencing energy both globally and domestically, developed a range of energy scenarios, and estimated the implications of the base case scenario for domestic energy supply and demand.

In Phase 3, the team narrowed its focus to electricity and estimated the implications of the scenarios for electricity demand, supply, storage and transmission in New Zealand. A series of internal and external workshops were run to test and refine emerging conclusions with experts.

During phase 4, the focus was on resolving material issues and uncertainties such as the implications of autonomous vehicles on available EV battery capacity or the economic feasibility of connecting New Zealand's and Australia's electricity grids. The estimates were refined, and initial hypotheses were developed regarding the implications of the project for Transpower and the wider electricity industry.

These hypotheses were further tested and validated during Phase 5, as the team prepared for another round of workshops, briefing sessions with leaders of New Zealand's energy system, and wider distribution via this report.

The report captures the team's thinking at the end of the project but should not be considered 'final'. The assumptions, scenarios and context of this paper will necessarily shift and change with time. This is the challenge of scenario planning in an age of increasingly rapid change. This is also why contributions such as this paper are so important to preparing for our collective energy future.

Analytical approach – an overview of supply and demand drivers

The research challenge behind Te Mauri Hiko was that global circumstances, policy settings, available technologies, electricity demand, supply, storage and transmission systems are all set to change, potentially significantly. Robust and quantified conclusions were needed without being able to analyse all possibilities.

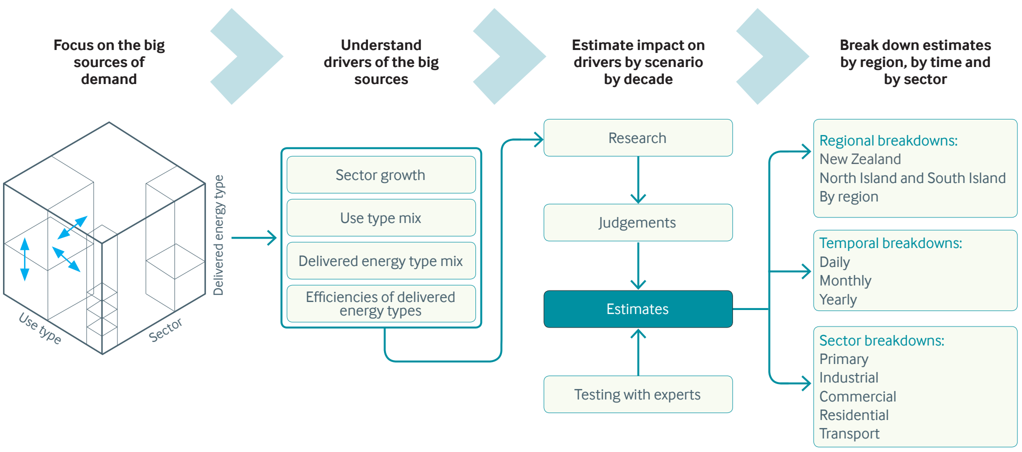
To manage this complexity, the project team broke analytical problems into solvable components, for example, by breaking down energy demand into demand by fuel type, by sector and by type of use. Approaches were developed which provided the minimum sufficient answer. Judgements were made based on the available evidence and an implicit recognition that there are asymmetric risks in underestimating demand (system failure versus a lower return on assets). Conclusions were debated and tested extensively among team members, with the steering group, and with experts via workshops and interviews.

To determine the implications of future energy scenarios for Transpower and the wider electricity industry, domestic demand, supply, and storage and transmission impacts needed to be estimated, by scenario, through to 2050. Analysis on both a national and regional level was required to understand the implications for the flow of energy between regions.

To estimate energy and electricity demand, the project team focused on understanding the drivers of the material sources of demand. For example, demand from the transport sector is driven by population, the number of vehicles per person (split between light transport and other use types), the average distance travelled per vehicle in a year, the speed at which EVs are adopted, and the differences in fuel efficiency between electricity and fossil fuels. Analysis was conducted and judgements made to estimate each driver of energy demand by decade and by scenario. Estimates were broken down by region, time (hourly within days, monthly within years, and annually) and sector. Throughout this process, assumptions and emerging conclusions were tested with experts.

Exhibit 1 illustrates the high-level approach.

Exhibit 1 **Estimating electricity demands**



The team followed a similar approach to estimate generation growth. The additional generation needed in TWh and gigawatts (GW) was determined by comparing demand growth against existing generation and expected plant closures under each scenario.

The team added the contribution expected from distributed solar PV generation by estimating the number of households and businesses that would install solar, and the generation potential that could be delivered with improved technology.

Finally, they estimated how the remaining generation gap would be filled with new utility generation by analysing future long-run-marginal costs of various generation forms, existing resource consents, and making qualitative judgements based on the supply scenario being considered.

The analysis concluded that battery storage is going to play an increasingly important role in the provision of electricity supply in New Zealand. Battery cost reductions, technology improvements, synergies with solar installations, and the need to reduce reliance on conventional thermal peaking plants combine to imply that batteries will contribute materially to meeting daily demand peaks.

Three kinds of battery storage needed to be estimated: batteries that accompany distributed and utility-scale solar installations, EV battery storage that can be available to the grid, and utility-scale battery-powered peakers that substitute for traditional peakers in meeting daily demand. The team also considered batteries for long-term storage but discovered this is not viable because of cost and limitations on the time that electricity can be stored in existing and emerging battery technologies.

To estimate potential residential and utility battery capacity, assumptions were made regarding how much capacity would be deployed alongside solar PV installations and how much of that capacity would be made available for supplying daily peaks.

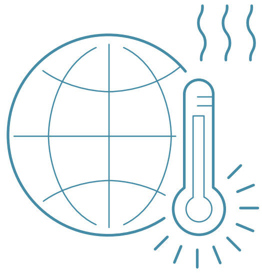
Storage from EVs was estimated based on the number of EVs expected in the national fleet and assumptions regarding the battery capacity that would be made available for discharging into demand peaks and the impacts of shared autonomous vehicle fleets. Utility battery peakers were added if available distributed and utility battery capacity was insufficient to meet the daily demand peak.

Transmission demands are difficult to estimate without the use of load-flow modeling, which was not feasible for this project. Instead, the team simplified the analysis by only considering indicative energy flows to and from three regions: the upper North Island, Hawke's Bay, and the high voltage direct current (HVDC) line between the North and South Islands. Based on the demand, supply and storage estimates, indicative estimates were developed for the three transmission lines and augmented with qualitative implications, for example, that voltage could become an issue in the North Island.

Transpower has commenced more detailed consideration of national and regional transmission system implications and challenges arising from Te Mauri Hiko's base case and alternative scenarios, as well as the ongoing work to identify any technical challenges that may emerge for the power system as a whole.

Factors influencing the future of electricity in New Zealand

Faster change and increasing uncertainty gives rise to long-term planning challenges. Analysis revealed five factors that are expected to strongly influence the future of electricity in New Zealand. They are: the risk of disruptive climate change, which is growing; the possibility of increasing economic, political and security uncertainty; new technologies that are disrupting the energy industry; evolving domestic policy; and New Zealand's unique combination of energy circumstances.



Climate change is a serious threat. Earth's temperature has already increased more than 1˚C over the average temperature in 1900.

Climate change

Climate change is a serious threat. Earth's temperature has already increased more than 1˚C over the average temperature in 1900. Another 0.6˚C increase is committed from emissions already in the atmosphere, with momentum for carbon emissions to drive an increase exceeding 2˚C. A 2˚C temperature increase over the 1900 average is the point at which scientists have concluded the risk of abrupt and seriously harmful climate change reaches 50 per cent.

There are reasons to remain optimistic that abrupt climate change can be avoided. Geoengineering interventions, which extract carbon from the atmosphere, are being developed. There are strong economic and geopolitical incentives to pursue climate-friendly policies – for example, to reduce reliance on Middle-Eastern oil. Awareness of the risks of climate change is increasing and leading to mobilisation.

The first-order impacts of expected and non-abrupt climate change in New Zealand may be less disruptive than elsewhere in the world. However, New Zealand should still expect more extreme weather events, sea-level increases within this century, and material changes to weather patterns. Second-order effects are likely to be more disruptive and potentially include impacts on global supply chains, more climate refugees, and conflict over scarce resources.

Economic, political and security uncertainty

In addition to climate challenges, the world also faces the potential for growing economic, political and security uncertainty. A future disrupted by any of these factors might experience materially less electricity demand driven by lower or negative economic and population growth, slower electrification of transport and process heat, and a shortage of resources available to transform the electricity system.

It is not the purpose of this paper to express a particular view on the prospects for the global economy or any economic measures such as employment or growth. However, for the purpose of scenario development, a range of outcomes was considered, including the electricity and energy-related impacts associated with a range of financial outcomes, including recessions and financial crises.

The same approach was taken in considering the energy implications of political and social tensions which, again, are likely to be affected by a range of environmental outcomes, including climate change and over-allocation of natural resources. These potential environmental outcomes will flow through into migration patterns. Protectionist policies aiming to increase self-sufficiency and to defend threatened industries may cause a reversal of globalisation and weaken ties between nations.

“More stringent climate policy is likely as it becomes widely understood that existing global targets fall well short of what would be required to reduce climate risk to acceptable levels.”

Again, it is not for this paper to predict outcomes here but rather to raise possible outcomes and implications in the context of how the world develops energy.

Disruptive technologies

Climate change, economic forces and geopolitical events represent risks that could lead the world towards a less attractive future than the base case scenario.

Developments in technology, however, support the ability to transform and steer the world towards a brighter future. The impacts of technological developments are diverse and uncertain, especially over longer time frames, but we have identified 10 impacts that are important to the evolution of New Zealand's energy system:

1. Electric cars are becoming economically competitive.
2. Electric trucks, planes and ships are being developed.
3. Distributed generation is becoming more accessible and effective.
4. Utility solar and wind generation are now competitive with conventional generation.
5. Batteries are becoming competitive for managing short-term demand peaks.
6. Unconventional generation and storage solutions are being developed, like nanoscale catalysts that convert water to ethanol.
7. Virtual/augmented reality and autonomous vehicles could reverse travel and urbanisation trends.
8. Advanced robotics and artificial intelligence could increase structural unemployment.
9. Smart homes, grids and markets challenge traditional utility business models.
10. Digital innovations enable new entrants.

Domestic policy

We expect New Zealand's climate policy to continue to evolve. Greenhouse gas emission reduction targets were agreed by New Zealand at the 2016 Paris Climate Accord and are currently being translated into climate policy. Central government is sending strong signals that it will take a more vigorous approach to emissions reductions and mitigating climate risk.

Corporates are advocating more strongly for early and decisive action – for example, Westpac and EY's recently released 'Climate Change Impact Report' argues that "taking earlier, planned action on climate change ... is modelled to save NZ$30 billion in GDP [gross domestic product] growth by 2050." More stringent climate policy is likely as it becomes widely understood that existing global targets fall well short of what would be required to reduce climate risk to acceptable levels.

The development of New Zealand's energy system is also uncertain. The landscape will change as demand grows, households and businesses become active participants in both supply and demand, new technologies are introduced, and new entrants like Amazon enter the market.

Digital innovations enable new entrants
Electric cars are becoming economically competitive
Electric trucks, planes and ships are being developed
Distributed generation is becoming more accessible and effective
Utility solar and wind generation are now competitive with conventional generation
Batteries are now attractive for managing short-term demand peaks
Unconventional generation and storage solutions are being developed like nano-scale catalysts that convert water to ethanol
Virtual/augmented reality and autonomous vehicles could reverse travel and urbanisation trends
Advanced robotics and artificial intelligence could increase structural unemployment
Smart homes, grids and markets challenge traditional utility business models
Identified technologies impacting New Zealand's energy system

New Zealand's unique energy circumstances

> There is a very strong incentive for New Zealand to pursue rapid electrification as the means of meeting its greenhouse gas emission obligations and moving the country as quickly as possible towards a lower carbon economy.

New Zealand's circumstances relating to energy and electricity are globally unique – no other country in the world has the same energy characteristics as New Zealand.

There is a very strong incentive for New Zealand to pursue rapid electrification as the means of meeting its greenhouse gas emission obligations and moving the country as quickly as possible towards a lower carbon economy. While agriculture produces more emissions than the entire energy sector, those emissions currently appear more difficult to curtail and have less potential as means of achieving emission reductions.

New Zealand also has a stronger incentive to electrify than most other countries because most generation is, and can continue to be, from non-fossil fuel sources. Many other countries lack a strong endowment of low-emission generation potential and in those countries electricity is much more likely to continue relying on generation using fossil fuels.

Where other countries will use solar matched to air conditioning to smooth seasonal peaks in electricity demand, New Zealand uses the greatest amount of electricity during winter. As solar will be significantly less effective in winter, but electrification will grow, the size of the winter supply shortage is expected to increase with the penetration of solar. New Zealand will continue to be exposed to winter and dry-year supply shortage risks because of continued reliance on existing hydro assets and the variability of solar and wind.

Finally, New Zealand is isolated from the rest of the world and therefore cannot rely on connection with foreign grids and collaborative load-sharing arrangements.

> New Zealand must invest resources in innovation and adopt new technologies, as related to energy development – we do not have the luxury of time to follow the lead of others.

These unique circumstances make it clear there will be need for a customised solution to meet New Zealand's future demand for electricity. New Zealand cannot wait for solutions to be developed and deployed overseas before importing them, and will need to be at the leading edge of energy innovation to supply winter demand, especially in dry years.

New Zealand must invest resources in innovation and adopt new technologies, as related to energy development – we do not have the luxury of time to follow the lead of others.

New Zealand's future demand for electricity. New Zealand cannot wait for solutions to be developed and deployed overseas before importing them and will need to be near the leading edge of energy innovation to manage winter demand and dry years. New Zealand must invest resources in innovation and adopt new technologies, as it relates to energy development, because it does not have the luxury of time to follow the lead of others.

New Zealand's energy transformation under the base case scenario

The base case

Under the base case scenario, the effects of climate change continue to increase as global average temperatures exceed 1.6˚C compared to the 1900 average. In this scenario, disruptive or catastrophic climate change is expected to be avoided by technical geoengineering solutions and vigorous coordinated efforts to reduce emissions.

There is widespread adoption of technologies that are available today, such as electric and autonomous vehicles. After 2030, future technologies that are on the horizon today, such as electric air and sea transport, are beginning to be adopted.

In New Zealand, the base case scenario includes a strong pathway to mitigating greenhouse gas emissions by electrifying transport and industrial heat systems and processes. The effects of climate change continue to increase – there are more droughts in the east, more rain in the west and more frequent severe weather events.

In recognition of the challenges presented by electricity system transformation, New Zealand takes a coordinated approach to industry development. Major challenges, such as deploying enough new generation or ensuring distribution systems operate effectively, are assumed to be navigated successfully.

Exhibit 2 provides a richer overview of the major components of the demand base case.

The base case energy supply scenario shows a continuation of current trends in generation and energy storage. Distributed solar PV generation becomes a material contributor to the country's energy mix, however, significant new utility generation is also required. Utility-scale wind, geothermal and solar generation make up the bulk of the new large-scale generation provided.

New Zealand's coal- and gas-fired peakers are fully retired, leading to a 100 per cent renewable electricity sector. Daily demand peaks are met by an ample supply of batteries that are deployed alongside solar PV installations and EV battery capacity.

Exhibit 2: **Overview of the demand base case**

Now to 2030

Global climate change

- Increasing recognition of climate change impacts and threat of abrupt change
- Temperatures increase towards 1.6°C above 1900 global average
- Renewable energy and electrification of transport and industry are prioritised

Global political economy

- Globalisation continues, populations and economies continue to grow without major conflict.
- Second global financial crisis in 2020s but is navigated successfully. Inequality continues to grow

Global technology

- Widespread adoption of electric and autonomous vehicles, robotics, smart homes, 3D printing, solar PV and batteries, new forms of renewable utility energy generation

NZ Climate response

- More climate change impacts—pressure grows to reduce greenhouse gases
- New Zealand takes a strong pathway to mitigating climate risk by electrifying transport and industrial heat

NZ industry development

- New Zealand takes a coordinated approach to industry development and resolving the challenges presented by widespread electrification
- Electricity markets evolve as mass participation, intermittent generation, battery storage and new players like Amazon enter

2030 to 2050

Global climate change

- Direct and second-order impacts of climate change grow as temperatures exceed 1.6°C
- Humanity avoids disruptive climate change thanks to geoengineering and large emitters reaching net-zero

Global political economy

- Geopolitical and economic insecurity continue to grow but without catastrophe.
- China and India successfully rise as global Superpowers
- Inequality grows and is exacerbated by unemployment following AI deployment

Global technology

- Future technologies arrive—electric air and sea transport, artificial intelligence, nanotechnology, new forms of energy generation (such as renewable hydrocarbons), and geoengineering
- Stage 1 technologies improved and cheaper

NZ Climate response

- Increasing impacts of climate change experienced
- Climate policy response continues and comes to fruition with widespread electrification of transport and industry complete

NZ industry development

- By the end of the period the electricity system has transformed and electricity makes up a much larger proportion of total energy demand
- Coordinated development addresses issues like uneconomic bypass, winter supply and dry-year security

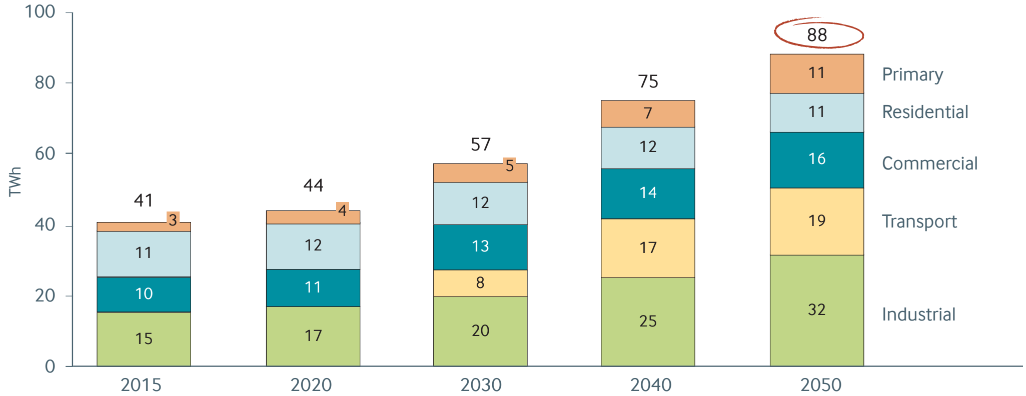
Base case impacts

Demand – the electrification of transport and industry

> **The major difference between the last 10 years and the next 30 years will be significantly more electrification – the shift from other energy sources (coal, gas, oil) to renewable electricity.**

In the demand base case, New Zealand's electricity demand is estimated to more than double by 2050. Today, New Zealand uses ~40 TWh of electricity per annum, or 40,000 gigawatt hours (GWh). By 2030, demand is estimated to have increased to ~60 TWh and to reach ~90 TWh by 2050. Exhibit 3 illustrates the projected growth in electricity demand to 2050 by sector, and reveals the industrial and transport sectors are expected to be the largest sources of growth.

Exhibit 3: **Estimated delivered electricity demand by sector**



The conclusion that New Zealand should plan for material demand growth may be surprising, as demand has been roughly flat for the last decade. The major difference between the last 10 years and the next 30 years will be significantly more electrification – the shift from energy sources such as coal, gas and oil to renewable electricity.

Electric vehicles

> **EVs will be cheaper to run, cheaper to buy, cheaper to maintain, and will have a longer lifespan than internal combustion engine vehicles.**

Electrification of transport is expected to be highly significant, both in increasing electricity demand and in emissions reductions.

Electricity for transport will account for 13 TWh of the estimated growth and is driven by the assumption that EVs reach ~40 per cent market share by 2030 and ~85 per cent by 2050.

EVs will be cheaper to run, cheaper to buy, cheaper to maintain, and will have a longer lifespan than internal combustion engine vehicles.

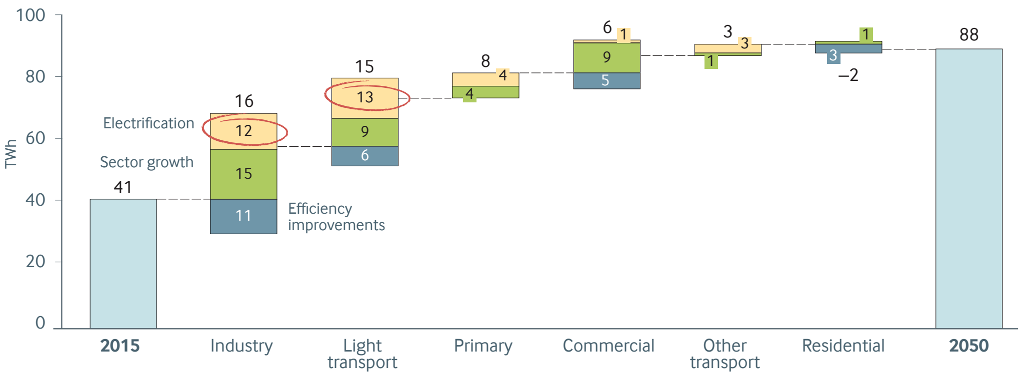
Light vehicles powered by hydrogen fuel cells are also on the horizon but are not as attractive as EVs because of the inefficiencies in converting electricity to hydrogen to motive power, and because of the momentum already behind EVs.

Heavy land transport is also expected to electrify but there is more uncertainty behind this assumption because of issues with range that need to be overcome. If hydrogen does play a larger role, especially for heavy vehicles, then demand for electricity could be higher than projected because of the relative inefficiency of converting electricity to hydrogen to motive power.

Electrification of industry

Exhibit 4 deconstructs estimated electricity demand growth between 2015 and 2050 by sector and source. 'Electrification' (yellow) indicates the growth from substituting fossil fuels for electricity. 'Sector growth' (green) indicates the amount of demand growth that is driven by New Zealand's economy and population. 'Efficiency improvements' (grey) indicate the reduction in electricity demand that results from reductions to the amount of electricity use per unit of GDP or population.

Exhibit 4: **Breakdown of electricity demand growth**



It is estimated that 12 TWh of New Zealand's electricity growth by 2050 is created by the electrification of industry – it is assumed that 100 per cent of coal and 40 per cent of gas as industrial fuels is substituted by electricity by 2050. Electrification of industry becomes more likely as more solar and wind is added into the system, as wholesale electricity prices decrease, and as the cost of carbon emissions increase. Businesses are beginning to take stronger positions on climate change and several major industry participants are already planning electrification of their process heat operations.

It is estimated that 12 TWh of New Zealand's electricity growth by 2050 is created by the electrification of industry – it is assumed that 100 per cent of coal and 40 per cent of gas as industrial fuels is substituted by electricity by 2050.

Economic and population growth also account for a large share of the electricity demand growth, and are based on projections that grow in line with Stats NZ's and Treasury's forecasts.

Growth driven by GDP in industry is estimated to be 15 TWh and is supported by conservative growth assumptions. It is also informed by qualitative assessments that New Zealand may become a home for climate-friendly manufacturing, that there is potential for adding more value to primary products prior to export, and that sunset industries will be replaced with new ones.

It is expected that much of the industrial demand growth will be offset by continued trends in efficiency improvements. For example, efficiency improvements in industry are estimated to reduce industrial electricity demand by 11 TWh.

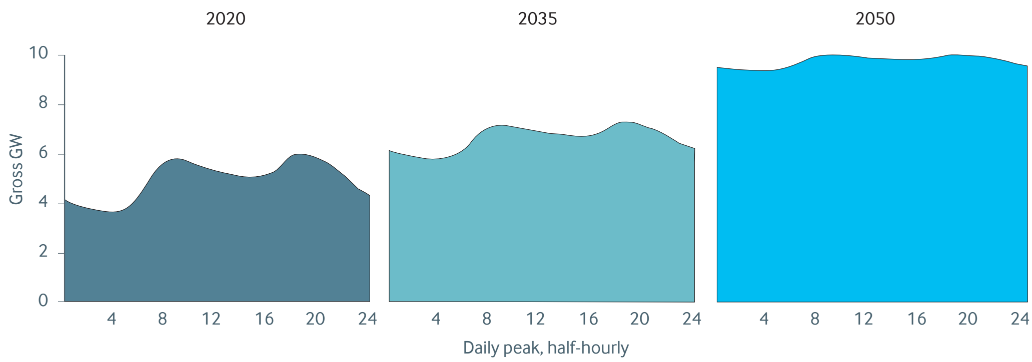
Managing the peaks

Electricity demand needs to be estimated in two ways: 'energy demand', which refers to the total electricity demand over the course of a year and is measured in TWh; and 'daily peak demand' or 'capacity demand', which refers to the maximum demand in an hour and is measured in GW. In New Zealand, the hour which has the greatest demand usually falls during an evening in mid-winter when people return home from work and turn on their heaters, lights and appliances.

Under the base case scenario, energy demand as seen in Exhibits 3 and 4 is estimated to more than double, while New Zealand's daily peak increases by ~66 per cent, from ~6 GW in 2020, to ~7 GW in 2035, to ~10GW in 2050.

Exhibit 5 demonstrates the steady growth in New Zealand's daily demand peak under the base case.

Exhibit 5: **Average daily winter load profile estimated**



Note: Analysis based on average winter day, not the most "peaky" day of the year.

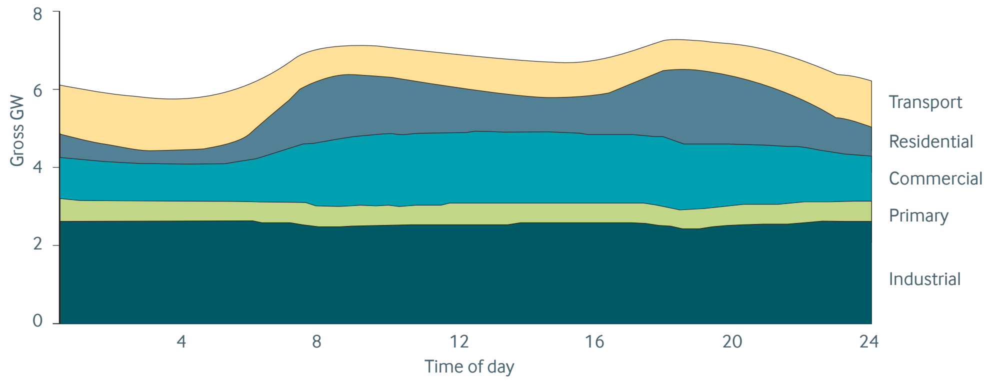
The daily peak in 2050 is not double the 2020 peak for two reasons. Firstly, residential demand, which contributes to a large increase in evening demand, reduces as a share of total demand as electrification of other sectors occurs and industry demand grows.

Secondly, it is assumed that EV charging is managed or smoothed to avoid mass charging in times of high demand, such as during the evening peak. Instead, charging will occur slowly overnight and during the midday demand trough.

In a future world with digital and smart technologies, charging outside of peak demand times will be convenient and financially attractive to households and industry. There will be opportunities for bundling of new services, products and offers combined with energy management systems, for example, a new phone application, EV or appliance as part of a household energy management package that helps to avoid energy demand peaks.

Exhibit 6 shows the smoothed daily demand profile in 2035 by sector, with residential demand peaking in the morning and evening, and EV charging contributing to a smoother overall demand profile.

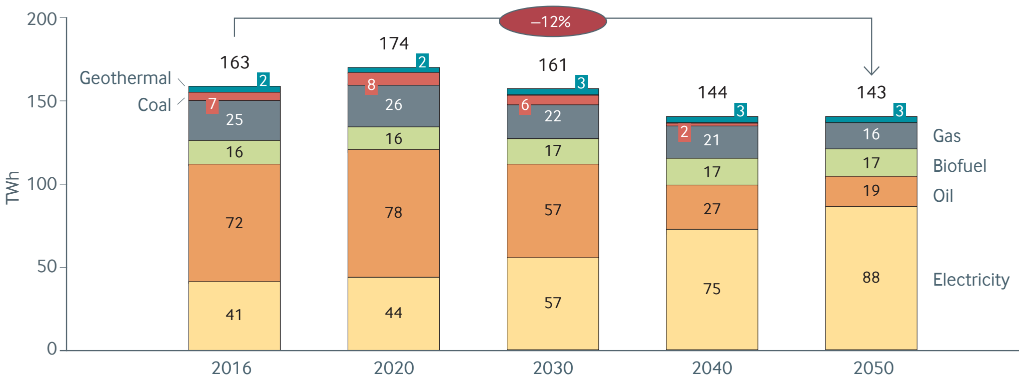
Exhibit 6: **Average daily winter load profile estimated by sector in 2035**



Despite a doubling of electricity demand, total energy demand (which includes demand for oil, biofuels, gas, coal and geothermal fuel sources) is estimated to decrease by 12 per cent between now and 2050.

The estimated reduction in total energy demand is predominantly due to switching from other sources of energy to electricity as a more efficient source of power for transport and industry. The efficiency of converting electricity to transport energy is ~80 per cent, while the efficiency of petrol is ~30 per cent and diesel is ~20 per cent. In industrial process heat, electricity's efficiency rate is ~95 per cent compared to ~80 per cent for coal, natural gas and oil.

Exhibit 7: **Estimated delivered energy demand by sector and type – 2016 to 2050**



Note: Overall energy reduction is the result of electrical energy more efficiently converting into transportation and heating; Coal and biofuels not modelled closely.

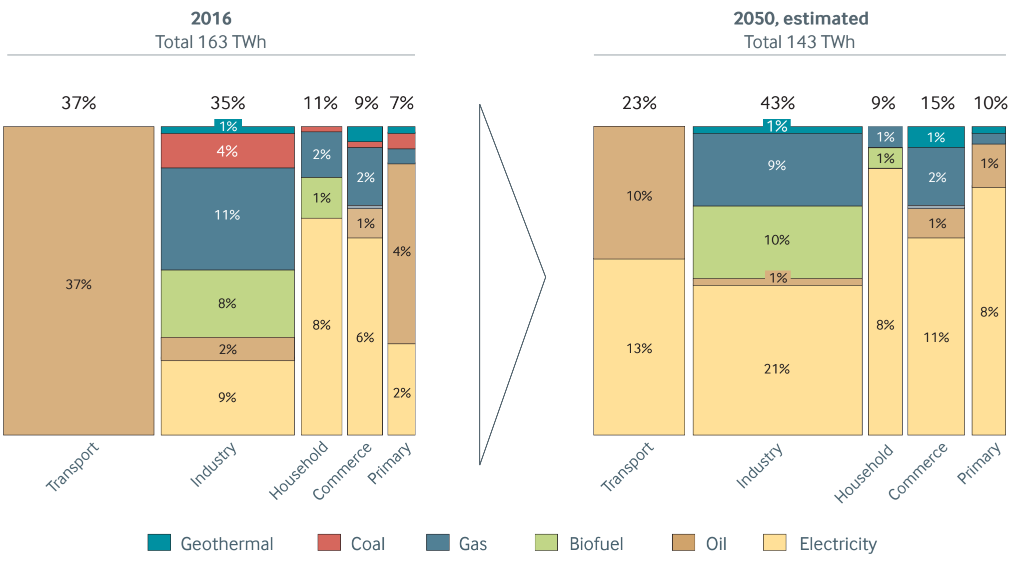
The conclusion that demand for conventional liquid fuels will decline significantly is not radical – it is based on current technologies and their expected future economics. Widespread electrification could be disrupted if an inexpensive and climate-friendly liquid fuel substitute was developed – for example, Daniel Nocera's bionic leaf might evolve to provide a carbon-neutral liquid fuel that could be burned in internal combustion engines. However, any climate-friendly liquid fuel substitute would have to be developed and deployed readily at massive scale in order to challenge conventional fossil fuels.

"Despite a doubling of electricity demand, total energy demand (which includes demand for oil, biofuels, gas, coal and geothermal fuel sources) is estimated to decrease by 12 per cent between now and 2050."

"The efficiency of converting electricity to transport energy is ~80 per cent while the efficiency of petrol is ~30 per cent and diesel is ~20 per cent. In industrial process heat, electricity's efficiency rate is ~95 per cent compared to ~80 per cent for coal, natural gas and oil."

Exhibit 8 shows that New Zealand's energy system in 2050 is estimated to be much more electric. Electricity demand as a proportion of total delivered energy demand is estimated to increase from 25 per cent in 2016 to 61 per cent by 2050.

Exhibit 8: **Estimated delivered energy demand share by type and sector**



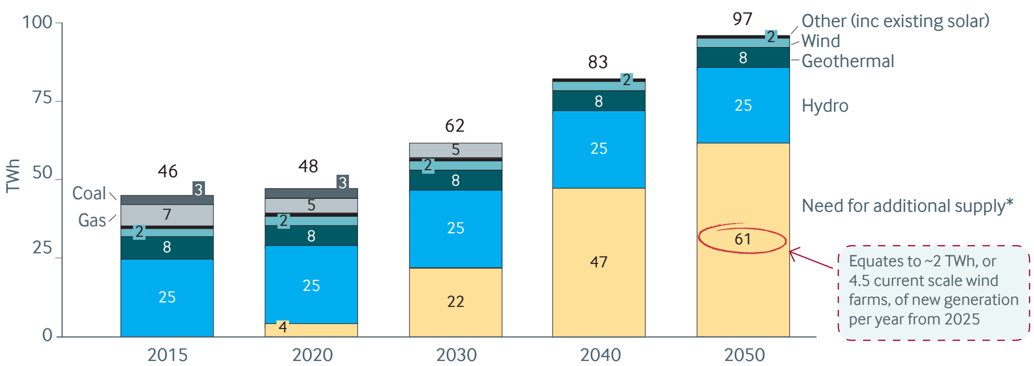
Supply

The electricity supply base case scenario highlights what will be a significant challenge in meeting projected demand. The scenario estimates that over 60 TWh of new generation will be needed to meet estimated demand growth – and the retirement of some existing power stations, including all thermal power stations – by 2050.

To give an idea of the size of this challenge and to reinforce the need for significant investment in New Zealand's energy future, 60 TWh of new generation equates to ~2 TWh per year – roughly equivalent to 4.5 typically sized wind farms with ~ 60 turbines each. Additional supply requirements are estimated by projecting demand growth, increasing that forecast demand by ~20 per cent to ensure there is redundancy, and subtracting currently available generation that is assumed will be closed in 2050.

Exhibit 9 shows how the need for additional supply grows rapidly over time.

Exhibit 9: **Estimated need for additional supply**



* Represents the difference between estimated electricity demand growth, grossed up to ensure redundancy, and the net of currently generation assets less currently expected closures.

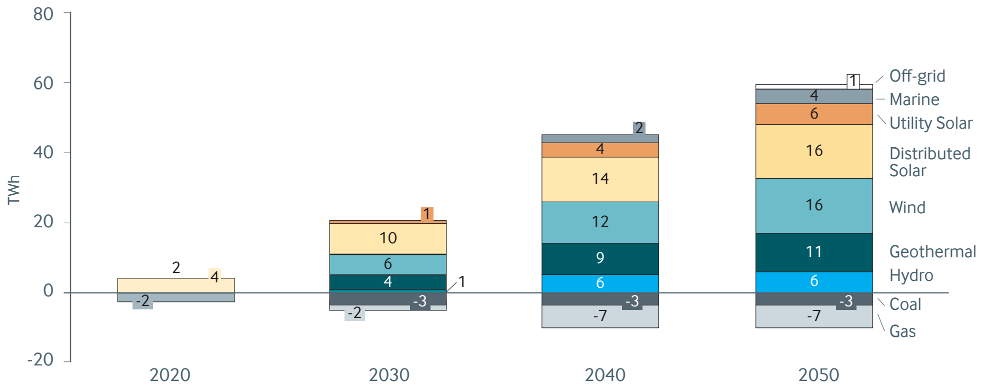
To keep up with demand growth, New Zealand will need material growth not only in grid-connected power stations, but also in distributed and utility generation.

The base case estimates have projected distributed solar PV generation growing to 16 TWh by 2050. The analysis assumes that ~1.5 million houses install solar panels on their roofs and conservative increases in the generation potential of panels through time. The remaining additional supply needed would have to be filled by utility-scale investors, who are anticipated to provide 16 TWh of wind, 11 TWh of geothermal, 6 TWh of solar and 6 TWh of hydro generation.

Marine and off-grid supply make small contributions, and gas and coal-powered generation is assumed to be fully retired.

Exhibit 10 shows that geothermal, solar and wind generation is estimated to make up over 80 per cent of the supply growth. Geothermal is an attractive means of providing baseload generation, and recent innovations are helping to make it more climate-friendly.

Exhibit 10 : **Estimated sources of new electricity supply**



The economics of solar and wind are compelling. They are already cheaper than conventional generation sources in many countries and costs will continue to decrease. New Zealand has ample space, wind and sunlight to allow for wind and solar generation to play a material role in the country's energy mix.

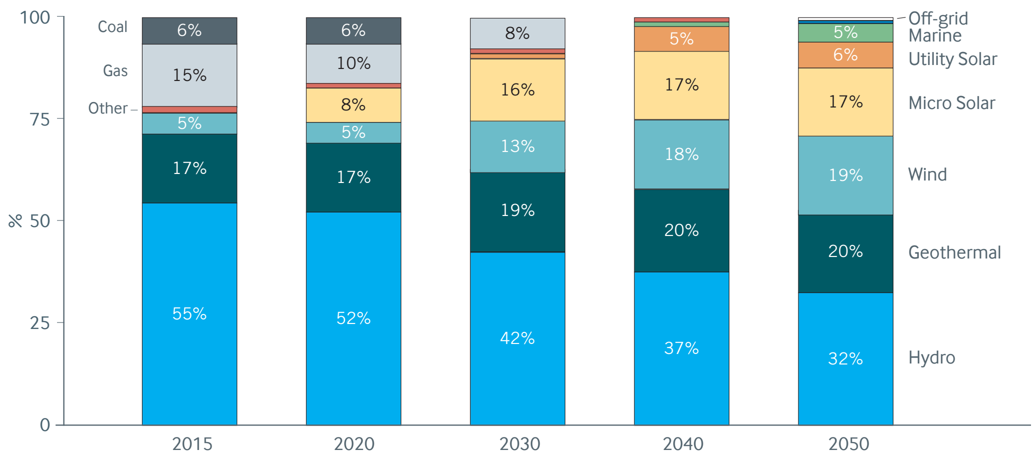
Offshore floating wind projects may be deployed in New Zealand if it becomes prohibitively difficult to consent onshore wind farms due to local objections. New Zealand's narrow continental shelf and steep offshore slopes mean that fixed offshore wind generation could only be located close to shore where it would be visually obtrusive.

The base case scenario anticipates a material amount of solar generation will be deployed in New Zealand, but uncertainty remains regarding the split between utility scale and distributed solar. The distributed solar estimates include commercial-scale rooftop solar PV, which is more attractive because the timing of consumption more closely matches daylight hours, but may be constrained by roofs not having the structural support required to hold solar PV panels.

As Exhibit 11 shows, by 2050 New Zealand's electricity generation portfolio is likely to be much more diversified than it is today. In the base case scenario, New Zealand becomes less dependent on hydro generation but more dependent on intermittent wind and variable solar generation. New distributed solar generation accounts for ~25 per cent of new generation deployed.

Other forms of distributed generation, such as micro wind turbines, have been developed and could play a bigger role than currently anticipated.

Exhibit 11: **Composition of New Zealand's electricity supply portfolio by generation type – 2015 to 2050**



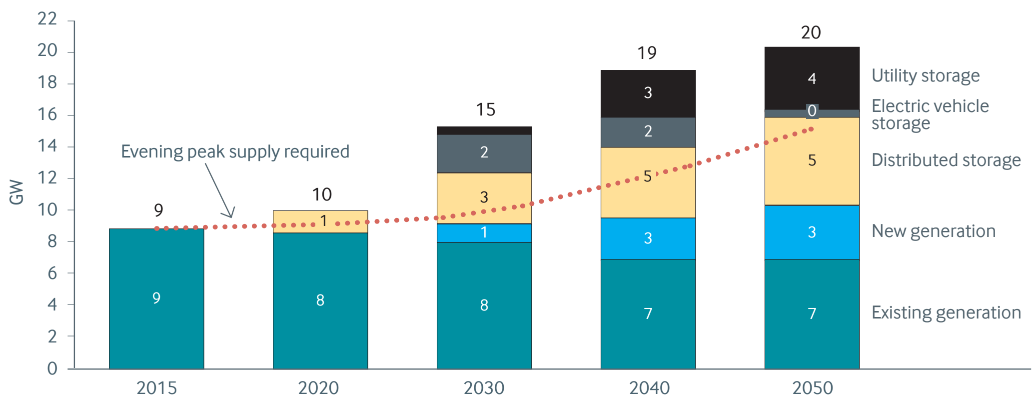
In the base case scenario, accessible battery capacity allows for daily peaks to be met with a material amount of redundancy.

This conclusion warrants particular explanation of the three key assumptions behind it:

1. Utilities, businesses and households installing solar PV are expected to install battery packs to enable electricity generated during the day to be used during the evening peaks. Utility-scale batteries are assumed to discharge 100 per cent of installed capacity into peaks when prices are highest, while residential and commercial batteries are assumed to contribute 50 per cent of their available capacity. Modest battery capacity growth is assumed, for example, residential battery pack capacity grows from 7.5 KWh to 13.5 KWh by 2050.
2. Private EV owners contribute up to 35 per cent of their vehicle's battery capacity during the morning and evening peaks as required to meet demand. EV owners are unlikely to make 100 per cent of their battery capacity available to the system, preferring instead to retain some charge for unexpected use. If the average range for an EV is 500 kilometres by 2030, and 35 per cent of EV battery capacity was made available to discharge into the grid to smooth peaks, then over 300 kilometres of charge would remain available.
3. Fleet-owned autonomous EVs are assumed not to contribute any capacity during the peak and will begin to make up a material proportion of the vehicle fleet by 2030 in the base case. It is assumed that fleet-owned autonomous vehicles will be highly utilised and unavailable for discharging. As they replace privately owned vehicles, the amount of battery capacity available for discharging into demand peaks is estimated to reduce. Batteries of retired privately owned EVs may be repurposed to provide peak supply but this is uncertain and not included in the scenario's estimates.

Exhibit 12 shows that estimated existing generation, new generation and available battery capacity would allow New Zealand's daily evening peak to be met with a material amount of redundancy.

Exhibit 12: **Estimated winter evening peak supply required and supply**



Winter and dry-year supply and managing shortages – emerging technology possibilities

Given the unique characteristics of New Zealand's energy system, managing winter and dry-year energy shortages is one of the most fundamental issues addressed in this report.

While the base case scenario suggests these issues can be managed via a number of initiatives and technology developments, it is important to be clear that doing so represents a significant and critical challenge to the sector and policymakers. It will not be easy.

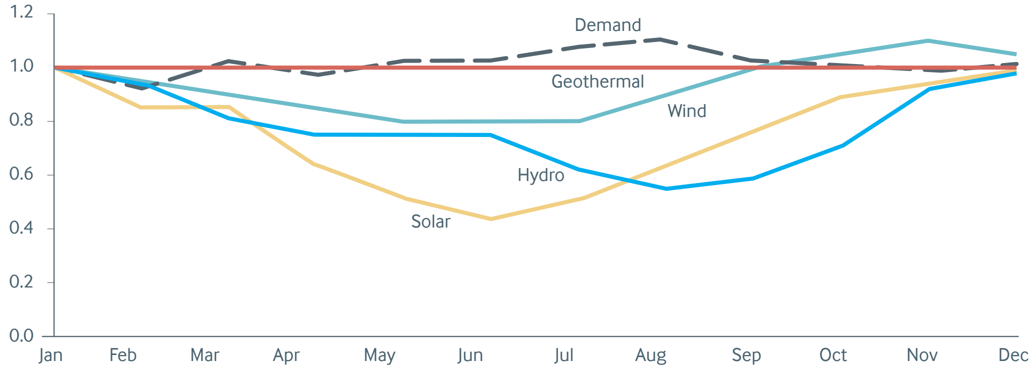
This section of the report tests and explores some unusual and unconventional ideas as to how this winter and dry-year security of supply risk might be mitigated. It is informed by thinking in the realm of possibility rather than current feasibility and is contributed in the spirit of attempting to leave no possibility unexplored.

Under the base case scenario, the significant growth in electricity demand, combined with an assumed greater reliance on solar and wind, and continued dependence on hydro, leaves New Zealand more exposed than it already is to supply shortages in winter or a dry year.

According to University of Canterbury research, solar, wind and hydro generation output can decline by as much as 50 per cent, 20 per cent and 40 per cent in winter, respectively.

Meanwhile, New Zealand's demand for electricity increases as homes are heated through winter, as shown in Exhibit 13.

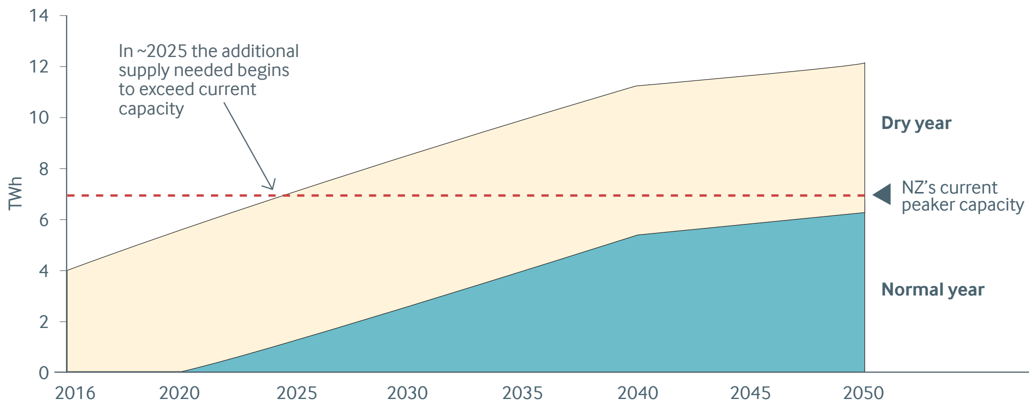
Exhibit 13: **Normalised seasonal generation by type compared to demand**



In the base case scenario, New Zealand's exposure to supply shortages in winter and/or a dry year is expected to grow from 4 TWh today, which is covered by 7 TWh of current thermal generation capacity, to 9 TWh by 2030 and 12 TWh by 2050, partially driven by the reliance on solar.

The growth in New Zealand's exposure to supply shortages is illustrated in Exhibit 14.

Exhibit 14: **Estimated additional supply needed by type of hydrological year**



New Zealand's exposure to winter supply shortages, in a normal year from our base case generation mix, is estimated to grow as solar generation grows to over 20 per cent of New Zealand's generation capacity by 2050.

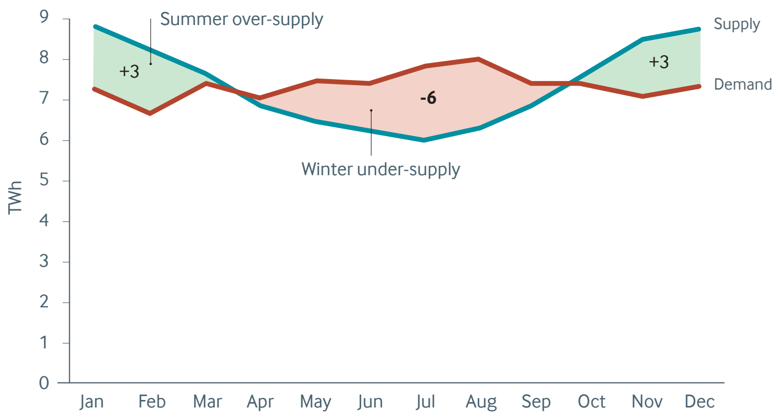
Exposure also increases as thermal peakers are progressively retired. Thermal peakers are the current means for securing reliable and controllable winter supply.

In the base case scenario, a warming climate does not lead to anywhere near enough air conditioning/cooling load to reduce New Zealand's seasonal demand peak. Indicative analysis of New Zealand's residential electricity demand did not show a strong relationship between increases in temperature and electricity demand. Heating in winter may increase as more extreme weather events such as cold snaps occur, and demographic trends such as lower household occupancy rates and population growth contribute to an increase in the amount of space that needs to be heated in winter.

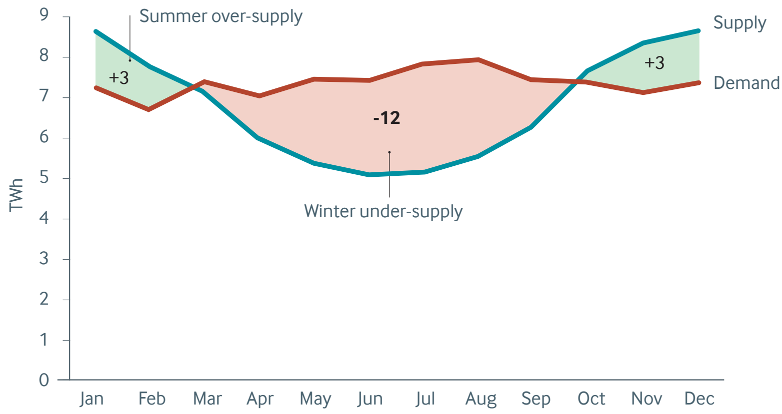
Exhibit 15 shows the 2050 normal and dry-year estimates of electricity supply and demand, where annual supply is assumed equal to annual demand. In the winter, supply reduces and demand increases, so in winter months there is a deficit of electricity. Correspondingly, because annual supply is matched to annual demand, there is a surplus of electricity in summer. Both of these factors would be exacerbated by increased solar penetration without a storage solution.

If electricity could be stored for long periods of time, it would be possible to generate electricity in the summer and use it in the winter. The gap between the 'supply' (green) and 'demand' (red) lines indicates the amount of over- or under-supply available to provide for demand in each month. The green-shaded areas represent the summer over-supply while pink represents the winter under-supply, which must be met from storage or from additional generation, known as 'over-build'.

Exhibit 15: **Monthly supply and demand estimate for normal year**



Monthly supply and demand estimate for dry year



Several potential technical solutions for managing New Zealand's unique winter and dry-year energy issue have been identified but none appears definitely feasible and economically attractive. Nonetheless, there are emerging alternative options worthy of early consideration.

Battery peakers

Batteries that store energy for short periods – 'battery peakers' – will soon be cost-competitive. However, forward estimates of costs for batteries that could store energy generated in summer to be used in winter indicate it is very unlikely that they could provide an economically acceptable solution to the winter energy shortfall.

In a normal year, New Zealand is estimated to have a surplus of 6 TWh in summer and a shortage of 6 TWh in winter. In a dry year with the same demand, the winter shortfall increases to 12 TWh, because there is less hydro energy available. In this situation, stored summer supply of 6 TWh would be insufficient to provide enough energy to meet winter demand. An additional energy reserve would be required.

"Several potential technical solutions for managing New Zealand's unique winter and dry-year energy issue have been identified but none appears definitely feasible and economically attractive."

Hydrogen-ammonia

At the time of writing this report, generating and storing hydrogen as ammonia seems feasible. Hydrogen currently provides a more effective means for inter-seasonal storage than other forms of storage, such as batteries. Hydrogen production and storage is scalable, modular, and some ammonia could be stored in existing facilities.

Excess solar generation capacity in the summer could be used to create hydrogen, which could be stored as ammonia. In winter, the ammonia could be burned directly to generate electricity. Hydrogen stored as ammonia, or in another form, would not be climate- or weather-dependent.

Research and piloting of hydrogen-ammonia technologies is in progress. The hydrogen solution is still rudimentary but there are several other solutions that might prove feasible.

Retaining gas peakers

Gas-fired peakers might be retained as a reserve-of-last-resort and to make use of existing assets and infrastructure. That might be politically challenging, and keeping gas peakers open could create a risk of insufficient gas availability domestically. Further, keeping existing gas peakers open would not provide sufficient capacity, so additional peaker capacity or a combination of solutions would still be required.

Generation over-build

The problem with generation over-build as an option to managing security of supply is that it would require generation capacity to be built that would be needed only in winter. This would (somewhat obviously) make investment in that additional capacity uneconomic and, therefore, unattractive. In the absence of storage or over-build, there would be a supply shortfall in winter.

Biofuels

It might be possible to convert at least some thermal plants to use wood-based biofuels. Existing economics of wood collection may make this option difficult, but it may become more feasible if wood becomes more available and transport energy costs reduce.

Other possibilities

New Zealand could over-build renewable generation, but that is unlikely to be attractive given the capital cost of capacity that might only be used in winter or in dry years. Some geothermal generation might be switched from year-round baseload to controllable generation that contributes during winter and dry years, but the economics, feasibility and contribution potential of this solution is uncertain.

New Zealand could develop additional hydro capacity for storage but would almost certainly encounter community and political opposition. One possibility that has been explored by Professor WE Beardsley and others is a pumped hydro scheme in the Onslow-Manorburn depression, located in the South Island. The depression could hold the 12 TWh of energy required during a dry year and could be developed in several stages. Another hydro solution would be to allow access to additional storage capacity in existing hydro lakes to a greater extent than is currently allowed. Both of these hydro options would require large investments and planning would need to begin soon, but both options are likely to generate significant community and political opposition.

Storage of energy as compressed air is possible but would require a very large amount of storage capacity, much more than for hydrogen, and the technology has not been tested at the scale that would be required.

Truly disruptive innovations, such as Daniel Nocera's bionic leaf, advanced nanotechnology solar or other inventions, might emerge in the future. The artificial leaf might provide a means to convert solar energy to a liquid fuel so that electricity generation does not need to grow rapidly and the winter supply challenge is smaller. Nanotechnology-based solar might be so cost-efficient that building sufficient capacity for winter needs becomes affordable, and battery peakers would be cost-effective for short-term time-shifting and to cover periods when there are a few days without sufficient wind or sun.

International grid connection

New Zealand might eventually connect to a global transmission grid via Australia, which could allow access to low-cost solar energy generated in the world's deserts. Interconnecting is beginning in Europe, and undersea connections are also being established. It is possible that connections could spread to Asia, and eventually Australia could be connected to Asia and New Zealand.

Uncertainty about the future of interconnection means that it is not a solution that can be relied upon today. However, it is important to form a view about the future of interconnection because it would materially affect the economic competiveness and attractiveness of alternative solutions, possibly creating stranded assets.

There might be some advantages to developing a range of solutions, which could be 'stacked' and progressively implemented by merit to diversify risk.

Transmission implications

With more and more of the national economy dependent on electricity as opposed to a wider range of energy sources such as coal, gas and oil, resilience and reliability of the electricity system becomes essential to the country.

To deliver the additional utility generation needed under the base case scenario, Transpower would need to connect almost 10 GW of additional generation capacity. The mix of generation types is uncertain, and some would be embedded within distribution networks, avoiding the need for grid connections.

All parts of the transmission system will need to be fully functioning to realise its potential. New generation will be both grid-connected and connected into local distribution networks. Both the national grid and local electricity networks will need to ensure sustained investment in their assets is sufficient to connect and reliably distribute new forms of energy.

For the national grid, it is expected multiple new grid connections will be required from increasingly intermittent energy sources. Local networks will need to actively consider the resilience of their assets to handle increasing peak loads, greater solar PV and battery penetration, and the charging of EVs.

Exhibit 16 outlines the number of grid connections required in the base case scenario by type of generation. The following estimates are unlikely to be accurate, but were developed to indicate the scale of the challenge for Transpower and the electricity industry more generally.

Exhibit 16: **Estimated additional connection requirements by 2050**

Generation type	Installed capacity (MW)	Avg. MW/project	Number of projects
Wind	4670	126	37
Hydro	798	40	20
Geothermal	1455	73	20
Marine	1000	100	10
Utility solar	1370	152	9
Total	9293	97	96

In addition to delivering new connections, Transpower may also need to make further investments in the transmission network as demand grows. Indicative analysis of three lines indicates that thermal constraints might be encountered in the upper North Island and that the HVDC line might flip to predominantly north-to-south flow. It should be noted, though, that this analysis was simplified; Transpower is currently undertaking detailed load-flow analysis to explore the implications of the base case scenario for the national electricity transmission grid.

Qualitative analysis indicates that voltage and other operational issues might challenge the transmission network before thermal line capacity constraints are reached. The forecast closure of coal generation at Huntly, growth in demand for Auckland, and uptake of distributed solar generation may all combine to create significant new challenges for upper North Island transmission.

This paper has not attempted to explore the implications of the base case scenario for New Zealand's 29 electricity distribution networks. Significant demand growth, mass participation, EV charging and embedded solar generation are likely to increase the power management and capacity capabilities required of distribution businesses.

Greenhouse gas emissions

Although this paper did not set out to explicitly estimate the implications of the base case scenario on New Zealand's greenhouse gas emissions, it soon became clear that electrification would have a significant effect on the country's greenhouse gas emissions.

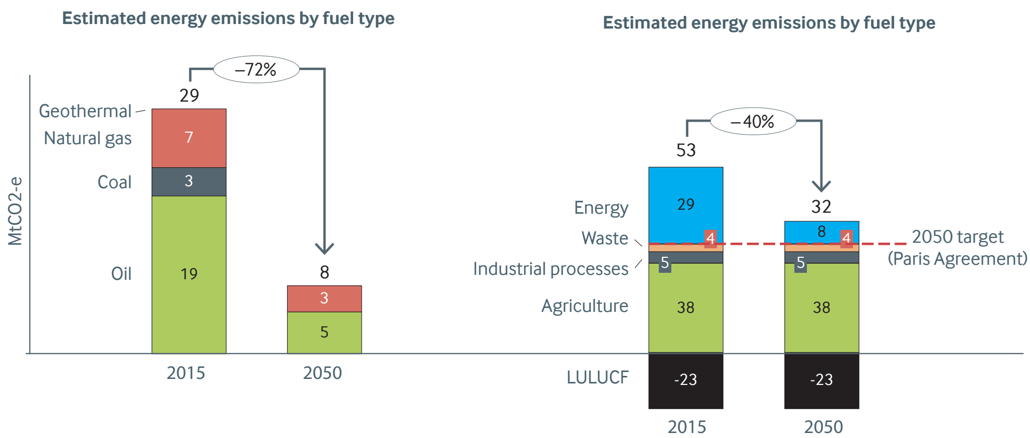
New Zealand has high greenhouse gas emissions per capita relative to other economies and has committed to emission reduction targets. Agriculture and energy are the largest sources of emissions. Agriculture emissions are difficult to reduce, agriculture is a large contributor to export earnings, and New Zealand produces food the world needs with a relatively low carbon footprint, so there are strong incentives to seek reductions from other sectors.

A large proportion of energy production is from low emissions sources such as hydro, wind and geothermal, so there is limited potential for emission reductions from electricity. Transport and energy for process heat are important sources of greenhouse gas emissions, and electrification can have a large impact on those emissions, making electrification a significant opportunity.

In the base case, New Zealand rapidly electrifies transport and industry process heat and closes the thermal power plants. As a result, the energy sector's greenhouse gas emissions are estimated to reduce by 72 per cent and contribute a 40 per cent reduction in New Zealand's overall greenhouse gas emissions by 2050.

Exhibit 17 shows that a 40 per cent reduction would nearly allow New Zealand to meet its Paris Agreement obligations. Emission reduction targets are likely to be increased in the future because the current Paris targets fall short of what would be required to reduce climate risk to acceptable levels. More stringent targets and policies should be expected.

Exhibit 17: **Energy industry's potential contribution to emission reduction**



Note: LULUCF is Land Use, Land Use Change, and Forestry—our environmental sources/sinks have a net negative effect on emissionsSource: Stats NZ, *Greenhouse gas emissions;* Productivity Commission, *Low emissions economy issues paper;* MBIE, *Greenhouse gas emissions;* ShS Analysis

Impacts of uncertainties and alternative energy future scenarios

Many forces with the potential to affect New Zealand's energy future remain uncertain. Some forces are global and outside New Zealand's control. The world may have to navigate a future disrupted by climate change, a reversal of globalisation, or stalling technology development. Other forces are local, such as policy choices and investment decisions.

New Zealand might or might not take a strong position on climate change mitigation or electrification. Electrification might be planned for but not successfully implemented.

The base case scenario developed within Te Mauri Hiko will not play out as described here; no individual or organisation can predict the future. There will be surprises and unexpected developments in the future, just as there have been in the past.

Scenarios have been developed to explore the implications of uncertainties. When developing investment plans, Transpower considers how outcomes might be altered if alternative scenarios emerge, and planning scenarios will be updated to reflect lessons from Te Mauri Hiko. Three alternative demand and three alternative supply scenarios were developed to ensure a robust examination of a wide range of possible electricity futures.

None of the scenarios anticipate large qualitative differences in New Zealand's energy future, even if global circumstances change a lot or domestic demand growth varies significantly. The scenarios differ mainly in the magnitude and speed of demand growth and in the mix of generation types used to supply growth in demand.

For example, electrification of transport occurs in all scenarios, reflecting confidence in the underlying economic, technological and environmental forces promoting widespread adoption of EVs. However, the level and speed of electrification of transport varies significantly between scenarios.

Demand scenarios

The alternative demand scenarios were selected to help test uncertainty in both the global and domestic context.

Comparisons revealed that transformation of New Zealand's energy sector will be inevitable – it should be expected under all future scenarios.

Uncertain global drivers include disruptive climate change, sociopolitical instability and the extent and rate of technology development. Uncertainty in the New Zealand demand drivers include the rate and extent of electrification of transport and industrial process heat, economic and population growth, and differences in the ways that EVs might be charged.

The three demand scenarios presented below were selected from around 15 demand scenarios developed to explore the range of possible outcomes for New Zealand's energy system.

Comparisons revealed that transformation of New Zealand's energy sector will be inevitable – it should be expected under all future scenarios. The comparisons also indicated that demand growth drivers should be carefully monitored, as eventual energy demand could be materially higher, or lower, than estimated in the base case scenario. The scenario analysis also clearly suggested that the New Zealand energy sector should prepare for a future which is more disrupted than that outlined in the base case scenario.

NZ Inc – the demand base case scenario

'NZ Inc', which was selected as the demand base case scenario, assumes a positive global context with mid-range economic and population growth as forecast by Treasury and Stats NZ. Climate change progresses, inequality continues to increase and there is increasing geopolitical instability, but New Zealand and the rest of the world continue approximately along their current courses. Policy encourages decarbonisation and electrification of transport and industry. New Zealand's energy sector becomes more complex but avoids major risks that could disrupt a successful transformation.

The Vibrant Haven demand scenario

The global assumptions for the 'Vibrant Haven' scenario are similar to the base case scenario, but New Zealand's performance is relatively better than the performance for the rest of the world. Climate outcomes are more benign here. Land, water, value-added exports and innovation allow continued economic advancement. Geographic isolation protects New Zealand from the worst effects of geopolitical instability. New Zealanders living overseas return, along with migrants seeking a safe haven that is more protected from increasing global risks. Population grows to reach about 10 million by 2050. Energy demand is higher as a result, and that, combined with electrification, means electricity demand almost triples by 2050.

Exhibit 18: **Vibrant Haven scenario**

Now to 2030

Global scenario

- Increased climate change but no abrupt change or seriously disruptive change
- Stable world order
- Widespread adoption of currently emerging technologies

Climate response

- More climate change impacts
- Pressure grows to reduce greenhouse gases
- New Zealand takes a strong pathway to mitigating climate risk by electrifying transport and industrial heat

Industry development

- New Zealand takes a coordinated approach to industry development and resolving the challenges presented by widespread electrification
- Electricity markets evolve

2030 to 2050

Global scenario

- Climate, economic and security uncertainty grows
- As an isolated country, with economic and environmental resilience, New Zealand is seen as a safe haven so inwards migration, population and GDP grow quickly

Climate response

- More climate change impacts
- Electrification continues and puts pressure on New Zealand's ability to fully convert the electricity system to clean generation types

Industry development

- Electricity demand grows rapidly
- Market participants struggle to keep up and industry development is less coordinated
- The market becomes more complex

The Mobilise demand scenario

The 'Mobilise' scenario has a similar context of increasing climate change effects and geopolitical instability, except that the world changes course. A more vigorous and concerted effort to reduce global emissions and greenhouse gas concentrations in the atmosphere comes about with the recognition that the combination of decarbonisation and geoengineering will be insufficient to protect against risks of unacceptably disruptive climate change.

A motivation to reduce consumption emerges as societies focus more on environmental risk reduction and preserving well-being, becoming more discerning about the quality rather than just the quantity of economic growth. Wasteful production and consumption are curtailed. This results in a broader global economic transformation, with growth continuing, but more slowly than for the 'NZ Inc' and 'Vibrant Haven' scenarios.

Under the 'Mobilise' scenario, technological advancement slows. Existing and emerging technologies are deployed but 'futuristic' technologies are not.

Exhibit 19: **Mobilise demand scenario**

Now to 2030

Global scenario

- Increased climate change but no abrupt change or seriously disruptive change
- Stable world order
- Widespread adoption of currently emerging technologies

Climate response

- Climate change threats motivate stronger policies to reduce climate-changing activities
- New Zealand takes a strong pathway to mitigating climate risk by electrifying transport and industrial heat

Industry development

- Less coordinated industry development
- More consumers go "off-grid" or deploy uneconomic distributed generation
- Electricity markets evolve

2030 to 2050

Global scenario

- Climate change exceeds 1.6°C
- The world does not develop future technologies and must reduce consumption and production to limit climate impacts
- Economies suffer but the world order remains integrated

Climate response

- New Zealand requires significant reduction in consumption and outputs to abate emissions
- Reduction in GDP and increased unemployment

Industry development

- There is little industry coordination
- Uneconomic bypass creates risk of entering a dangerous cycle – those who can afford to disconnect do and leave the others with a greater share of the network costs

Struggling Alone demand scenario

The 'Struggling Alone' scenario was developed to understand the implications of a more disrupted future with even less favourable climate, geopolitical and technological outcomes.

Under this scenario, globalisation reverses as countries become more concerned with protecting the availability of resources, leading to investments in self-sufficiency and a shift to bilateral trade relationships that emphasise securing access to food, energy, critical material resources and security rather than access to markets. Under the 'Struggling Alone' scenario, New Zealand's economic growth reverses after 2030.

Exhibit 20: **'Struggling Alone' demand scenario**

Now to 2030

Global scenario

- Increased climate change but not disruptive
- Stable world order
- Widespread adoption of current technologies

Climate response

- More climate change impacts
- Pressure grows to reduce greenhouse gases
- New Zealand takes a weaker pathway to mitigating climate risk but electrification continues for economic reasons

Industry development

- New Zealand takes a coordinated approach to industry development and resolving the challenges presented by widespread electrification
- Electricity markets evolve

2030 to 2050

Global scenario

- Disruptive climate change
- World order declines
- Agricultural output declines
- Current technologies improve but future technology is not develop

Climate response

- Global climate change effects increase materially, resulting in increasing temperatures and adverse weather events
- Food sources change
- Nearby climate refugees seek safe haven in New Zealand

Industry development

- Significant reduction in GDP and population growth
- Urbanisation reverses as people seek self-sufficiency and safety in regions
- Low electrification
- High demand for irrigation

Exhibit 21: **Overview o f demand scenarios developed for Te Mauri Hiko**

Scenario	Disruptive climate change avoided?	World remains integrated?	Future tech adopted?	NZ growth?
NZ Inc	✓	✓	✓	✓
Vibrant Haven	✓	✓	✓	✓✓
Mobilise	✓	✓	✕	✕
Struggling Alone	✕	✕	✕	✕✕

Disruptive climate change is experienced when our way of life is challenged by the state of the environment. It could come about as a consequence of triggering a series of adverse climate feedback loops or tipping points that leads to "abrupt" climate change or as the result of steady temperature and impact growth.

Other broad demand scenarios were developed and analysed, covering an increasingly virtual future, a self-sufficient and isolationist scenario, and one covering a future characterised by global conflict.

The demand scenarios chosen for inclusion in this paper offer sufficient variation to explore a wide range of possibilities, while being judged as plausible and relatively likely. From a Transpower perspective, the high-demand scenarios illustrate the stresses from rapid and large-scale electrification, while the lower-demand scenarios illustrate circumstances where resilience and risk come into focus.

In all demand scenarios, New Zealand's energy sector is transformed. Exhibit 22 shows demand growth tracking along similar trajectories to around 50 TWh in 2030. After 2030, material differences begin to appear.

The divergence around 2030 is not a prediction of change specifically at that time, rather it is a function of the project methodology. The project team separated a period up to 2030, with electrification beginning to ramp in global conditions that are similar to conditions today, from a period post-2030 in which different global conditions affect the evolution of the New Zealand energy system.

Demand varies widely. In the 'Vibrant Haven' scenario, demand grows to over 100 TWh while in 'Struggling Alone', demand reduces post-2030 to return to a little below today's level.

Exhibit 22: **Estimated delivered electricity demand by scenario**

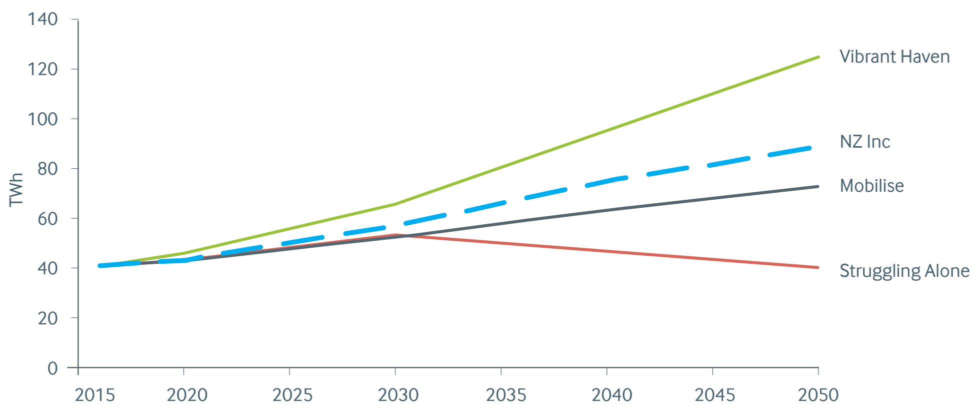
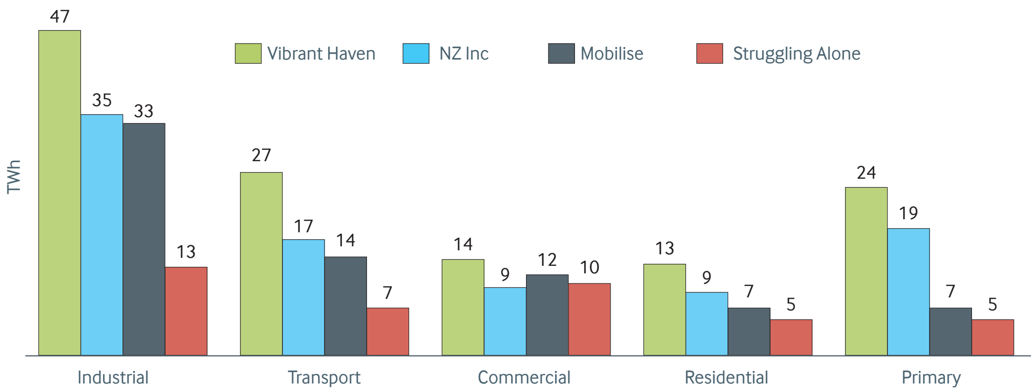


Exhibit 23 identifies the two main sources of divergence amongst the scenarios; industrial demand and transport demand.

Exhibit 23: **Estimated delivered electricity demand by sector**



Industrial electricity demand, the biggest source of divergence, is driven by economic growth and assumptions around the rates of electrification.

The 'NZ Inc' scenario followed Treasury's forecast of +2.1 per cent growth per annum.

In the 'Vibrant Haven' scenario, a higher growth rate of +3.2 per cent was assumed. The 'Mobilise' scenario was lower, at +1.1 per cent growth. The 'Struggling Alone' scenario used +2.1 per cent for growth until 2030 and then reversed to -3.0 per cent.

The 'NZ Inc', 'Vibrant Haven' and 'Mobilise' scenarios all assume that 50–55 per cent of industrial energy process heat is converted to electricity by 2050, but 'Struggling Alone' assumes just 35 per cent conversion by 2050.

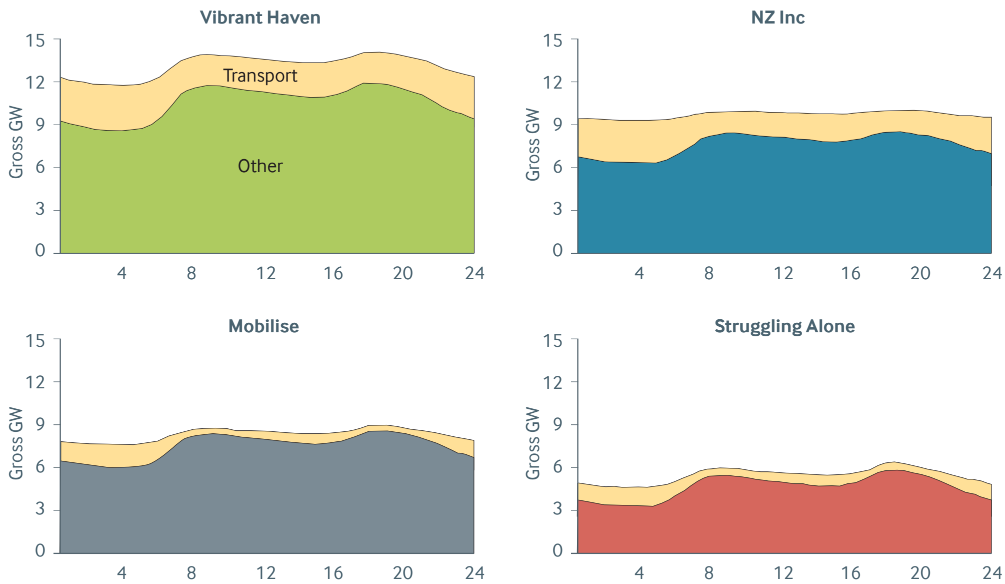
Differences in demand from the transport sector are driven by assumptions regarding population growth and electrification rates. In the 'NZ Inc' scenario, New Zealand's population grows in line with Stats NZ's mid-point estimate of +0.8 per cent per annum.

In the 'Vibrant Haven' scenario, the growth rate increases to +2.0 per cent. The 'Mobilise' scenario assumes a slightly higher growth rate of +1.0 per cent to reflect New Zealand's relative attractiveness as a safe haven. Under the 'Struggling Alone' scenario, New Zealand's population is assumed to grow in line with 'NZ Inc' until 2030, when it stagnates at zero growth.

EV adoption rates are similar for the 'NZ Inc', 'Vibrant Haven' and 'Mobilise' scenarios, reflecting confidence in the underlying drivers of EV uptake in New Zealand. Under the 'Struggling Alone' scenario, New Zealanders buy fewer EVs as some global supply chains collapse and limit availability, and technology development stalls.

The different scenarios also reveal the degree to which New Zealand's daily demand profile can vary in size and shape. As Exhibit 24 illustrates, in the 'Vibrant Haven' scenario, daily demand peaks at ~14 GW, 40 per cent higher than for the demand peak estimated in 'NZ Inc'. Demand in the 'Vibrant Haven', 'Mobilise' and 'Struggling Alone' scenarios continues to have strong morning and evening peaks, due to less effective management of EV charging times.

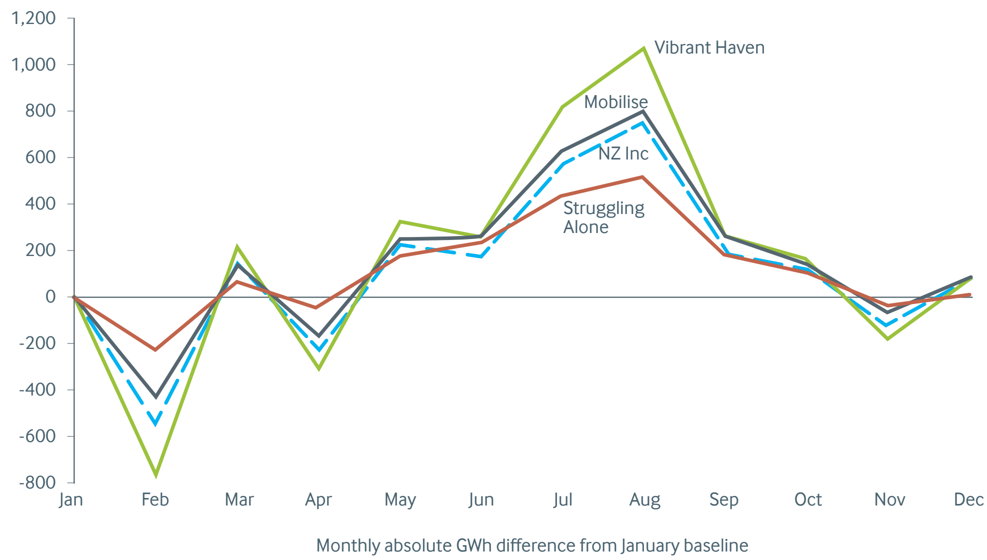
Exhibit 24: **Estimated daily load profile by demand type – 2050**



If New Zealand's energy future developed in line with the 'Vibrant Haven' scenario, the country would need considerably more new supply to be provisioned as a contingency for winter and dry years.

As Exhibit 25 shows, higher demand futures magnify the absolute amount of additional generation required and therefore exacerbate winter and dry-year shortage risks.

Exhibit 25: **Monthly demand profile estimate by year 2050**



The analysis of alternative supply scenarios revealed that differences in the composition of supply did not materially change the supply challenges New Zealand will face.

Alternative supply scenarios

The supply scenarios were developed to test the implications of different compositions of new generation for New Zealand's electricity system.

The project team sought to test the base case supply conclusion that daily peaks would be manageable with battery capacity and that winter/dry-year supply is an important problem to solve. These are fundamental points that reflect some of the unique challenges and characteristics presented by the New Zealand electricity system.

The project team also sought to test the transmission implications of different forms of new generation, for example, having significant new utility solar, and provided indicative conclusions.

The analysis of alternative supply scenarios revealed that differences in the composition of supply did not materially change the supply challenges New Zealand will face.

Under all scenarios it was found that:

- material new generation is needed to supply the demand ramp, starting in the mid-2020s
- New Zealand should have developed sufficient accessible storage to meet daily peaks
- the biggest supply problems will be resolving winter and dry-year shortage risks.

The supply base case 'Clean NZ' explores a continuation of current trends, which see a large increase in distributed solar generation, the eventual retirement of coal and gas-fired generation, and new utility wind being the most developed source of new generation.

The 'Peakers Permitted' scenario provides one means of ensuring security of supply during winter and a dry year.

'Mass Solar' reveals the implications of considerably more distributed solar generation, driven by advances in nanotechnology.

'Big South' explores the impacts on the HVDC line of much more hydro generation in the South Island.

Exhibit 26 illustrates simply how the supply scenarios differ.

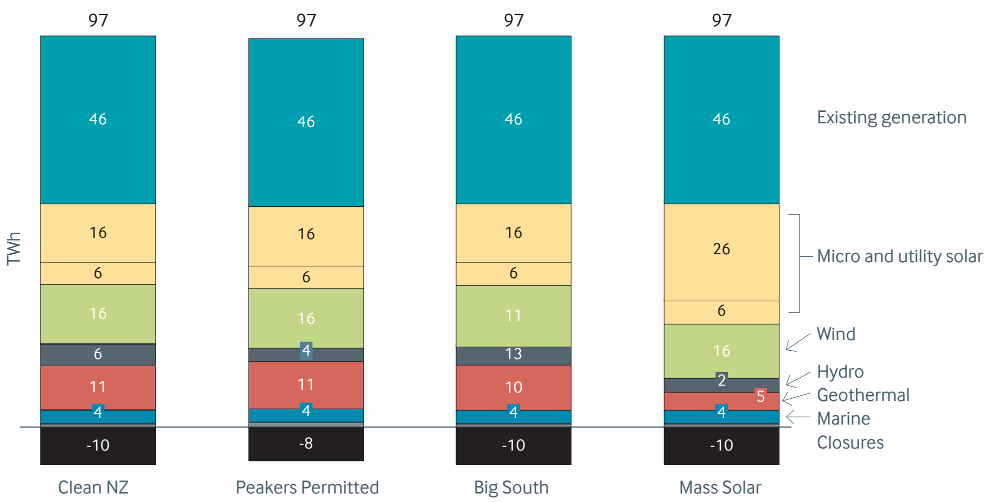
"under all scenarios new generation is assumed to be mostly composed of solar, wind, geothermal and some hydro[2]"

Exhibit 26: **Overview of supply scenarios**

	Amount of distributed solar?	Peakers retired?	Main source of new utility generation (exc. geothermal)
Clean NZ	Medium	Yes	Wind
Peakers Permitted	Medium	No	Wind
Mass Solar	High	Yes	Solar
Big South	Medium	Yes	Hydro

Excludes geothermal which is developed under all scenarios as the most attractive baseload generation source.

Exhibit 27: **Estimated 2050 future electricity energy supply by scenario**



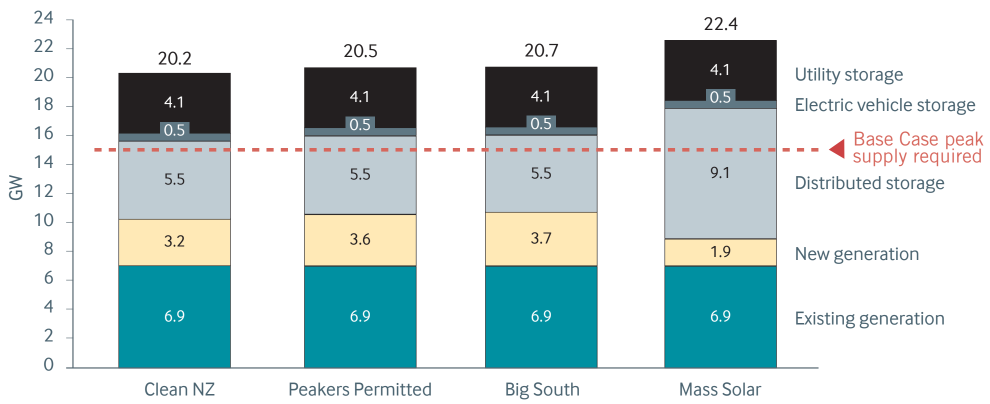
As Exhibit 27 shows, under all scenarios new generation is assumed to be mostly composed of solar, wind, geothermal and some hydro.[1] In a 'Mass Solar' future, the development burden on utility-scale investors is reduced as distributed generation reaches 26 TWh by 2050, up from 16 TWh in 'Clean NZ'.

In 'Big South' roughly twice as much new hydro generation is developed in the South Island.

Under each supply scenario, the daily peaks are estimated to be manageable with estimated accessible utility and distributed battery capacity that is deployed alongside solar installations and EV battery capacity. In the 'Mass Solar' scenario, residential batteries are even more widespread and contribute to a daily peak surplus of up to 9.5 GW by 2050, compared to a 4.2 GW surplus as estimated in the 'Clean NZ' scenario.

> **Utility-scale investors would need to construct between 1.5 TWh and 2 TWh of new utility-scale generation per year. That compares with an average utility scale investment of ~0.5 TWh per year over the last decade.**

Exhibit 28: **Estimated 2050 winter evening peak demand and supply by scenario**



Only under the 'Peakers Permitted' scenario is New Zealand's exposure to supply shortages during winters and dry years eliminated. Estimates indicate that by 2050, even in a 'Peakers Permitted' scenario, if all existing thermal peakers were retained, New Zealand would need to build six or seven more (~400MW) gas peaker plants to meet the full shortage estimated in a dry year.

Under a 'Mass Solar' future, the winter shortage will be particularly challenging to manage, due to reduced sunlight hours and increased demand. Under the 'Big South' scenario, New Zealand's exposure to dry years would increase materially, as reliance on hydro generation is greater than for the 'Clean NZ' scenario.

[1] Note: The analysis underlying this exhibit was undertaken with 2050 electricity demand under the demand base case, 'NZ Inc', as the driver of additional supply required.

Implications for the industry and Transpower

Te Mauri Hiko concludes that New Zealand will transform its electricity ecosystem over the next two decades. All scenarios point to this transformation.

“The costs of solar PV have been rapidly decreasing and these cost reductions are expected to continue.”

New Zealand’s electricity system is expected to grow rapidly from the middle of the next decade, with most of that growth from renewable, intermittent sources. There will be many additional industry participants as distributed generation becomes widespread.

Successful transformation of our energy future will likely deliver low-cost renewable energy supplies and reduced greenhouse gas emissions.

Some of the forces driving electrification and uncertainty are global, notably including technology change, climate change and geopolitics. Neither Transpower nor New Zealand can influence those forces.

Other forces are local, notably policy choices and investment decisions by industry participants.

Transpower must make its plans based on understanding the sources of uncertainty and an informed view as to how the future will play out. Because it faces high capital costs, long-life investments and long planning horizons, Transpower must be well-informed and should contribute to the conversations that will influence decisions about the future of New Zealand’s energy ecosystem.

Most industry participants spoken to by the project team agree that leadership and coordination will be essential to facilitating a successful transformation of New Zealand’s energy future.

In a recently released report, the World Economic Forum and McKinsey & Company argue that “the diverse challenges facing the energy system today cannot be addressed by a single government, industry, company or other institution alone. A broader variety of expertise, convictions and resources are required for effective action. Moreover, relevant actors and initiatives must be organised to understand and prepare to successfully leverage the underlying transformational forces and direction of energy transition.”

Transpower has identified seven issues which will be critical to resolve as New Zealand sets out on the path to transform its energy future. These seven fundamental issues are:

1. *How will New Zealand ensure utility investors are prepared to deploy new renewable generation?*

In the base case scenario, by 2050 there is approximately 60 TWh difference between future demand and New Zealand's currently planned generation.

Approximately three-quarters of that difference is estimated to be provided with new utility generation – mostly wind, solar and geothermal. Utility-scale investors would need to construct between 1.5 TWh and 2 TWh of new utility-scale generation per year. That compares with an average utility scale investment of ~0.5 TWh per year over the last decade.

Utility investors will only invest if they are confident that demand growth will eventuate, that prices will be high enough to provide a return, and that relevant policies will be stable and encourage investment.

Recently, energy demand growth has been muted because efficiency gains have offset population and economic growth. Decision makers may be justifiably sceptical or uncertain about future demand growth because of this recent experience or because of lack of confidence that the electricity demand growth will eventuate.

With current market arrangements, the prices realised by generators are determined by the highest prices bid by generators who wish to sell and whose volume is required to satisfy demand. All market participants receive that highest price. Often, the market prices are set by the prices offered by thermal generators, who must bid high prices because their costs are high due to the costs of the fossil fuels they burn.

If a large volume of capital investment is made in wind, solar and geothermal generation capacity, then thermal plants would be needed less frequently, leading to market prices being determined by the marginal costs of the renewable producers. These prices will be lower than the marginal costs of thermal producers, particularly if increasing carbon prices are factored into the mix. Under those circumstances, market prices would be much lower, and the expectation of materially lower prices has the potential to deter investment in the renewable generation capacity, creating a form of 'investment gridlock'.

Investors might also be deterred if they are not confident about the stability of policy or regulatory settings. Investors do not like uncertainty. In the absence of reliable assurances about long-term policy stability, investors could also be deterred by concerns about the possible introduction or absence of introduction of policies, for example, closing peaking thermal plants, incentivising distributed renewable generation, carbon charges, or changing market and pricing regulations.

Uncertainty, including regulatory uncertainty, is a fact of life for investors. However, investors in energy capacity will make high-value long-term bets and the energy transformation New Zealand needs will only be possible if the investment environment is sufficiently attractive.

2. *How can New Zealand unleash the growth of distributed generation and storage?*

New Zealand's households and businesses have an important role to play in enabling New Zealand's energy transformation. The Te Mauri Hiko project estimates that around one-quarter of future generation will be distributed, mostly solar PV located on houses and commercial buildings.

The costs of solar PV have been rapidly decreasing and these cost reductions are expected to continue. A domestic installation industry is emerging and will grow with demand. Many people will want to invest in solar PV to reduce their regular energy bills, to contribute to climate change mitigation, or because they believe there is a benefit from being more self-sufficient. Under the base case scenario, most homes and commercial buildings remain connected to the national electricity grid to ensure security of supply and, significantly, to enable sale of excess electricity back into the network.

Homes and commercial buildings will also install batteries, so they can use electricity generated during the day in the evening when demand is highest. Many homes will have EVs, each with a battery capable of storing electricity and distributing it when electricity is needed elsewhere.

Widespread battery deployment will help manage daily demand peaks, facilitating avoidance of investment in generation capacity that would only be used during times of peak demand.

In the base case scenario, households are estimated to contribute up to 16 TWh of solar generation, 6 GW of battery pack storage, 8 GW of excess EV battery capacity, and capacity for instantaneous demand response.

Platforms and markets will evolve to make contributing excess generation and battery capacity convenient. Future platforms and markets will accommodate many more participants – up to 1.5 million households in the base case. Markets will connect new kinds of services such as contributing spare EV and home battery capacity.

New ways of managing supply and demand will mature, for example, digital technologies are likely to control households' electricity demands and contributions in real time. There will also be a need to accommodate new ways of executing market transactions, for example, peer-to-peer trading enabled by blockchain.

Technology, data, communication and privacy innovation will be needed to ensure system operators can successfully integrate distributed generation and storage into the electricity supply system.

Much of this change will be enabled by effective operation of existing competitive markets. However, some of the changes required will benefit from standards, regulation and sharing of information. For some elements of the new electricity system, it may be important to have a consistent New Zealand-wide approach, especially where there are geographic diversity and network benefits available.

“The next steps should include confirming there is a future winter supply problem to be solved, and then identifying an economically preferred physical solution.”

Decisions about investment in distributed generation and storage are complex. Households differ widely in their generation potential, technologies are evolving and costs are decreasing rapidly. Households and businesses should be made aware of the valuable roles they can play in facilitating New Zealand's energy future and provided with information that will help them navigate the increasing range of energy options.

3. How can New Zealand ensure pricing policies and signals encourage renewable electricity supply growth?

Pricing policies will play an important role in ensuring new generation and storage is deployed and made accessible. Analysis has revealed three areas where pricing innovation might be valuable: ensuring connection charges encourage first-mover and other generation investments; introducing real-time pricing to complement artificial intelligence-driven demand response and integrated ancillary services; and ensuring distributed pricing structures encourage contributions from excess generation and available storage.

Existing transmission pricing can discourage new generation by requiring the first mover to pay for any new lines required, even if the lines are likely to be shared by other generation assets in the future. Given the need for additional utility-scale generation, transmission pricing needs to be revised to ensure it encourages new generation.

If new supply is not deployed quickly enough, electricity prices could increase and become more volatile. Higher prices could slow electrification and lead to weaker emission reductions. Temporarily higher prices might encourage households and businesses to bypass transmission and distribution networks; this could lift transmission and distribution prices, creating the risk of a cycle whereby high prices cause bypass, which causes higher prices, and so on.

4. What is the solution to the growing winter and dry-year need for additional supply?

Under the base case scenario, New Zealand's exposure to supply shortages in winter and dry years is expected to grow from 4 TWh today, which is comfortably covered by hydro storage and thermal generation capacity, to 9 TWh by 2030 and 12 TWh by 2050.

The winter supply gap is largely driven by expected growth of intermittent supply, especially solar, and is partly offset by a modest flattening of the seasonal demand profile. Closure of coal- and gas-fired generation is anticipated in Te Mauri Hiko's base case scenario, and that contributes about half of the growth of the seasonal supply shortage.

Several potential technical solutions have been identified, but none appears definitely feasible and economically attractive.

Keeping peakers available to meet peak and dry-year demand is counter to current government policy. Additional gas peakers would have to be built to ensure demand is met and there is risk that there might not be sufficient domestic gas supply.

"Government has a critical leadership role to play in ensuring shared understanding, a clear direction, established policies and alignment so that New Zealand can reap the significant potential advantages and benefits from a successful energy transformation."

If retaining the ability to use gas peakers was selected as the preferred and only strategy, then additional peakers would need to be built.

One answer to the winter shortage challenge would be to charge batteries using excess energy in summer and use the energy during the winter. Examination of the expected technical and cost futures of current and emerging battery technologies suggests that batteries are not likely to offer an attractive solution.

The amount of storage required for a long-term energy storage solution and the expected costs of batteries combine to make a battery solution unlikely.

Te Mauri Hiko has not identified an obvious 'best option'. Solar PV is projected to be a low-cost generating option; entrepreneurs will be able to invest easily and to time-shift electricity over short periods using batteries; and large-scale solar deployment would increase the winter supply challenge.

The next steps should include confirming there is a future winter supply problem to be solved, and then identifying an economically preferred physical solution.

Policy and regulatory settings must explicitly acknowledge the investment demand pressures that New Zealand's energy future represents and encourage direct investment across all sectors of the industry.

5. How will New Zealand ensure networks evolve to handle greater demand, and changes in power system performance and complexity?

New Zealand's power system, distribution and transmission networks will adapt to growth, change and increased complexity.

The distribution network will have to increase capacity to provide charging for EVs, manage more customers who will be trading their electricity supply and storage, and handle batteries and more complex electricity flows. Smaller-scale utility generators are also likely to connect directly to distribution networks.

Many of New Zealand's distribution businesses are small organisations, and some may be challenged by the competence and financial requirements for change. Solutions are emerging as profit-motivated technology providers seek opportunities, and some of the larger distributors may find ways to provide the technical and financial resources required by smaller distributors.

Transpower will have to make many more new connections than in the recent past and will have to manage more challenging and complex energy flows. There may be sections of the grid where more transmission capacity is needed. Again, technology is available and being developed to support these changes.

The challenges distribution businesses and Transpower will face will be similar to those faced by similar organisations in other countries. Overseas, the large-scale uptake of wind and solar has created significant challenges for power system operations, requiring new products to provide system stability and services to coordinate solar and batteries in distribution networks. The best solutions will now begin to emerge and organisations will need to monitor international developments and choose the most suitable options to apply here.

A recent report by the International Energy Agency (IEA), *Getting Wind and Sun onto the Grid,* raises system issues that may need to be resolved when wind and solar generation become a material share of total generation. According to the IEA, when wind and solar exceed 25 per cent of total supply "the ability of the power system to maintain stable operating conditions immediately following disturbances to the system" becomes more important.

Artificial intelligence, and integrated real-time market and power management solutions are likely to become available here. New Zealand's electricity industry needs to be ready to learn and deploy solutions so that the possibility of being caught flat-footed and incapable of rapid change does not become an impediment to successful transformation.

6. How will New Zealand provide enough skilled people to deliver the future electricity system?

Market demand for skilled people to build and connect generation will increase globally as EVs grow their share of light and then heavy transport, and as renewable energy increasingly substitutes for fossil fuels.

Markets for skilled people are internationally connected, so New Zealand may become a source of workforce supply for other countries. While New Zealand electricity firms may be able to compete effectively and to source additional workers offshore – as New Zealand has for Internet connectivity, agriculture and construction – it would be prudent to increase domestic training of electricity workers now.

New Zealand has experience of issues that arise when workforce skills are in short supply. Periodic shortages of teachers, house-builders, medical staff and agricultural workers, for example, arise in part because of a lack of forward thinking and planning.

While many workforce shortages can be remedied with time and money, often drawing on available international supply, the challenge in electricity might be larger. The electricity transformation will be happening globally, not just in New Zealand, so there may not be workforce surpluses in other countries that can be readily tapped for supply. Successful transformation will be important for New Zealand's energy cost-competitiveness and for meeting climate change obligations.

With job losses anticipated from deployment of technologies such as artificial intelligence and robotics, the electricity industry provides potential for well-paid job opportunities for skilled workers, provided they have been adequately trained.

Lead times for planning, approving and establishing advanced training programmes and then training people mean that investment in training should begin well in advance of the demand growth that would signal the need. That means now.

7. *What must each stakeholder do, and when, to ensure sufficient action is taken?*

An important and relatively rapid transformation of New Zealand's energy industry is inevitable.

With rapid change across several domains required for successful transformation, industry participants and New Zealand's industry and political leaders need assurance that the parts will change in an aligned way. For example, New Zealand should not plan to close peakers without an energy storage solution; should not plan to change prices without ensuring the new price regime will encourage generation connections; and should not plan for a large-scale electrification programme without ensuring there will be trained people available to install, maintain and operate the new system.

Several institutions and work programmes in progress will play important roles in deciding the policy and regulatory context for electricity transformation. Their work should be aligned and there are already many conversations in progress to promote that alignment. Those work programmes and conversations should deliver a coherent, consistent and effective future electricity system, where growth and electrification are enhanced and encouraged, and not impeded by bottlenecks.

“From our power stations to our transmission network to our local distribution networks to our homes, now is the time to prepare for the transformation we know is coming.”

Uncertainty is greater than it has been in the recent past and that increases the likelihood that change will not take place as expected. In turn, that implies it will be valuable to provide increased certainty where possible, and to adopt management strategies that can accommodate uncertainty.

Electricity planning should include ensuring resilience in case New Zealand's future is disrupted in ways that are highlighted in some of Te Mauri Hiko's scenarios or in ways that are not currently anticipated. Disruption could come from several sources, for example: climate change effects or global climate policies could be more severe or arrive earlier than expected; global security could deteriorate; supply chains could be interrupted; or an economic downturn may be harder to recover from than expected.

Government has a critical leadership role to play in ensuring shared understanding, a clear direction, established policies and alignment so that New Zealand can reap the significant potential advantages and benefits from a successful energy transformation.


Anti-Shock

Conclusion

The implications of the findings from the Te Mauri Hiko project for Transpower are important and are still being developed. Transpower in 2030 will look very different from Transpower today but the national grid's role in enabling the electrification and decarbonisation of the New Zealand economy is, and will continue to be, critical.

"From our power stations to our transmission network to our local distribution networks to our homes, now is the time to prepare for the transformation we know is coming."

Yes, electricity will increasingly become a distributed tool that consumers will generate and manage themselves at their homes. Transpower supports this.

However, electrifying the New Zealand economy will depend upon many new large-scale, grid-connected renewable power stations to meet the nation's doubling of electricity demand. This supply must be distributed via a modern, flexible and resilient national transmission grid to provide safe, secure supply to industrial and residential consumers under a wider-than-ever range of operating conditions.

With more and more of the New Zealand economy – including homes, businesses and road transport – dependent on clean electricity, all sectors of the supply chain must ensure they are fit for their evolving purpose.

We must invest in our assets and our industry now to prepare for the future. From our power stations to our transmission network to our local distribution networks to our homes, now is the time to prepare for the transformation we know is coming.

Priorities for Transpower right now include strengthening its internal strategy, forecasting and planning functions to allow the organisation to improve its acuity and reduce uncertainty where possible.

Transpower is revisiting its long-term network, investment and capital plans to ensure they incorporate significant growth in electricity demand, increasingly intermittent renewable supply and the growing number of industry participants. Transpower is also further investigating dry-year risks and responses. The scenarios used to include uncertainty in planning processes are being updated.

Transpower is improving its agility to ensure the organisation can react with shorter lead times to demand for the inevitable connections. It is building understanding of the capabilities and capacities it will need to connect new generation and transmit electricity.

Transpower is developing its understanding of the products and services New Zealand will need the organisation to deliver in order to facilitate the coming revolution in New Zealand's energy future.

All of the issues raised in this report are under active consideration by Transpower. The organisation will use this report to engage constructively with the full set of industry, business and political stakeholders as part of building a common understanding and pathway towards the potential of New Zealand's combined energy future.

On this point, and finally, this report seeks to engage New Zealanders – particularly the energy industry. The unique characteristics of New Zealand's electricity industry are our opportunity, but they are also our challenge. We will not have the luxury of sitting back and observing the decisions made in other parts of the world before deciding which path we forge.

If the energy opportunities facing New Zealand are to be realised, it will require a level of engagement, participation, innovation and commitment to a common goal from all participants: government, investors, consumers and the people of this industry who every day generate and distribute the lifeblood of New Zealand's economy – electricity.

The opportunities are considerable and the challenges are very real. It's time to start.

Source material

The conclusions drawn in the Te Mauri Hiko – Energy Futures project were compiled by exploring existing information from many sources, including:

Analysis	Major sources
Energy and electricity demand	Energy Efficiency & Conservation Authority, Ministry of Business, Innovation and Employment, StatsNZ, Treasury, Ministry of Transport, International Energy Agency, Bloomberg New Energy Finance, Sapere Research Group, Electricity Networks Association, Energy Futures analysis
Electricity supply	Ministry of Business, Innovation and Employment, Bloomberg New Energy Finance, Electric Power Engineering Centre, National Institute of Water and Atmospheric Research, University of Auckland, Transpower, Energy Futures analysis
Electricity storage	Bloomberg New Energy Finance, Transpower, Energy Futures analysis
Electricity transmission	Transpower planning team, Energy Futures analysis
Greenhouse gas emissions	Ministry of Business, Innovation and Employment, BP, Energy Futures analysis

Acknowledgements

The Te Mauri Hiko – Energy Futures project benefited greatly from contributions made by many leaders and experts from within Transpower, the wider New Zealand energy ecosystem, academia and abroad, including Rick Boven and the team at Stakeholder Strategies.

Contributors represent a diverse range of perspectives including generation, distribution, consumers, environment, innovation, economy, and academia.

While Transpower engaged with external parties to develop *Te Mauri Hiko – Energy Futures*, it is important to note the conclusions drawn are Transpower's own.

Kind regards,

Alison Andrew

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